

Context dependence in sequential motor learning

The impact of context manipulation on motor
chunks in a go/no-go DSP task

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Abstract

Context dependency is known in the domain of verbal and motor learning, as it refers to the performance improvement in matching learning and testing contexts. Recent research has investigated the development of context dependency in sequential motor learning, focusing on the impact of context manipulation in the preparation phase of this process. Findings suggested that practice and task difficulty would additionally play a role during this process. The present study therefore aimed to further acknowledge the development of context-dependency in sequential motor learning in manipulated contexts, paying special attention to the role of practice and motor chunking, as it refers to task difficulty. Motor chunks describe units of information, which are loaded in cognitive processor and motor processor and allow a fast accomplishment of even complex motor actions. In this study, a go/no-go DSP task was conducted with two context manipulations (switched and novel), two practice conditions (extended practice vs. limited practice) and two sequences, one with an integrated chunk (1x6 vs. 2x3) to investigate effects of context, practice and motor chunks in sequences. Results of this study confirmed former expectations, verifying that (1) context manipulations (switched and novel context) weakened performance and that (2) context dependency increased with task difficulty, showing greater context effect for non chunked 1x6 sequence than for paired 3-chunk-combination sequence and that (3) practice mediated the development of context dependency. Motor chunking was therefore found to decreased context dependency, however, relation with practice still arise question for further study.

Introduction

Performing complex motor actions such as driving a car or playing the piano have become an integrated part of our daily life. In order to be able to learn such complex movements, we have to invest time and attention. For example, when learning to play a new musical piece on the piano, the piano player begins with performing the play part by part, practicing especially challenging parts over and over again until he or she has learned those motor actions. While performing, he or she focuses on this task only, ignoring the *context* in which the task is practiced. Context is formed of situational elements such as noises or colors that are present while the task is learned. Recent research has found that performance improves as context remains the same for the situation where the information is encoded and the situation of retrieval (Fernandez & Glenberg, 1985; Godden & Baddeley, 1975; Jacoby, 1983; Murnane & Phelps, 1993, 1994, 1995; Smith, 1985). These results were explained by the phenomenon of *context dependence*. In the present study, the development of context dependence and the influence of context manipulation, as well as the role of practice and task difficulty will be acknowledged.

Context dependency was first identified in the domain of verbal memory. The most famous experiment of context dependent verbal learning was conducted by Godden and Baddeley (1975). In their research, divers had to learn a list of words each in one of two different environments: on land or under water. Afterwards they were asked to freely recall the list of words in either their original learning environment or in the alternative environment. Results showed that lists which were learned underwater were also best recalled underwater and words learned on land were best recalled on land. Therefore, the context dependence of human memory becomes even more obvious. Further studies in this domain investigate the context dependency by analysing the contexts effects of visual contexts (Fernandez & Glenberg, 1985; Jacoby, 1983; Murnane & Phelps, 1993, 1994, 1995) and background music (Smith, 1985).

The development of such context effects can be explained by the *encoding specificity principle* of Tulving & Thomson (1973). The *encoding specificity principle* asserts that memory is supported as information which is available during encoding is also available at retrieval. Realizing

the explorative value of context dependence of memory found in the verbal domain, the concept of context dependence was extended to the domain of motor skill learning (Abrahamse & Verwey, 2008; Anderson et.al., 1998; Wright & Shea, 1991).

Context dependence in sequential motor learning

Wright and Shea (1991) were the first who extended the concept of context dependence and contextual cueing to the domain of perceptual-motor skill acquisition. To investigate context dependence in sequential motor learning, Wright and Shea (1991) focused on the influences of intentional and incidental cues on motor skill execution. The difference between intentional cues and incidental cues is that intentional cues are essential for the execution of a task, while incidental cues are not directly required for task performance providing context only. However, because incidental cues can be associated with intentional cues, they gain influence on the task. According to Wright and Shea (1991), intentional cues, as well as incidental cues, play an important role the learning of new motor skills as driving a car. They illustrated incidental cues as sounds of the car engine which remain as cues to gear regulation to a novice driver, but which are neither essential for driving nor intentionally brought to the driver's attention. An intentional cue in a driving situation could be the speed of the car which a novice driver would pay attention to in order to determine the occurrence of gear changes to react correctly in time.

In their study, Wright and Shea (1991) let their participants practice three- and four-key-sequences in different order with both hands. During the practice phase they were provided with incidental as well as intentional cues. The intentional cues were the numbers that indicated the keys and sequences that had to be executed. The incidental cues were the color of the display, the placeholder shape, the tone generated during presentation and the position of the stimuli on the screen (top, middle or bottom). In the test phase participants were provided with a switched context, which means that intentional stimuli were no longer presented by the incidental stimuli which they were presented within the practice phase, but with alternative incidental stimuli. Results of the study showed that when these incidental cues (context) were changed in the subsequent test phase, the performance correctness (PC) decreased significantly for the four key sequences only. Wright and

Shea concluded that this was evidence for “the development of a contextual dependency due to the emergence of an association between the intentional and the incidental stimuli” (p. 364) in a more difficult 4-key-sequence task. Furthermore, development of context dependence was shown to be mediated by task difficulty. Similar conclusions revealed from the study of Anderson, Wright and Immink (1998), measuring the effect of changing contexts on task performance in reaction time (RT) instead of performance correctness (PC). Wright and Shea (1991) further suggested that with sufficient practice, these associations would become stronger, resulting in an increasing contextual dependence. In summary, task difficulty and amount of practice are mentioned to play an important role in the development of context dependence in motor tasks.

Although, research acknowledged the phenomenon of context dependence as well as possible influencing variables, recent research of Ruitenbergh, Abrahamse, de Kleine & Verwey (under review) shows that the measurement has shortcomings, since it could not differentiate between preparation and execution of motor actions. According to Verwey’s (2001) *dual processor model (DPM)*, a distinction between preparation and execution of motor actions is necessary, as motor actions consist of a cognitive motor preparation process and a motorical execution process, which are each processed by a separate processor. In order to acknowledge context dependency in sequential motor learning, the motor preparation must be focused.

Recent research of Ruitenbergh et al. (under review) investigated the development of context-dependencies within motor skill tasks by using a go/nogo discrete sequence task (DSP), which offers the possibility to focus on the preparation separately. In this study, participants were assigned to two practice conditions in which they were offered two different sequences consisting of 6 key presses, which were tied to two different colors, creating context. After participants have completed the practice phase, context was manipulated through the change of colors in the test phase. Results showed that sequences were significantly slower executed in a context in which colors of the sequences were switched (switched context) compared to the original practice context. No effect was found as colors of both sequences were changed into one new color (novel context). Context dependency is therefore likely to be effected by conflicting contexts rather than by a novel context. Furthermore, the amount of practice and the phenomenon of motor chunking were assumed to play an

important role in motor preparation and therefore in the development of context dependency in manipulated contexts. The present study will replicate the study of Ruitenberg et al. (under review) paying special attention to the impact of context manipulation on motor chunking and practice in contextual dependent go/nogo DSP tasks.

Motor chunking in a go/no-go DSP task

The interest of the present study refers to the development of context dependence in sequential motor tasks in manipulated context and the role of practice and task difficulty, referring to motor chunking, during this process.

Chunking describes a cognitive process, which originates from the verbal domain of memory (Miller, 1956; Simon & Barenfeld, 1969). It is defined as process of unitization where co-occurring elements are represented together as a single unit, a so called *chunk* (Perlman, Pothos, Edwards & Tzelgov, 2010). Verwey (1996) applied the chunking process to sequential motor learning, specifying chunks as *motor chunks*. Motor chunks are defined as integrated and unified memory representations of motor actions (Verwey, 1996). According to Verwey (1996), the development of motor chunks can be explained with the DPM. The DPM, which hypothesized that motor actions are processed by two processors in two phases, was verified by Verwey's (2001) observation of overlap between cognitive preparation and motor execution of motor action. Cognitive information of a motor action is processed by the cognitive processor, while the motor processor handles information about executing a motor action. Both types of information could be loaded during practice process of motor actions, called *buffer loading*. As the buffer of both processors is repeatedly filled "with the same elements through the gradual development of interelement associations" (Verwey, 1996, p.545) motor chunks developed. Sequences of motor action together with interrelated stimuli as context factors are consequently stored as motor chunk and can be programmed in advance in a short term motor buffer (Verwey, 1996), if sufficient practice time is available (Verwey, 1999). Once loaded, motor chunks can be executed rapidly, improving reaction time and performance by minimizing needed capacity (Verwey, 1996, 2001). In sequential motor learning, Verwey (1992, 1996) generally views practice as the major determinant of proficient motor performance, pointing that with extended practice, chunking

can speed up the selection and initiation of familiar segments. Therefore, fewer stimuli would be needed to receive similar performance (Verwey, 1999).

In order to acknowledge the development of context dependence in manipulated contexts and the role task difficulty, referring to motor chunking, and practice during motor preparation, the recent makes use of a specific form of a discrete sequence production (DSP) task- a *go/nogo DSP task*. A typical DSP task described a motor sequence task of two to six stimuli, which are presented in a determined order on a pc monitor. The participant directly responds to the stimuli as it appears by pressing the consecutive key on the keyboard. In order to be able to separate preparation and execution of the motor sequences a go/no-go DSP task (De Kleine & Van der Lubbe, 2011) is used which is in line with the DPM of Verwey (2001, 2003). In a go/no-go DSP task, the whole sequence which should be practiced is presented prior to execution (De Kleine & Van der Lubbe, 2011; Rosenbaum, 1980). However, participants are only allowed to respond to the presented sequence of stimuli if a go signal appears, and are restricted to respond to the appearance of a no-go signal. Due to these signals, preparation and execution could be distinguished.

The present study

In the present study a go/nogo DSP is used to investigate the development of context dependence in manipulated contexts and the role of task difficulty, referring to motor chunking, and practice during this process. According to former assumptions, we hypothesize that (1) context manipulations (switched and novel context) will weaken performance and that (2) context dependency will increase with task difficulty, showing greater context effect for non-chunked sequence (1x6) than for chunked sequence (2x3), (3) practice will mediate the development of context dependency.

In order to test the former hypothesis, a mixed design key-press-experiment is conducted with three context conditions (same, switched, and novel), two practice conditions (extended practice vs. limited practice) and two sequences, one with an integrated chunk (1x6 vs. 2x3).

To explore the effects of context manipulations (switched context and novel context) (1) on motor performance the original learning context was manipulated in color. In the original learning context, the 1x6 sequence was presented by blue stimuli, 2x3 by yellow stimuli. In the switched

context condition, colors of sequences were switched and in the novel condition both sequences were presented in red color. After letting the participants practice the sequences which were always presented to them in the same colors, participants were additionally assigned to the two manipulated contexts: switched and novel context. However, encoding specificity principle (Tulving & Thomson, 1973) suggested that both context manipulations would weaken performances, Ruitenberg et al. (under review) emphasized that a context effect should only be found for switched context, as a result of conflicting context information. The present study will further encourage the effect of both manipulations, hypothesizing that performance in RT will be decreased more in the switched context than in the novel context.

In order to explore the possible effect of task difficulty, referring to motor chunking, on context dependency (3), two different sequence designs were used: 1x6 sequence vs. 2x3 sequence. According to both Wright & Shea (1991) and Verwey (2003), task difficulty referring to the length of the sequences, plays a significant role in the development of context dependency in motor tasks. Wright & Shea (1991) found that performance in PC was significantly more context dependent in four-key-sequences compared to three-key-sequences. Verwey's results (2003) confirm this assumption, referring to his dual processor model. According to this theory, context dependency increased with the length of sequences because of an increasing load on the cognitive processor, which is slowing down the performance. However, Verwey's (1996, 2001) DPM suggests that besides the length of the sequences, differences in task difficulty are also created by motor chunking. According to Verwey (2001), chunks would speed up the buffer loading process, resulting in lower reaction time (RT). In the present study, a 6-key-sequence is compared to a paired 3-chunk-sequence-combination to explore possible effects of task difficulty.

We assume that higher task difficulty is experienced for the 1x6 discrete motor sequence which consists of six consecutive key presses. Task difficulty is hypothesized to be lower for the 2x3 discrete motor sequence which consisted of two 3-key chunks which are separated by a short break interval. In order to acknowledge the effects of task difficulty on context dependency, relating to the effect of chunking, these two types of discrete motor sequences were used to create a go/no-go discrete sequence production task (DSP) which is in line with Verwey's (1996, 2001) DPM.

According to former assumptions of Verwey (2003) and Wright & Shea (1991), it is hypothesized that context dependency will decrease for chunked sequence as well as RT and PC. In the present study performance in the go/nogo DSP task is measured in reaction time (RT) and error rates (ER). Reaction time (RT) is defined as the time between onset of the go-signal and depression of the first key as well as the time between the onsets of two consecutive key presses within a sequence. ER replaced PC, which is used to investigate response accuracy in former research of Wright & Shea (1991). A response is defined as an error (ER) when the participant is not pressing the appropriate keys in the correct order right after the occurrence of the DSP go-signal.

To acknowledge the influence of practice (2) on context dependence in changing contexts, one half of the participants practices the two different sequences for an extended time period (six practice blocks), while the other half practices the sequences only for a short time period (one practice block). Verwey (1996) further observed that with sufficient practice motor chunks can be used with less information given. The reason therefore lies in the phenomenon of chunking which he referred to in his DPM. Because cognitive load and motor load can work independent of the each other, performance time can be reduced even if context is not the same. Based on this assumption, we can consequently hypothesise that context dependence of the chunks should decrease with sufficient practice. According to findings of Wright and Shea (1991), contrary hypothesis can be developed. In Wright's and Shea's (1991) theory the tie between intentional and incidental information becomes even stronger with practice, which consequently means that context dependence would increase with extended practice. In the present study, we will therefore focus on whether context dependence increases or decreases with practice.

In summary, the phenomenon of context dependency is known in the domain of verbal learning (Fernandez & Glenberg, 1985; Godden & Baddeley, 1975; Jacoby, 1983; Murnane & Phelps, 1993, 1994, 1995; Smith, 1985) and motor skill learning (Abrahamse & Verwey, 2008; Anderson et.al., 1998; Wright & Shea, 1991). More recent studies focused the preparation of motor actions, to examine context dependency in manipulated contexts (Ruitenberg et al., under review). However, the impact of manipulated contexts on development of contextual dependency in sequential motor tasks was analyzed with a go/nogo DSP task, the influence of practice and motor chunking as instrument to

manipulate task difficulty, were not acknowledged, yet. This study aims to reproduce and deepen knowledge concerning the question whether and how context-dependency developed in manipulated context and which role practice and task difficulty, concerning motor chunking, play in this process. To be more precise, this study will acknowledge whether and in which way (1) context manipulations (switched and novel context) will weaken performance, (2) context dependency will increase with task difficulty, showing greater context effect for non chunked 1x6 sequence than for paired 3-chunk-combination sequence (3) and practice will mediate the development of context dependency.

Method

Participants

The experiment involved 48 students of the University of Twente with either Dutch or German nationality. As participants were either Dutch or German, instructions of the experiment were available in both languages, even though all participants were familiar with the Dutch language. The age of the participants (39 women and 9 men) ranged from 17 to 32 years (mean age 22). According to Annett's (1970) Handedness Inventory, 96% of the participants were right handed (38 women and 8 men), 4% were ambidexter (one man and one woman). Participants did not suffer from colour-blindness, dyslexia or ADHD. For participation, student credit points were offered.

Design

The design of this experiment was a 2 (sequence) x 2 (practice) x 3 (context) mixed design. During the experiment, participants had to learn two different sequences, a *1x6 sequence* and a *2x3 sequence*. In order to prevent finger-specific effects, different versions of both sequences were constructed. The 1x6 sequences consisted of a follow up of 6 keys which were formed out of the four keys *cvbn*: *bcncbv*, *nvbvnc*, *cbvbcn*, *vncnvb*. The 2x3 sequences consisted of an identical pair of keys, a 3-key-sequence which is repeated, formed out of the 4 keys: *vnc-vnc*, *bcn-bcn*, *nvb-nvb*, *cbv-cbv*. As illustrated by the strike between the letter pairs, they were separated by a short break (random 200,

400 of 600 ms) between the first and the second 3-key-sequence, in order to indicate chunking. Each participant was provided with one 6-key-combination and one paired 3-key-chunk-combination.

In the practice phase, participants were randomly assigned to either the limited or extended practice condition. In the limited practice condition participants are provided with one practice block, while in the extended practice phase participants were given six practice blocks before entering the test phase. In the test phase, all the participants were provided with three different context conditions: *same*, *switched* and *new* context. Contexts were created by colours. In the same context condition sequences were presented in the same colours as in the practice phase, while in the colours of the sequences were switched in the switched context condition and changed into one new colour in the novel context condition. In order to avoid order effects, the conditions were counterbalanced across the participants.

Apparatus

Stimulus presentation, timing, and data collection was achieved using the E-prime_ 2.0. Stimuli were presented on a computer with a Philips 107 T5 colour monitor with a Keytronic MRR II Key standard keyboard.

Task

The participants placed their little finger, ring finger, middle finger and index finger of the left hand on the keys *c*, *v*, *b* and *n* of a computer keyboard. In order to examine the preparation of sequence learning in isolation from motor execution, each of the 50 trial per sequence per block was presented in DSP go/no-go task. Each trial of the experiment started with a white fixation cross on the middle of the black screen with four white squares below. The squares were aligned horizontally functioning as placeholders for the stimuli. The task started with the trial onset (1000 ms). After the trial onset, squares per sequences lit up for 750ms after each other. As illustrated in Figure 1, the 2x3 sequence included a break interval of 200, 400 of 600ms, which is not present for the 1x6 sequence.

When all stimuli of a sequence were presented, a preparation interval of 1500ms was shown before the go or no-go signal was finally given.

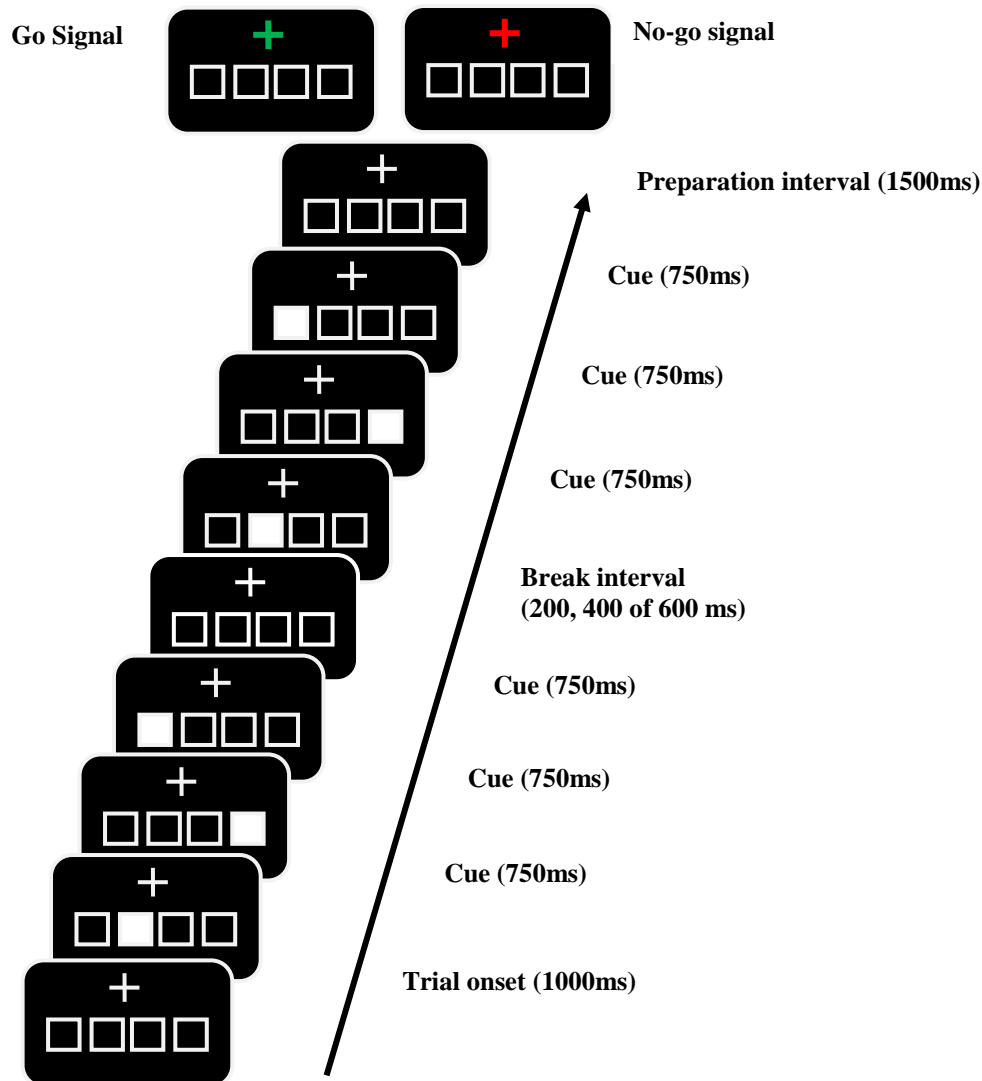


Figure 1 Illustration of a complete trial of a go/nogo DSP task for a paired 3-key-chunk sequence.

The go/no-go signal functioned as symbol for executing/not executing the six spatially corresponding key presses. The signal appeared as colour change of the white fixation cross. When the fixation cross turned green (go signal) after the stimuli sequence was completed, it had to be followed by execution of the six consecutive key presses. When the fixation cross turned red (no-go signal), no reaction of the participant to the presented sequence was required. In 92% of all cases participants were provided with a go-signal, in 8% with a no-go-signal.

The task is intended to make participants learn two sequences which differ in construction (2x3 sequence and 1x6 sequence) and colours given, which created the context. In the practice phase, the 1x6 sequences were constantly represented in blue enlightened squares, while 2x3 sequences were constantly represented in yellow. In the test phase, all participants performed both sequences in the *same*, *switched* and *new* context condition. In the same context condition participants were provided with yellow 2x3 sequences and blue 1x6 sequences, as in the practice phase, while in the switched context condition the sequence which was presented in yellow during the practice phase was now presented in blue and vice versa. In the new context condition, the colours of both sequences were changed into red. Participants were instructed to respond as fast and as accurately as possible in both practice and test phase. Feedback was given at the end of a response sequence, or directly when the participant reacted before the go/no go signal, or when a false button press was conducted. At the end of each block, the participant's feedback on error rates (ER) and mean reaction time (RT) during the process were given.

Procedure

Before the experiment could start, the participants were asked to fill out a short personal questionnaire and an informed consent form. In the personal questionnaire, participants were asked to report personal details as gender and age as well as specific information about whether they suffered from colour-blindness, dyslexia or ADHD¹. Furthermore, they were asked about which hand they use for execution of actions in different situations to determine their dominant hand. Next, the participants were seated in front of the computer and received a written instruction on the task to be performed. They were asked to read this instruction carefully before starting the experiment.

In the practice phase, participants performed the practice block(s) which included a break of 30 seconds halfway through and a longer break (2 min) at the end of each block. The procedure was the same for participants in the limited and extended practice conditions, except for the fact that participants in the extended practice condition completed six practice blocks instead of one. After the

¹ Participants were excluded from the study if they had color-blindness, dyslexia or ADHD.

participant has finished one block the researcher started the next one of the experiment and finally started the test phase after the participant had completed the practice phase.

After participants had finished the test phase, they were asked to fill out a questionnaire that consisted of three parts. In the first part participants were asked to recall the two practice sequences with only an illustration of the keys on the keyboard presented to them. In the second part, twelve sequences were shown to the participants. The participants were asked to choose the sequences that they had performed during the experiment without referring to the first part of the questionnaire. In the third part, additional questions about retrieval cues of the participants, used to memorize sequences, were asked.

For participants in the limited practice condition, the experiment lasted 1 hour, for participants in the extended practice condition it lasted 2,5 hours.

Results

Practice phase

Limited practice

For the limited practice condition, a repeated measures ANOVA on RTs was performed with Key press (6; hereafter referred to as Key) and Sequence (2) as within subject variables. Results showed significant main effects for Sequence, $F(1, 23) = 7,684, p < .05$ and Key, $F(5, 115) = 20,38, p < .001$. Taking a closer look at the effect of Sequence, the 2x3 sequence ($M_{2x3} = 450\text{ms}$) was executed faster than the 1x6 sequence ($M_{1x6} = 518\text{ms}$). As expected, some key presses were executed faster than others as main effect of Key confirmed. As results showed strong difference in RT between the first key and the other key, another ANOVA on the first practice block with Sequence (2) and Key (5), was performed to investigate if effect of Key can be attributed to the first key. According to Verwey (1996), the RT on the first key was longer because the DSP task slowed down the first response on the one hand and because the first key asked for more demand on the cognitive processor of the DPM compared to the others. Results indicated that effect of Key is still significant without the first key, $p = .001$. To investigate if there is a difference between practice groups a second ANOVA was

performed on the first practice block with Key (6) and Sequence (2) as within subject variables and practice as between subject variable. Results showed no effect of Practice on the first block, $F(1, 46) = 0,131, p = .719$.

Extended practice

For the extended practice condition, a repeated measures ANOVA was performed with Practice block (6; hereafter referred to as Block) and Sequence (2) and Key (6) as within a subject variable. Results showed significant main effects of Block, $F(5, 115) = 110,75, p < .001$, Sequence, $F(1, 23) = 6,076, p < .05$, and Key, $F(5, 115) = 49,165, p < .001$, as well as interaction effects of Block x Sequence, $F(1, 115) = 4,136, p < .05$, Sequences x Key, $F(5, 115) = 3,268, p < .05$ and Key x Block, $F(25, 575) = 3,018, p < .05$.

Main effect of Block indicated performance in RT differs among blocks. However, RT was highest for the first block, an ANOVA performed as repeated measures with Block (5), Sequence (2) and Key (6) showed that main effect of Block remains significant, $p < .001$, as the first block was excluded from analysis. The effect of Block can therefore not be attributed to a single block as block one.

Moreover, Block x Sequence and Block x Key interaction revealed that one sequence is performed with less RT in some blocks compared to others. Taking a closer look on this Block x Sequence interactions, the 2x3 sequence was executed faster than the 1x6 sequence among all blocks. Furthermore significant interaction effect of Block x Key indicated that some keys are executed faster in some blocks compared to the others, showing an especially high RT on all keys in the first block as illustrated in Figure 2. To investigate if the effect was attributed to the first block only, another ANOVA was performed, which excluded the first block from the analysis. Results of the repeated measures ANOVA with Block (5) and Key press (6) and Sequence (2) for extended practice group, showed no interaction effect of Block and Key, $p = .195$, which indicated that interaction effect of Block x Key can be attributed to the first block (Figure 2).

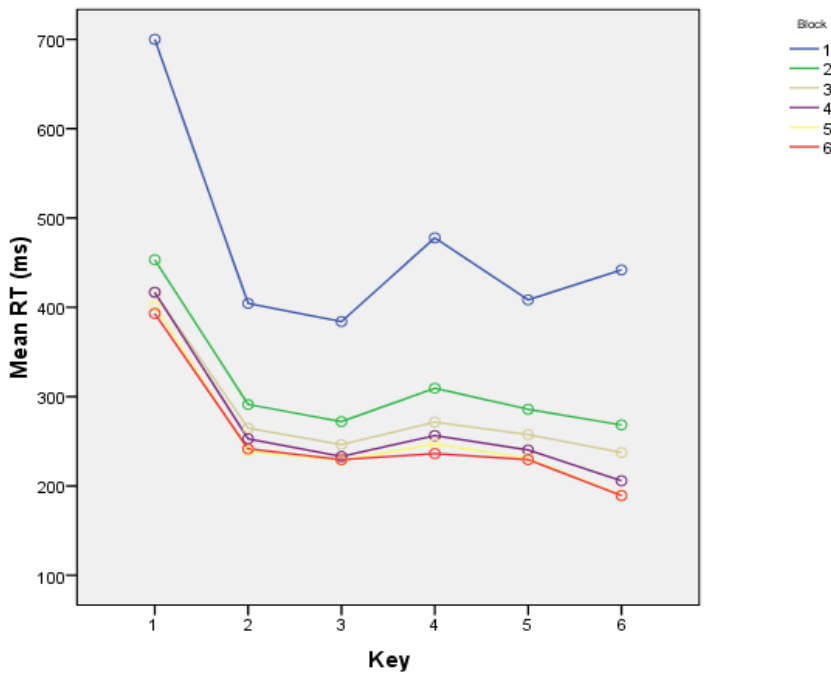


Figure 2 Mean reaction time per Key and Block.

Investigating the effect of Sequence, the 2x3 sequence ($M_{2x3} = 296\text{ms}$) was performed faster than the 1x6 sequence ($M_{1x6} = 318\text{ms}$). The main effect of Key indicated that some keys were executed faster compared to others. Because this study is interested in whether and in which way chunking in the 2x3 sequence causes more decreased RT per key compared to non chunked 1x6 sequence, we take a closer look at the interaction effect between Sequence and Key. Sequence x Key interaction indicated that some keys are executed faster than others in one sequence. In order to further acknowledge the interaction effect, two repeated measures ANOVAs with Block (6) and Key (6) were performed, one each per sequence. Results showed significant main effects of Block, $ps < .001$, and Key, $ps < .001$, for both sequences. Taking a closer look at the main effect of Key, which was found for both sequences, all keys, except the key four were executed faster in the 2x3 sequence than in the 1x6 sequence (Figure 3). The fact that key four was executed faster in the 1x6 sequence indicated that participants executing the 2x3 sequence were making use of the integrated chunk by taking a longer break between key 3 and 4 which was not integrated in the 1x6 sequence.

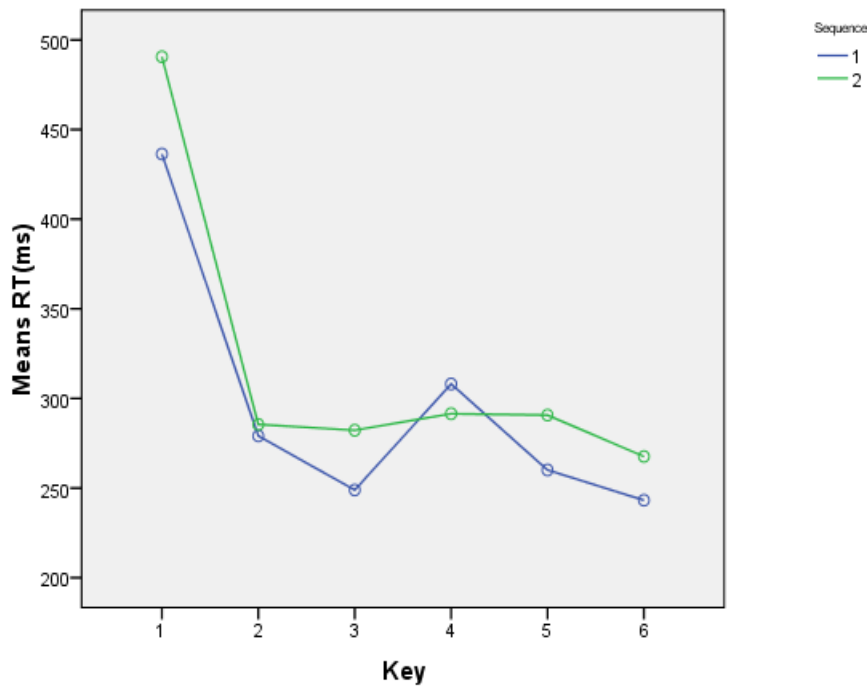


Figure 3 Reaction time per Key for 2x3 sequence (1) and 1x6 sequence (2).

Error rates

In the limited practice condition error rates (ERs) of participants were analyzed with an ANOVA which was performed as repeated measures with Key (6) and Sequence (2). Results showed significant main effects of Key, $F(5, 115) = 30,650, p < .001$, and Sequence, $F(1, 23) = 7,221, p < .05$, as well as a significant interaction effect between Key and Sequence, $F(5, 115) = 3,195, p = .05$, which indicated that some keys were executed with more errors than others in one sequence compared to the other. Focusing the interaction effect of Key x Sequence, more errors on all keys were made in the 1x6 sequence (9.79%), compared to 2x3 sequence (6.21%). Interestingly, because it is contrary to RT results, the error rates on key four of the 1x6 sequence increase rapidly while it decreased on key five and six (9.9%). The strong decrease of ER in key six could be attributed to the *recency effect*, stating that people would respond better to the last key they saw. To investigate if there is a difference between practice groups a second ANOVA was performed as repeated measures on the first practice

block with Key (6) and Sequence (2) as within subject variables and Practice as between subject variable. Results showed no effect of Practice on the first block, $F(1, 46) = 0.006, p = .940$.

For the extended practice condition a mixed ANOVA was performed as repeated measures with Block (6), Key (6) and Sequence (2) as within subject variables. Main effects of Block, $F(5, 115) = 10.233, p < .001$, and Key, $F(5, 115) = 27.694, p < .001$, as well as an interaction effect between Block and Key, $F(25, 575) = 3.647, p < .01$, were found. Main effects of Block and Key indicated that RT decreased more in some block compared to the others and on some key compared to the others. A closer look at the interaction effect of Block x Key showed that ER of all keys decreased across Blocks. Consequently, ER on all keys were highest in block one. In order to investigate if effect can be attributed to the high mean ERs in block one (7.87%) only, an ANOVA was performed as repeated measures with Block (5), Key (6) and Sequence (2), showing significant main effect of Block, $p < .001$.

Test phase

The participants' performance in the test phase was analyzed via a repeated measures ANOVA on RTs with Key (6), Sequence (2) and Context condition (3; same vs. switched vs. new) as within-subject variables and Practice (2; limited vs. extended) as between-subject variable. Results showed significant main effects of Context, $F(2, 92) = 3.383, p < .05$, and Sequence, $F(1, 46) = 12.628, p < .01$, as well as significant interaction effects between Context x Practice, $F(2, 92) = 3.383, p < .05$, Context x Sequence, $F(2, 92) = 3.100, p = .050$ and between Sequence x Key, $F(5, 230) = 2.832, p < .05$.

Taking a closer look at the main effects, the main effect of Context, confirmed the former assumptions that RT decreased more in same context compared to manipulated contexts.

Two repeated measures ANOVA on RTs with Key (6), Sequence (2) and Context condition (2; same vs. switched and same vs. new) showed significant context effect for same and novel context, $F(1, 47) = 6.663, p < .05$, showing that RT decreased more in same context ($M_{\text{same}} = 273$ ms) than novel context ($M_{\text{novel}} = 289$ ms). However, no significant difference in RT was found for switched (M_{switched}

= 278 ms) and same context ($M_{\text{same}} = 273$ ms), $p = .484$. These results are in line with the findings of Ruitenberg et al. (under review).

Referring to the main effect of Sequence, findings confirmed former states that 2x3 sequence ($M_{2 \times 4} = 270$ ms) is performed in less RT compared to the 1x6 sequence ($M_{1 \times 6} = 290$ ms). In other words, context manipulation consequently has a negative influence on performance, while motor chunking showed a positive effect on participant's performance. Results furthermore indicate that RT in some contexts decreased more with extended practice compared to the others (Context x Practice interaction). In addition one sequence in some context showed more decrease in RT than the other (Context x Sequence interaction) as well as that some keys in one sequence are performed with a lower RT than others (Sequence x Key interaction).

Because the interest of the present study is to examine the roles of practice and task difficulty, relating to motor chunking vs. no chunking, in the development of context dependence in manipulated context, we will take a deeper look at these interaction effects.

Role of task difficulty: 2x3 sequence vs. 1x6 sequence

Interaction effect of Sequence x Key showed that compared to the 1x6 sequence, performance of 2x3 sequence decreased more in RT among all keys, except for key four. High RT on key four in 2x3 sequence indicated a successful application of motor chunking due to the use of paired 3-key-chunk combination which were separated by a break interval (Figure 4).

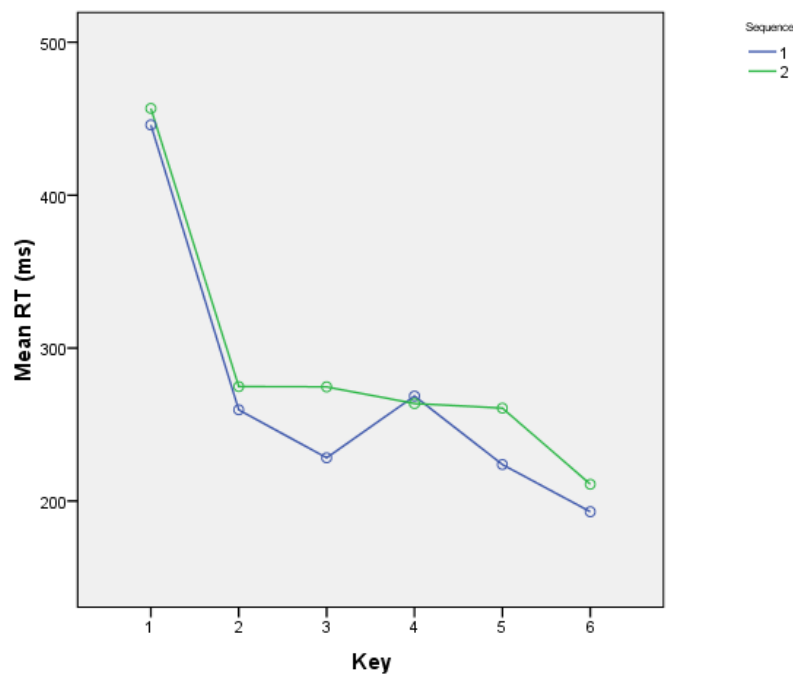


Figure 4 Mean RT per Key for 2x3 sequence (1) and 1x6 sequence (2).

Furthermore, interaction between Context and Sequence showed that in some contexts one sequence is performed with more decrease in RT compared to the other as illustrated in Figure 5.

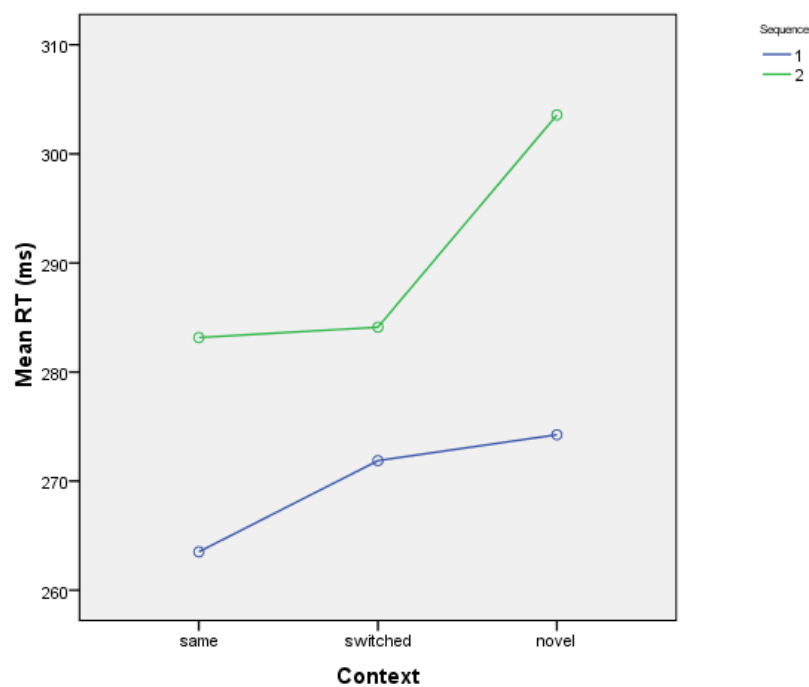


Figure 5 Mean RT per Context for the 2x3 sequence (1) and the 1x6 sequence (2).

To investigate effects per sequence and key in context manipulations, two mixed ANOVAs as repeated measures were performed with Context (3) and Key (6) for the both, the 2x3 sequence and the 1x6 sequence.

2x3sequence

Results for the 2x3 sequence showed that significant main effect of Key, $F(5, 230) = 55,282, p < .001$ as well as interaction effect of Context x Practice, $F(2, 92) = 4,923, p < .05$, and Context x Practice x Key, $F(10, 460) = 3,174, p < .05$. No context effect, $p = .275$ and no effect of Practice, $p = .181$, were found here.

Context x Practice interaction of the 2x3 sequence revealed that the 2x3 sequence is executed faster in some context with extended practice compared to others. To further investigate this interaction effect, context were compared separately per practice group. Therefore two mixed ANOVAs as repeated measures with Context (2: same vs. switched; same vs. novel) and Key (6) as within subject variables were performed per practice condition.

With extended practice, comparison of same and switched context condition showed significant main effect of Context, $F(1, 23) = 9,858, p < .01$ and Key, $F(5, 115) = 16,112, p < .001$. Main effects of Context, $F(1, 23) = 10,303, p < .01$, and Key, $F(5, 115) = 20,262, p < .001$, were also found by comparison of same and novel context. Results showed that with extended practice, RT for 2x3 sequence was highest for switched context and lowest for same context. Within limited practice, comparison between same and switched context only showed effect of Key, $F(5, 115) = 42,515, p < .001$. No significant effect of Context, $p = .241$, was found. Similar effects were found for the comparison between same and novel context: Main effect of Key, $F(5, 115) = 29,996, p < .001$ and no effect of Context, $p = .706$. Results indicated that with limited practice no difference in RT for 2x3 sequence is found among context. The role of Key within this the context and practice interaction is investigated within the scope of the analysis of Context x Practice x Key interaction.

The interaction effect of Context x Practice x Key, indicated that some keys within the 2x3 sequence are performed with less RT in some context with extended practice compared to the others. In the limited practice group, RTs on keys in manipulated conditions showed minimum variance compared to the RTs on the keys in same context condition, while variances between RTs on keys in manipulated context and same context become stronger with extended practice. In limited practice condition, RTs on keys one and two were highest in same context and lowest in switched context. However, key three, showed lowest RT in same context compared to novel and switched context, while RT of the keys four, five and six showed minimal variance among context as illustrated in Figure 6. With extended practice same context showed constantly lower RT per key compared to switched and novel contexts as illustrated in Figure 6. Especially, RTs on key four showed stronger variance among contexts with extended practice (Figure 6).

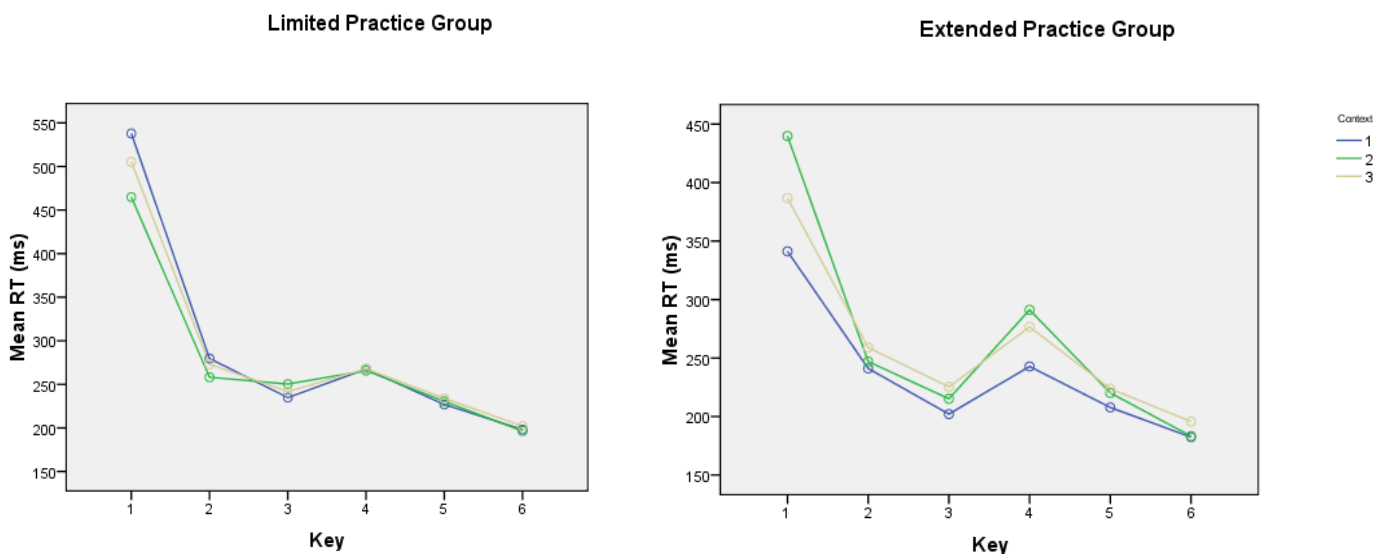


Figure 6 Mean RT per Key in 2x3 sequence for the limited practice and extended practice group in same (1), switched (2) and novel context (3).

1x6 sequence

Results showed significant main effects of Context, $F(2, 92) = 5,245, p < .01$, and Key, $F(5, 230) = 55,237, p < .001$. No interaction effect was found. To investigate the effect of Context two ANOVAs were performed as repeated measures on with Key (6), and Context condition (2: same vs.

switched and same vs. novel). Results showed that the Context effect can be attributed to difference in RT in same and novel context condition only, because there was no context effect found for same and switched context, $p = .895$.

The effect of Key can be attributed to the keys one and six, as mixed ANOVAs on with Key (4), and Context condition (3) demonstrated. One reason way key one is executed slower, lies in the DSP, which slowed down the performance on the first key (Verwey, 1996). One explanation for the slow response to key six could be found in the *recency effect*, which stated that people respond better to the last key they saw.

Role of Practice: Limited practice vs. extended practice

The Context x Practice, $F(2, 92) = 3,383$, $p < .05$, indicated that RT decreased more in some context with extended practice compared to other contexts. As illustrated in Figure 7, that performance in RT was faster with extended practice for all context conditions, however, performance per context showed strong difference between RT pattern for limited and extended practice.

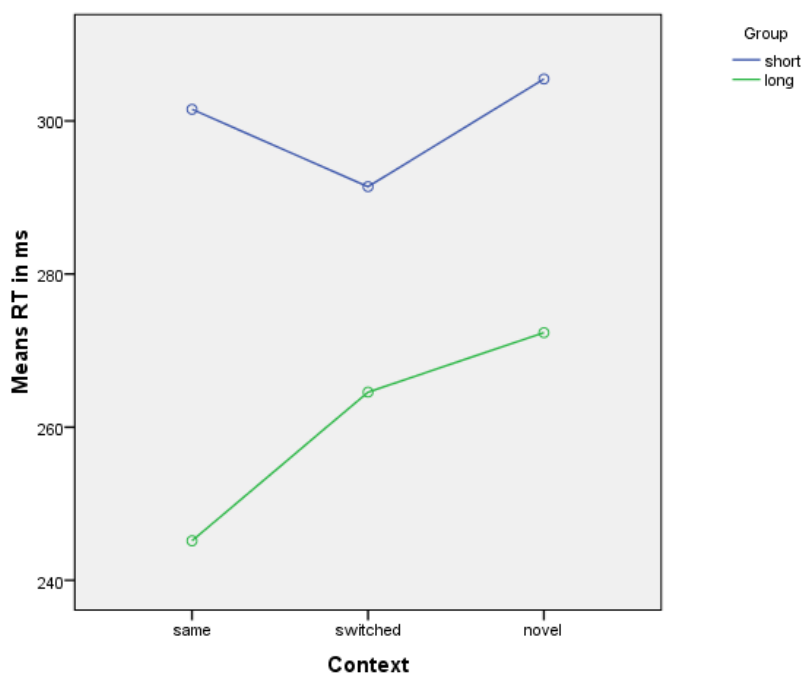


Figure 7 Mean RT for Context per Practice group.

To take a deeper look at the effects of context per practice group, two mixed ANOVAs as repeated measures were performed with Key (6), Sequence (2) and Context (3) as within-subject variables per practice condition.

Limited practice

For limited practice, results showed a significant main effect of Sequence $F(1, 23) = 9,513, p < .01$, and Key, $F(5, 115) = 39,883, p < .001$. Referring to the effect of Sequence, the 2x3 sequence ($M_{2 \times 3} = 285$ ms) was performed faster compared to the 1x6 sequence ($M_{1 \times 6} = 313$ ms). No significant interaction between Sequence and Key was found, which demonstrated that no significant difference among keys in sequences were found. This indicated that chunking during 2x3 sequence was not yet fully applied and loaded within limited practice condition. According to Verwey (1991), the development of motor chunks asked for sufficient practice time, which is consequently demonstrated here.

The effect of Key indicated that some keys were executed faster compared to others. To investigate if effect can be attributed to specific keys, three ANOVAs as repeated measures with Sequence (2), Context (3) and Key (5: excluding either key one or key six) or Key (4), or excluding both keys. Results showed that effect of Key remains significant in all three analysis, $ps < .01$. Furthermore, no effect of Context was found, demonstrating that within limited practice condition no significant difference in RT between same, switched and novel context was found.

Extended practice

In the extended practice condition, main effect of Context, $F(2, 46) = 6,438, p < .01$, and Key, $F(5, 115) = 30,292, p < .001$, as well as interaction effect of Context x Sequence, $F(2, 46) = 4,361, p < .05$, were found. Referring to the main effect of Context, two ANOVAs as repeated measures with Context (2: same vs. switched; same vs. novel), Sequence (2), and Key (6) were performed. The results of the comparison between same and switched context showed main effect of Context $F(1, 23) = 5,878, p < .05$, and Key, $F(1, 115) = 29,837, p < .001$, as well as Context x Sequence interaction,

$F(1, 23) = 5,827, p < .05$. These results indicated that RT decreased more for the 2x3 sequence in the same context, while RT decreased more for the 1x6 sequence in switched context.

Comparing same context and novel context, results showed significant main effect of context $F(1, 46) = 7,080, p < .05$, which indicated that performance in RT decreased more in the same context compared to the novel context. However, no significant Context x Practice interaction was found here, $p = .053$, results at least showed a trend towards stronger decrease in RT in the same context with extended practice compared to the novel context. Overall, results of the separate analysis of the main context effect showed significant effect of Context for both comparisons, $ps < .05$, demonstrating that with extended practice, same context ($M_{\text{same}} = 245$ ms) as performed faster than switched ($M_{\text{switched}} = 265$ ms) and faster than novel context ($M_{\text{novel}} = 272$ ms).

The main effect of Key indicated that some keys were executed faster compare to others. Three ANOVAs as repeated measures with Sequence (2), Context (3) and Key (5: excluding either key one or key six) or Key (4), or excluding both keys, showed that the effect of Key can be attributed to the strong increase in RT in key one and key six, $ps = .198$.

Taking a closer look at the interaction effect of Context x Sequence, context manipulation increases RT for both sequences. Although, RT increased more for the 1x6 in same and novel context, RT in the switched context increased more in the 2x3 sequence compared to the 1x6 sequence (Figure 8). This could indicate an increase of context dependence for the chunked sequence, concerning the switched context condition. A possible explanation for the increase in RT in switched context could lie in the presents of contrary information, which causes another sort of context dependency as Ruitenberget al. (under review) suggested.

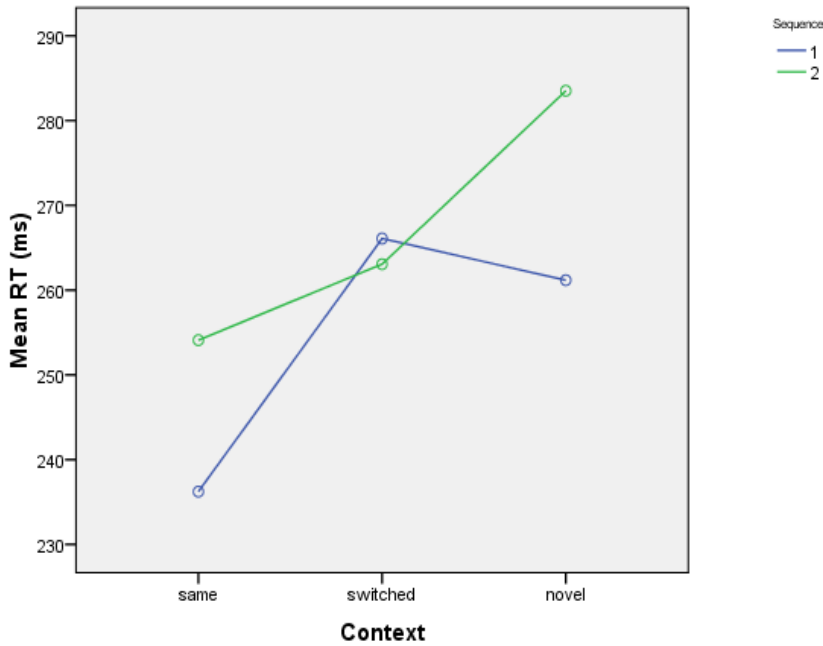


Figure 8 Mean RT in for 2x3 sequence (1) and 1x6 sequence (2) per context condition.

Error rates

Error rates of the test phase were analyzed with an ANOVA, which was performed as repeated measures with Context (3), Key (6) and Sequence (2) as within-subject variables and Practice (2) as between-subject variable. Results showed a main effect for Key, $F(5, 230) = 14,465$, $p < .001$, as well as interaction between Context x Sequence x Key interaction, $F(10, 460) = 2,672$, $p < .05$, which emphasized that in some context some keys were performed with fewer errors within one sequence compared to the other. No effect of Practice was found, $p = .501$.

To investigate the interaction effect between context, sequence and key per sequence, two mixed ANOVAs as repeated measures with Context (3) and Key (6) were performed one for 2x3 sequence and one for 1x6 sequence.

2x3 sequence

Results showed main effect of Context, $F(2, 92) = 4,075$, $p < .05$, and Key, $F(5, 230) = 4,333$, $p < .05$, which indicated that in some context the 2x3 sequence was performed with fewer errors

compared to others and that on some keys within the 2x3 sequence fewer errors were made compared to others.

In order to take a closer look at effects of Context, two ANOVAs as repeated measures were performed with Key (6) and Context (2: same vs. switched and same vs. novel), comparing same context with switched and novel context. Comparing ER of 2x3 sequence in same and switched context condition, results showed a main effect of Context, $F(1, 46) = 7,180, p < .01$ and Key, $F(5, 230) = 4,489, p < .05$. Same context ($M_{\text{same}} = 2, 26\%$) was performed with fewer errors compared to switched context ($M_{\text{switched}} = 5\%$). Results for the comparisons of same and novel context showed no significant effect of context, $p = .161$.

Referring to the main effect of Key, highest ER is found on key four ($M_{\text{key4}} = 4,65\%$), however, main effect of Key cannot be attributed to key four only, as the significant context effect, $F(4, 188) = 4,446, p < .05$, which results of the repeated measures ANOVA with Context (3), Sequence (2) Key (5; excluding key four), confirmed. The high ER is in line with the RT results and indicated the use of chunking.

1x6 sequence

Results of repeated measures mixed ANOVA with Context (3) and Key (6) for 1x6 sequence showed significant main effect of Key, $F(5, 230) = 11,288, p < .001$, and Context x Key interaction, $F(10, 460) = 2,605, p < .05$. To investigate interaction effect two mixed ANOVAs as repeated measures were performed with Key (6) and Context (2: same vs. switched and same vs. novel), comparing same context with switched and novel context. Results of the comparison between same and switched context showed a significant main effect of Key, $F(5, 235) = 10,737, p < .001$, which indicated that keys one to three in the switched context were performed with higher ER per key compared to the same context, while ER on the keys four to six showed were lower in switched context. Comparison between same and novel context showed a significant effect of Key, $F(5, 235) = 10,118, p < .001$. However, only minimal differences between ER on the keys one to three in same context and the same keys in novel context were found here (Figure 9).

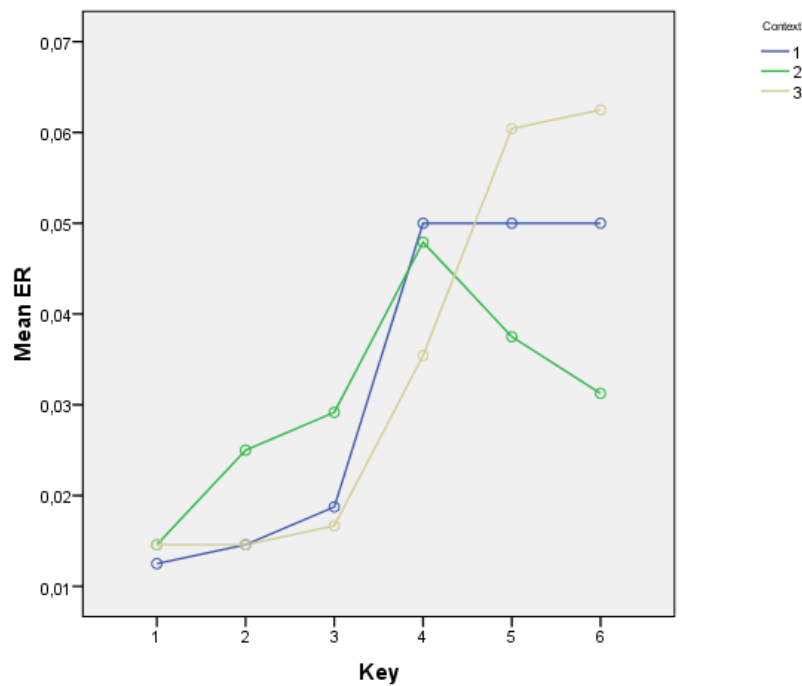


Figure 9 Mean RT per Key for the same (1), switched (2) and novel context condition (3).

Awareness

To examine the participants' awareness of the performed sequences, the number of correctly recalled and recognized sequences in the questionnaire was determined for every participant. Results of the questionnaire showed that 19 participants (79%) in the limited practice group and 23 participants (96%) in the long term practice group correctly reproduced both learned sequences. The other participants were unable to correctly recall either of their sequences. A total of 23 participants (96%) in the limited practice group correctly recognized both their sequences, as compared to 21 participants (87.5%) in the extended practice group. Again, the rest did not recognize either of their sequences correctly.

While recall performance differed among Practice, $F(1, 46) = 5.308, p < .05$, showing that performance was better with extended practice ($M_{\text{extended practice}} = 1.88$) compared to limited practice ($M_{\text{limited practice}} = 1.54$), recognition was not significantly influenced by Practice, $p = .535$. A possible explanation for these results could be that participants in the limited condition have more difficulties to recall the whole sequence by themselves, while it is easier for them to

recognize the sequences in a list, because sequences were not yet fully loaded into their buffer and therefore support is still needed. Participants in the extended practice condition could easily recall and recognize the sequences, because they are fully loaded into their motor buffer. Recall and recognition were therefore better after extended practice.

No difference was found between limited and extended practice for recall and recognition of the paired 3-key-chunk sequence, $ps < .367$.

Discussion

As the phenomenon of context dependence is known in the domain of verbal and motor learning, the present study aimed to extend current knowledge by investigating the development of context dependence in context manipulation. Special attention was paid to the roles of practice and task difficulty referring to the concept of motor chunking.

In this study the go/no-go DSP task (De Kleine & Van der Lubbe, 2011) was used to zoom in on context effects in manipulated contexts during motor preparation. Participants of this go/no-go DSP task experiment were assigned to either the limited or the extended practice condition. Both practice groups were prepared with two sequences, which differ in task difficulty, 1x6 sequence and paired 3 chunk-combination. Those sequences were presented to the participants in same context condition during the practice phase and additionally in two manipulated contexts during the test phase: switched and novel context. We hypothesized that (1) context manipulations (switched and novel context) will weaken performance and that (2) context dependency will increase with task difficulty, showing a greater context effect for non chunked 1x6 sequence than for paired 3-chunk-combination sequence and that (3) practice will mediate the development of context dependency.

As predicted, manipulated context slowed down performance compared to the same context condition. Found results were in line with the findings of Ruitenberg et al. (under review), demonstrating the development of context dependency in manipulated contexts. Changes in sequence colors, thus changes in context influence performance negatively while performance of participants was better within same context condition. Explanation of this context effects is found in Tulving and

Thomson's (1973) encoding specific principle, which emphasized that memory is supported as information available at encoding is also available in retrieval.

Former studies of Wright & Shea (1991) and Ruitenberg et al. (under review) further suggested that development of context dependency is influenced by amount of practice and task difficulty, referring to the manipulation of task length. In this study, we related to these suggestions, however, we manipulated task difficulty by the use of motor chunking. According to Verwey's (2001) DPM motor chunks can speed up performance, because buffer loading on cognitive processor will be reduced. Based on this model, we suggested motor chunking could be used to manipulate task difficulty in sequential motor learning.

As expected, results confirmed that chunking was successfully applied during the 2x3 sequence, as paired 3-key-chunks were executed with remarkable break in between the sequence, which was not present in the 1x6 sequence. Referring to these results we can further conclude that motor chunks speed up execution, compared to non-chunked sequence, and therefore indeed cause lower task difficulty. To be more precise, the 2x3 sequence was performed faster than 1x6 sequence, because motor chunks create lower task difficulty. As lower task difficulty should lead to less context dependency (Wright & Shea, 1991), we expected to find decrease in context dependency for the 2x3 sequence compared to the 1x6 sequence. Results confirmed that 2x3 sequence showed no context effect, indicating decrease in context dependency, while 1x6 sequence showed a significant context effect, which indicated increase in context dependency.

Taking a closer look at the chunked sequence with the lower task difficulty, interaction effects between Context x Practice and Context x Practice x Key were found. This indicated the impact of practice and contexts manipulations on motor chunks during the development of context dependency. To be more precise, with extended practice, chunked sequence was performed faster in same context condition than in switched and novel context, as well as that performance in switched context was faster than in novel context. With limited practice condition, no differences among contexts were found. This can again be explained by the DPM of Verwey (2001), as it states that motor chunks need sufficient practice time to develop.

Interestingly, measured error rates showed contrary results to RT. Within the 2x3 sequence significant effect of Context was found, although, effect can be attributed to the difference between same and switched context only. This raised the question, why participants respond to the 2x3 sequence as accurately in the novel context as in the same context, but make more mistakes in the switched context? According to Ruitenberg et al. (under review) one possible explanation could be the confrontation with contrary information in the switched context condition. The color switch of the sequence confused the participants to a greater extent than the use of one new for both sequences. This suggestion is further supported by the cognitive consistency paradigm of Festinger (1957). According to Festinger (1957) people feel a strong tension to reduce dissonances among cognitive elements. Relating to the present study, participants have learned that both sequences were tied to a specific color. As colors of the sequences were switched, participants may at first, be unaware of color change and/or automatically reduce this dissonance by executing their learned color-sequence-combinations, what they can do fast, because sequences are fully loaded in the motor buffer. As colors were changed in the novel context the cognitive paradigm no longer has an effect. This could be a reason why in a switched context execution was even faster than in same context, however more mistakes were made compared to the other contexts. In order to further acknowledge this effect more research is needed.

As we expected, results of this study pointed that motor chunks decrease context dependency while non-chunked sequence increase context. However, because context effect of non-chunked sequence was limited, we follow up on the role task difficulty, referring to the non chunked sequence. Taking a closer look at the non-chunked 1x6 sequence, further analysis showed that this effect can be attributed to the same and novel context conditions, only. This means, that 1x6 sequence showed no significant difference in performance in same and the switched. Error rates (ER) were in line with this RT findings. An explanation for these results can be found in the theory of Verwey (2001). As we assumed that 1x6 sequence will become a unit of associated information, which is fully loaded into the motor buffer after sufficient time of practice, we could give consideration to Verwey's (2001) concept of the robustness of chunks. The robustness of chunks means that chunks can also be used in situations that differ from the original learning situation. Context dependence would therefore decrease with

sufficient practice, which could explain why the effect between the same and the novel context was not of significance. Because no effect of practice was found for the 1x6 sequence, this suggestion cannot be approved in this study. Therefore more research is need.

The role of practice in process of context dependency was well acknowledged in this study, however results indicated that more research is needed here. However, practice phase of this study proved significant effect of Practice, no significant main effect of Practice was found in the test phase. We well found interaction between Context and Practice, demonstrating general decrease in RT in all contexts with extended practice, whereas RT decreased most in same context and fewest in novel context. Therefore, we indicated that the amount of practice mediates the development of context dependency. Interestingly, within limited practice performance in switched context was even better than in same and novel context. A possible explanation could again be found in the Verwey's (2001) concept of the robustness of chunks. However, with this concept the question if limited practice is sufficient to construct robust motor chunks came up, asking for further research.

Finally, effect of extended practice significantly affected recall performance, which could be explained by the sufficient time participants in the extended practice condition had, to load the motor action, in contrast to participants in the limited practice condition. No effect of practice was found for performance of recognition, revealing that recognition does not ask for fully loaded chunks but recognizing skills, with chance of 2:12 to pick the right ones.

In summary, the presented study confirmed that task difficulty concerning motor chunking and practice play an important role in the development of context dependence in context manipulation. With a go/no-go DSP task (De Kleine & Van der Lubbe, 2011) we verified our former hypothesis, that (1) context manipulations (switched and novel context) weaken performance and that (2) context dependency increases with task difficulty, showing greater context effect for non chunked 1x6 sequence than for paired 3-chunk-combination sequence (3) and that practice mediates the development of context, however more research is required to satisfy question that arise from this study.

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