Contextual Dependencies during Motor-Preparation in the Go/No-Go DSP task

Name: Michael Golla
Student-No.: s0193615
Track: C&M
First Supervisor: M.F.L. Ruitenberg, MSc.
Second Supervisor: Dr. E.L. Abrahamse
Bachelor Thesis Psychology, University of Twente 30.01.2012, Enschede

Abstract

Context-dependant learning refers to the phenomenon that there is better performance on a task when the environmental context that is present during learning matches the context that is present during testing. The present study examined whether contextual dependencies, which have been found in motor movements, can also be found in the preparation phase of these movements. Furthermore a possible mediator role of task difficulty and practice was examined. Therefore two context manipulations (switched and novel), two sequence lengths (three-key and six-key) and two practice groups (limited and extended practice) were included. The results demonstrated contextual dependencies for the shorter three-key sequence in both context manipulations. However, these results were not confirmed for the six-key sequence because no effects of context manipulation have been found for this sequence length. A possible explanation for these findings is that context manipulation prevented full sequence preparation for the three-key sequence due to insufficient time for the cognitive processor to prepare the sequence – this was not the case for the longer sequence as time to prepare and identify the sequence was remarkably longer than for the shorter sequence. Furthermore no differences in the development of contextual dependencies between practice groups have been found indicating that the amount of practice does not mediate the development of contextual dependencies for three-key sequences in motor-preparation tasks.

Contents

1. Introduction

1.1 Introduction to context-dependant learning

In our daily lives we are confronted with a tremendous amount of information, yet just a small amount of this information is consciously processed by our brain. When we want to learn something new, for example, it seems necessary to put attention on the aspects that are necessary to master the ability of our interest and ignore elements that do not have anything to do with the task itself. These elements can be noises, colors, shapes, smells or feelings we experience during the process of learning. Together these and any other elements of the situation and the environment form the *context*. It is a known phenomenon that performance can be improved if the context that is present during encoding of information matches the context that is present during retrieval (Baddeley, Eysenck & Anderson, 2009; Godden & Baddeley, 1975; Jansen, Harris & Anderson, 1971; Smith 1985). This is what we call a *context-effect* which develops through *context-dependent learning*. A simple example is that a pupil's performance on free recall questions (short essay) and cued recall questions (fill-in-the-blank) decrements when there are substantial differences between classroom and test room during examination (Weir & May, 1988). A famous study regarding the topic of context-dependent learning was conducted by Godden and Baddeley (1975) who let divers learn a list of words either underwater or on land, and then tested recall of these words in either the same or another location. Results revealed that the divers who learned underwater could retrieve the words better underwater than on land and vice versa, which implicates that context has an influence on the divers' performance, thus a context-effect. Numerous other studies examined context effects, most of them also dealing with verbal learning in same and different contexts such as noises (Grant et al, 1998), visual contexts (Murnane & Phelps, 1993, 1994, 1995), background music (Balch, Bowman & Mohler, 1992; Smith, 1985) or even physiological state (Goodwin et. al, 1969; Rickles, 1973). A common explanation for the development of context-effects is the *encoding specificity principle,* which states that memory is facilitated if information available at encoding is also available at retrieval (Tulving & Thomson, 1973),

1.2 Context dependant learning in motor-skill tasks

Wright and Shea (1991) were the first who successfully extended the topic of context-dependent learning to the domain of motor skills as they conducted research on a possible relationship between environmental manipulations and motor-skill performance. They distinguished between intentional stimuli which are essential for the execution of the task and incidental stimuli which are not required for the execution of the task but can be later associated with the task "due to their selective presence in the learning environment" (Wright & Shea, 1991). Wright and Shea let their participants learn two sequences of different length, a three- and a four-key-sequence. To do so, participants had to repeatedly respond to stimuli that were presented on a display by pressing corresponding keys on the keyboard. The intentional stimuli - which were crucial for the execution of the sequence - were represented as number and horizontal position on the display, whereas incidental stimuli were also included to study the possible effects of different contexts. Incidental stimuli were included by the way that each sequence was paired with a combination of a particular display color, a specific tone, a certain vertical position on the screen, and a particular placeholder shape. After learning participants who had to execute the task in a switched context condition – which means that intentional stimuli were in the test phase presented with incidental stimuli that have former been presented with alternative intentional stimuli - showed significantly more erroneous responses than participants who had to execute the task in the test condition where the incidental stimuli were paired with the same intentional stimuli as during the learning phase. This evidence was only found for the longer four-key sequence. Wright and Shea concluded thus that (1) context has an influence on performance and (2) that the difficulty of a task (e.g. manipulated through the length of the sequence) mediates the development of these context-dependencies. In other words: they found that a switched context affects participants' performance negatively and that the execution of an easier task and therefore execution of shorter sequences is less prone to context manipulations than more difficult tasks with longer sequences. Anderson, Wright and Immink (1998) also conducted research on the possible influence of task difficulty on context-dependencies in motor tasks. They did not only use erroneous responses as an indicator for performance but mainly reaction time, so they asked participants – in comparison to Wright and Shea (1991) - to react as fast and accurately as possible. Task difficulty was manipulated by restricting the time that participants were allowed to view task-relevant information and the time they were afforded to execute a sequence of key presses. The results showed that in the test phase participants in the more difficult conditions (shorter viewing times) showed slower response times. Therefore they concluded that task difficulty plays a crucial role on the extent to which context-dependencies develop (Anderson et al., 1998). Another important study concerning contextual dependencies in the domain of motor tasks is the study by Wright, Shea, Li and Whitarc (1996) who let participants execute an immediate or a delayed retention test after switching the context in a motor-skill task. Results showed that participants who were asked to execute the immediate test showed decrement performance, whereas participants who were asked to execute the delayed test did not. In a second experiment participants who should execute the delayed test were asked to mentally reinstate the incidental contextual information that was present during execution, which in turn caused a context-effect also for this group (Wright, Shea, Li & Whitarce, 1996). Wright et. al concluded consequently that incidental contextual information can still play a role in participants' performance on a delayed test if participants are explicitly encouraged to mentally reinstate the context.

In summary, (a) contextual dependencies have been found in motor tasks and (b) task difficulty, e.g. manipulated through sequence length, can play a dominant role in the development of these dependencies.

1.3 Motor-Preparation in the Go/No-Go DSP task

The present study is particularly interested in the development of contextual dependencies in the preparation of motor movements and the role that practice and task difficulty play in this respect. A task that is suitable to measure motor movements is the *discrete sequence production* (DSP) task (Verwey, 1999; 2003). The DSP task is a motor sequence task that typically consists of sequences of two to six stimuli that are presented in a determined order. In the DSP task there are four rectangles presented on the screen which light up in a certain order to form a sequence. Subjects put their fingers on a keyboard in a specific manner and respond by means of a key press to a stimulus that lights up on a display. As soon as response is given, another stimulus lights up on the display until the sequence ends. Every stimulus on the display spatially corresponds to a specific key on the keyboard. After extensive practice subjects are very fast at performing the whole sequence which can be attributed to the development of movement representations called *motor chunks*. Through the use of motor chunks about 5 key presses can be executed as one single response (Verwey 1996), while the first stimulus functions as an indicator for the entire chunk. As this study particularly examines the preparation of a movement sequence, a modification of the original DSP-task will be used.

The *Go/No-Go DSP*-task, developed by de Kleine and Van der Lubbe (2011), is a purely memory-based version of the DSP-task and distinguishes between preparation and execution of a motor sequence. The crucial difference with the original DSP task is that during the Go-/No-Go DSP-task participants are not asked to respond to each stimulus immediately upon presentation, but instead they have to wait until the whole sequence is presented. After the presentation of the sequence a fixation cross, which is positioned central above the rectangles, fills with either green (go-trial) or red color (no-go trial). The go-trial indicates that the sequence should be reproduced by the participant, whereas the no-go trial indicates that no action should be taken. This strict division between presentation and execution of a sequence assures an execution exclusively from memory. The division between preparation and execution of a motor sequence furthermore takes account of Verwey's *dual processor theory* which states that motor tasks are prepared by a cognitive processor and executed by a motor processor (Verwey, 2003). The cognitive processor is responsible for the *preparation* of a movement; it selects and loads the elements of the sequence into the motor buffer while the motor processor has the function to read these elements and *execute* them. As after extended practice motor chunks develop the cognitive processor does not have to prepare every single key press separately and the motor chunk can be executed as a whole by the motor processor when the first stimulus of the motor chunk is presented as a cue. The development of motor chunks decreases thus the processing load on the cognitive processor and therefore reaction times decrease as motor chunks develop.

Recently researchers made use of the above described Go-/No-Go DSP task to show context-effects in the preparation phase of motor movements (Ruitenberg, Abrahamse, de Kleine and Verwey, under review). Ruitenberg et al. (under review) let participants learn two sequences consistent of six-key presses. In the test phase context was manipulated through the color of the sequences. Results showed that participants in a switched context condition executed the task significantly slower than participants in the same context condition, an effect of context was thus found. Ruitenberg et. al added a third context to the experiment, a novel context, which did not affect participants performance (Ruitenberg, under review). They proposed thus a type of context-dependency which only occurs when the participant is confronted with conflicting contexts rather than a merely new one. This paper aims to replicate and deepen these findings.

1.4 The present study

The present study includes two kinds of context manipulations, two sequence lengths and two practice groups to examine the possible role of context manipulations, task difficulty and the role of practice on the development of contextual dependencies in the Go/No-Go DSP task. We hypothesize that (1) both context manipulations will cause an attenuation of performance and that (2) task difficulty and (3) practice will mediate the magnitude to which the context manipulations affect performance. In the following the hypotheses will be discussed separately.

Each sequence was throughout the practice phase constantly presented in either yellow or blue color. To measure possible context effects we make use of two kinds of incidental context manipulations; after practice we present the sequences in a switched and in a novel context condition. In the switched context condition the sequences switch colors (blue sequence becomes yellow and vice versa), whereas in the novel context condition both sequences are presented in red. According to the *encoding specificity principle* (Tulving & Thomson, 1973), both context manipulations should cause an attenuation of performance because in both the switched and the novel context condition the context that was presented during encoding does not match the context that is presented during retrieval. However, on the basis of the findings of Ruitenberg et. al (under review) it can assumed that only the switched context condition would cause an attenuation of performance. If participants' performance would only decrement in the switched context condition but not in the novel this could be explained due to conflicting information as the incidental stimulus that was a cue for one sequence will then be presented with another sequence. The context-effect would then develop through misleading expectations and interference, thus in this case there would not necessarily be a context-effect in the traditional way as proposed by the encoding specificity principle.

Furthermore we divided participants into two groups to examine the possible role of practice in context-dependant learning; half of the participants received limited practice on the sequences, while the other half received extended practice. Two opposed hypotheses can be made regarding the influence of practice on the development of contextual dependencies. On the one side it can be assumed that after extended practice motor chunks are more developed than after limited practice and as motor chunks decrease participants' dependence on visual stimuli and the cognitive processor (Verwey, 1999) it can be expected that – since the contextual manipulations in the present study are of visual nature - the extended practice group will be less sensitive to contextual manipulations. On the other side it can be hypothesized that since it is assumed that contextual dependencies develop due to the association of intentional and incidental stimuli (Wright & Shea, 1991) these associations will be greater after extended than after limited practice and consequently the extended practice group would be more sensitive to context manipulations.

Our study included two lengths of sequences, to investigate the possible effect of sequence length and therefore task difficulty on context-dependency. In line with Verwey's dual processor theory we assume that context-dependency will be greater for the longer sequence due to the increased processing load on the cognitive processor as sequences get longer (Verwey, 2003). We expect a role of task difficulty on the forming of contextual dependencies as a possible role of sequence length on the development of contextual dependencies in motor tasks has already been indicated by other studies (Wright and Shea, 1991). Wright and Shea found that participants' performance was significantly more context-dependent with the four-key sequences than with the shorter three-key sequences in terms of correctly executed key presses (PC). However, a difference with the present study is that Wright and Shea focused on PCs whereas our study also includes response time (RT) as a dependent variable which is more sensitive to differences.

In summary, this study aims to deepen knowledge concerning context-dependencies in the preparation of exclusively memory-based motor skill tasks. As research in this specific domain was rarely conducted it seems not just useful to reproduce some recent results (Ruitenberg, under review) but also to include new aspects which add further knowledge to the topic such as the possible influence of different sequence lengths on context-dependent learning and the execution of the Go/No-Go DSP task.

2. Methods

2.1 Participants

Participants in this study were 48 students (25 male and 23 female) of the University of Twente. Their mean age was 22 years, ranging from 18 to 28 year. According to Annett's (1970) Handedness Inventory 46 participants were identified as right-handed and 2 participants as ambidextrous (an exclusion of the 2 ambidextrous participants did not have any influence on the results of the study, so they remained in the data set). Participants did not have ADHD, colorblindness or any neurological disorders. Course credits for participation were offered to each participant. The study was approved by the ethics committee of the Faculty of Behavioral Sciences of the University of Twente.

2.2 Apparatus

E-Prime© 2.0 was used for stimulus presentation and data registration. The program ran on a Pentium IV class PC. Stimuli were presented on a 17 inch Philips 107 T5 display.

2.3 Task and Procedure

Before the actual motor-task started participants had to sign an informed consent and a screening form to make sure the participants matched the requirements for participation (right-handed, no form of color-blindness, ADHD or any neurological disorders). Participants were then asked to execute the Go/No-Go DSP task. Therefore participants had to sit behind a computer and place their fingers of the left hand on the c, v, b and n keys. A fixation cross and four rectangles were presented on the screen, each of the rectangles corresponded with one key.

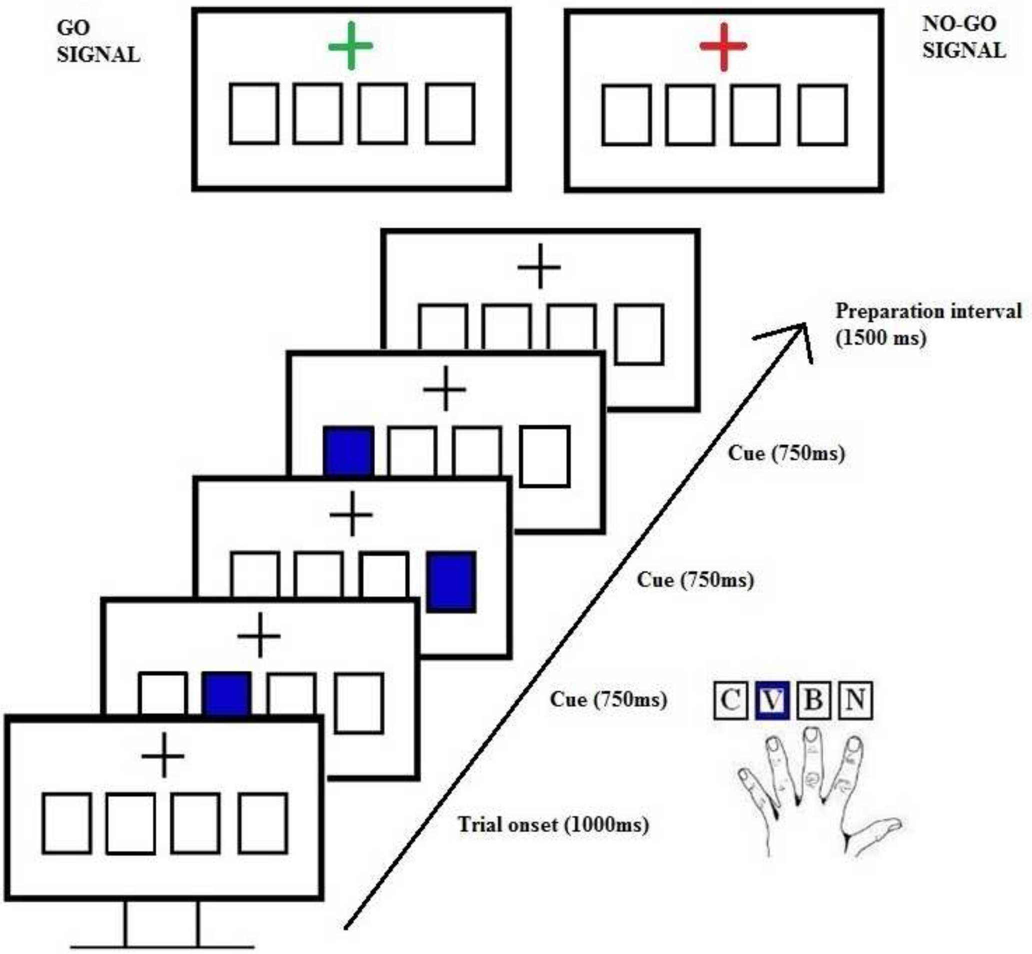

Figure 1: Illustration of a complete trial of the Go/No-Go DSP task for a 3-key-sequence (VNC). Participants had to place the fingers of their left hand on the C, V, B and N keys which corresponded with the four rectangles. After the whole sequence was presented the fixation cross above the rectangles indicated a go- (green color) or a no-go trial (red color).

After 1000ms a rectangle lit up for 750ms, then a second rectangle lit up (while the other rectangle's color disappeared), and so on until the whole sequence was presented in either blue or yellow color. After the sequence was presented the default screen reappeared for 1500ms and after that the fixation cross filled with either red or with green color. If the fixation cross filled red this was presented for 3000ms and no action should be taken (this happened in 8% of all cases and is called a *no-go trial*), whereas if the fixation cross filled green this was presented for 100ms and the participants should try to execute the sequence that has just been presented (in 92% of all cases, called a *go-trial*). An illustration of the Go/No-Go DSP task can be found in Figure 1. Participants had to learn two sequences of different lengths in the practice phase, one three-key-sequence and one six-key-sequence. In order to prevent finger-specific effects there were four versions of each sequence length created (6-key-sequences: bcncbv, nvbvnc, cbvbcn, vncnvb; 3.key.sequences: vnc, bcn, nvb, cbv). The sequences were combined in such a way that the sequences that participants had to execute did not start with the same key. During the practice blocks one sequence was always presented in yellow and the other sequence in blue and the sequences were always presented randomly. Half of the participants performed the sequences during one practice block (50 trials per sequence in total), the limited practice group, whereas the other half of the participants performed 6 practice blocks (300 trials per sequence), the extended practice group. A practice block consisted of 100 go and 20 no-go trials. There was a 30 second break halfway through each practice each block and a 2min break after a practice block was completed. During the test phase each participant had to execute the task in three different conditions. One was the *same context condition* in which the match between the sequences and the colors of the stimuli were the same as during the practice phase. Another was the *novel context* in which both sequences were now presented in red. The third condition was the *switched context* where the colors of the sequences were switched, thus the sequence that was presented in blue during practice was now presented in yellow and vice versa. As during practice the sequences were presented randomly. The order of the conditions was counterbalanced across participants to avoid order effects. After completion of the task participants were asked to fill out two questionnaires. The first asked participants to recall the sequences they just executed and write them down. In the second questionnaire participants were asked to recognize their two sequences out of 12 alternatives and furthermore to indicate how they remembered the sequences.

3. Results

For each participant the mean response time (RT) and accuracy per block were calculated. RT was defined as the time between the presentation of the go-signal and the first key press, and furthermore the interval between the first and the second key press and so on until the sequence ended. Only RTs of sequences without any erroneous responses were included in the analyses. Accuracy was defined as the percentage of correctly executed key presses.

3.1 Practice phase

3.1.1. 3-key-sequence

We performed an ANOVA with Key (3) as repeated measures on the limited practice group. The results showed that there was an effect of Key, $F(2,46)=45.02$, $p<.001$, which means that some keys were executed faster than others. This effect occurred due to the in comparison with the others keys slow RTs on the first key press which represents the response to the fixation cross. The following key presses depend on sequence knowledge which requires another kind of response that can be executed faster. A mixed ANOVA with Block (6) x Key (3) as repeated measures was performed on the extended practice group. Main effects showed that RTs decreased across practice blocks, $F(5,115)=60.77$, $p<.001$. A closer look at the data revealed that this effect occurred basically because of the high response times on the first practice block (348 ms) in comparison to the further blocks (RT second block = 258 ms, third block = 242 ms, fourth block = 239 ms, fifth block = 224 ms, sixth block = 208 ms). Furthermore there was an effect on Key, which means that some keys were executed faster than others, $F(2,46)=115.1$, $p<.001$. The ANOVA also showed an interaction effect of Key and Block, some keys were thus executed faster than others across blocks, *F*(10, 230)=3.01, *p*=.01. To account for possible differences between limited and extended practice group a second mixed ANOVA was performed on both groups for the first practice block. Evidence showed a main effect of Key, *F*(2,92)=100, *p*<.01, but execution of key presses did not differ significantly between both groups, *F*(2,92)=0.025, *p*=.98. Furthermore there was no difference in performance between both groups, *F*(1,46)=0.73, *p*=.4.

3.1.2. 6-key-sequence

The same analysis was executed for the 6-key-sequence. An ANOVA with Key (6) was executed for the limited practice group and again we found that there was an effect of Key, *F*(5,115)=42.01, p<.001, due to the slow response times on the first key press in comparison with the following key presses. Another ANOVA with Block (6) x Key (6) as repeated measures for the extended practice group showed that RTs decreased across practice blocks significantly, *F*(5,115)=86.64, *p*<.01 and that – also for this group - there was an effect of Key, *F*(5,115)=27.45, *p*<.01. However, no interaction effect of Block x Key has been found which means that there was no significant difference between the execution of keys across blocks, *F*(25,575)=1.17, *p*=.26 (Figure 2). To check for possible differences between groups a mixed ANOVA for both groups with Key (6) as repeated measures on the first practice block was executed. Again there was an effect of Key, *F*(5,230)= 52.02, *p*<.01, but no interaction effect of group and performance, *F*(1,46)=0.54, *p*=0.47, indicating that performance between groups did not differ on the first block.

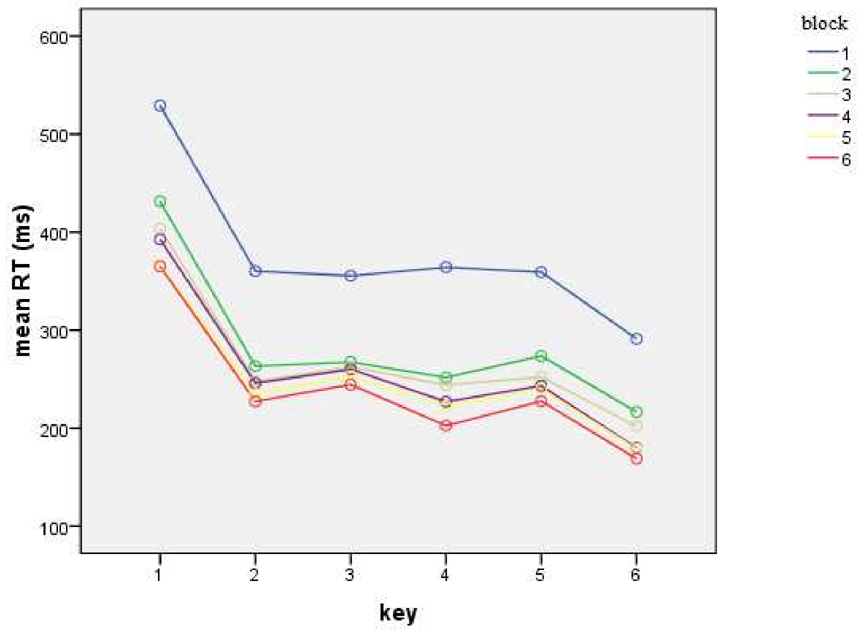

Figure 2: RTs of the extended practice group across the six practice blocks. The figure shows that the first key was executed slower than the other keys and that RTs decreased across practice blocks.

3.2 Test phase

3.2.1 3-key-sequence vs. 6-key-sequence

We performed a mixed ANOVA with Sequence (2; three-key vs. six-key sequence) x Condition (3; same vs. switched vs. new) x Group (2: limited vs. extended practice). Results showed an effect of sequence length, $F(1,46)=13.24$, $p<.001$, which means that the three-key sequence was executed faster (227 ms) than the six-key-sequence (251 ms). However, we did neither find an interaction effect of sequence length and condition, $F(2,92)=1.71$, $p=.186$, nor an interaction effect of sequence length, condition and the amount of practice, $F(2,92)=0.08$, $p=.92$ (Figure 3). In terms of accuracy we found similar results as there was an effect of sequence length (99.2% of correctly executed key presses in the three-key-sequence; 97.7% in the six-key-sequence), $F(1,46)=17.96$, $p<.001$, and no interaction effect of length and condition, $F(2,92)=0.02$, $p=.99$, or length, condition and the amount of practice, $F(2,92)=1.78$, $p=.17$. Contrary to our hypothesis there was thus no significant difference in contextual dependence between the two sequence lengths.

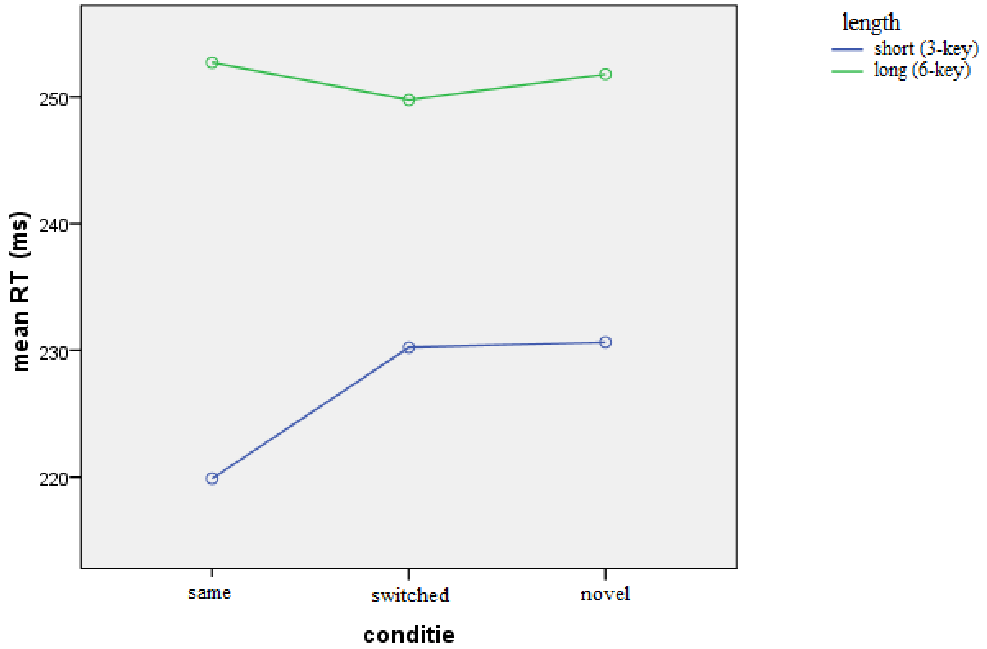

Figure 3 : This figure shows the mean RTs of the different sequence lengths in the three test conditions. Altough there were no significant differences in contextual dependency between both sequence lengths, this diagram shows that the shorter sequence had a stronger tendency to be sensitive to context manipulations.

3.2.2 3-key-sequence

We performed a mixed ANOVA with Condition (3) and Key (3) as repeated measures and Group (2) as between-subject variable. There was a tendency of Condition to become significant, $F(2, 92)=2.43$, $p=.09$ - mean RTs indicated that performance in the switched (230 ms) and in the novel condition (231 ms) decremented compared to the original context condition (220 ms) (Figure 3). Based on our hypotheses, we performed separate analyses to check for differences between both the same/switched and the same/novel conditions. A significant difference in performance was found between both the same/switched condition, $F(1,46)=3.51$, $p=.035$ (two-tailed=.067) and the same/novel condition (Figure 4), $F(1,46)=4.95$, $p=.0155$ (two-tailed=.031).

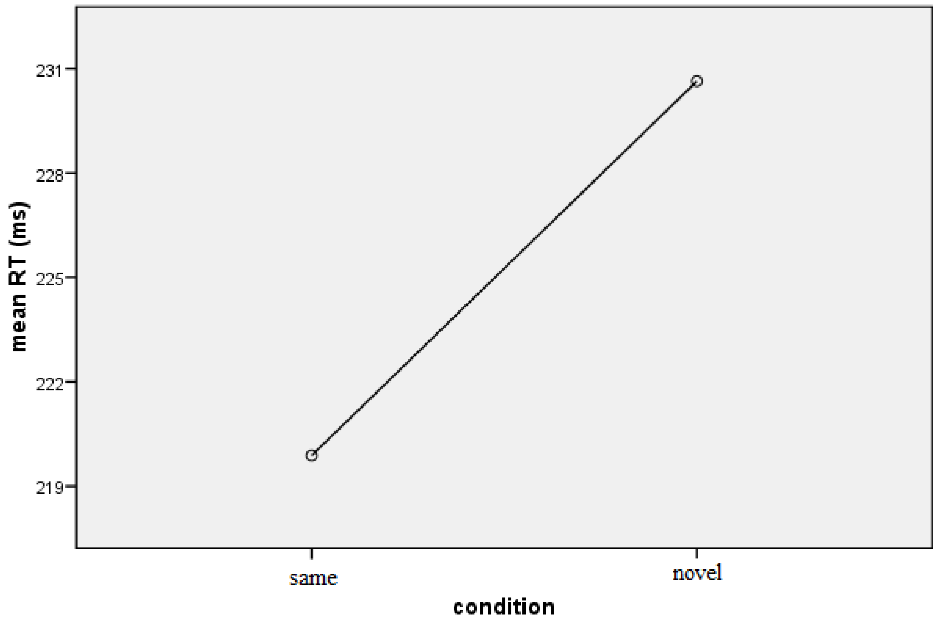

Figure 4: This figure illustrates the significant difference in performance between the same and the novel context condition (mean RT 220 ms vs. 231 ms) for the 3-key-sequence.

A closer look at the data reveals that the significant difference in performance between same and switched condition was basically caused by the difference in performance on the first key T1 (same condition = 319 ms vs. switched condition = 347 ms), $F(1,46)=2.921$, $p=.094$, while there was no difference in performance on T2 (185 ms vs. 186 ms) , $F(1,46)=0.072$, $p=.757$, and T3 (156 ms vs. 158 ms), $F(1, 46)=0.176$, $p=.677$ (Figure 5). This was not the case for the same/novel condition, with T1 (319 ms vs. 337 ms), $F(1,46)=2.542$, $p=.118$, T2 (185 ms vs. 195 ms) , $F(1,46)=3.42$, $p=.071$, and T3 (156 ms vs. 159 ms), $F(1,46)=0.314$, $p=.578$, where the second key was most affected.

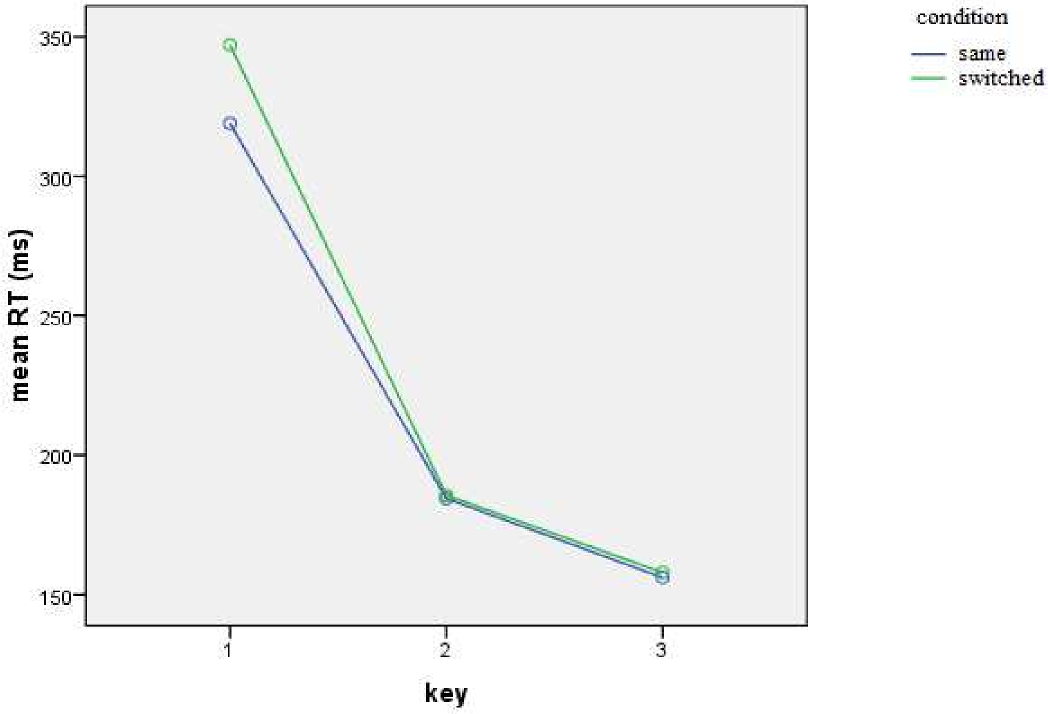

Figure 5: The difference in performance between same and switched condition occured basically because of the context-effect on the first key T1 (same = 319 ms vs. switched = 347 ms), while keys T2 (185 ms vs. 186 ms) and T3 (156 ms vs. 158 ms) remained nearly unaffected.

Performance between the limited (244 ms) and extended (211 ms) practice group did not differ significantly, $F(1,46)=2.01$, $p=.16$. Moreover, amount of practice did not mediate these results as in both cases no interaction effect between Group and Condition was found ($F(1,46)=0.237, p=.629$ for same/switched condition and $F(1,46)=0.927, p=.341$ for same/novel condition).

We also performed a mixed ANOVA to check for differences regarding participants' accuracy in the three test conditions. We found that participants executed averaged 99.6% of all key presses in the same context condition, 99% in the switched context, and 99.1% in the novel context correctly. These differences in terms of accuracy between the three test conditions were not significant, $F(2,92)=1.09$, $p=.34$.

3.2.3 6-key-sequence

We performed the same analysis for the 6-key-sequence. For the 6-key-sequence we did not find any effect of Condition, $F(2,92)=0.12, p=.89$. Furthermore performance between limited and extended practice group did not differ, $F(1,46)=2.2$, $p=.15$, and there was no interaction effect between Group and Condition, $F(2,92), p=.518$, which means that there was no difference in contextual dependencies between both practice groups. We found an effect of Key, $F(5,230)=52.74$, $p<.001$. Figure 6 reveals this effect occurred due to the relatively slow response times on the first key and the relatively fast response time on the last key in comparison with the other keys. Interesting is also the forming of motor chunks if one takes a closer look at the difference between limited and extended practice. A mixed ANOVA with Condition (3) and Key (5; T2-T6) as repeated measures and Group as between-subject variable shows an interaction effect of Key and Group, $F(4,368)=3.227$, $p=.014$ – this means that the amount of practice had a significant impact on the way individual keys were executed. Figure 5 illustrates how motor chunks have developed for the extended practice group.

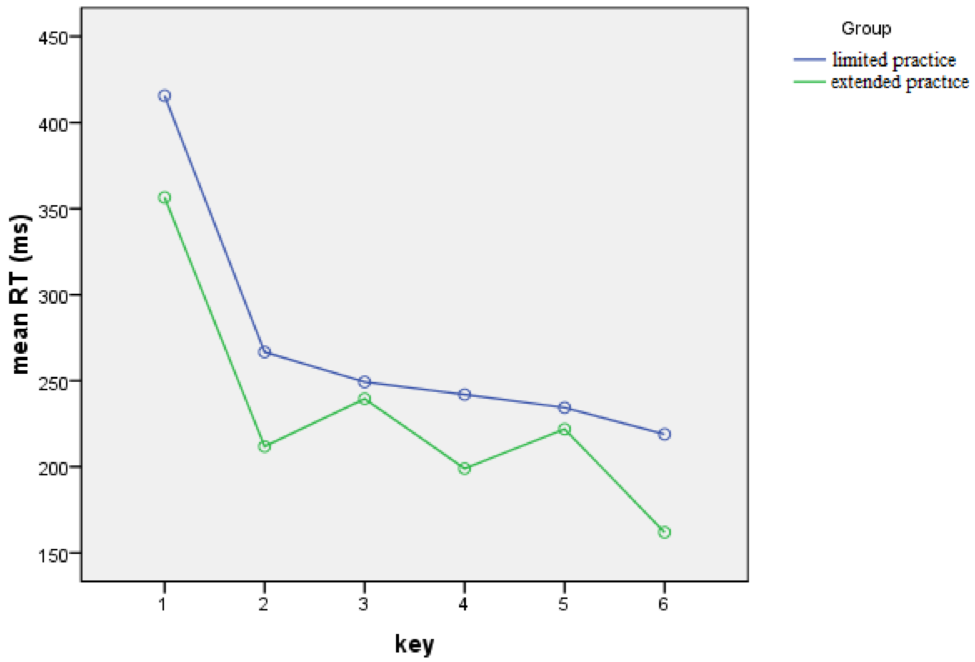

Figure 6: This figure illustrates the segmentation of the sequence into motor chunks. Key 1 was executed relatively slow in comparison with the subsequent key presses. Furthermore - in the extended group - Keys 3 and 4 and Keys 5 and 6 were segmented together.

Finally, a mixed ANOVA was conducted to check for differences in accuracy, but there were no differences between the three test conditions found (same context: 98.1% executed correctly; switched context: 97.4%; novel context: 97.5%), $F(2,92)=0.76$, $p=.47$.

3.3 Awareness

Analysis of the two questionnaires which asked participants to both recall and recognize their two sequences revealed that in both extended and limited condition all participants recalled and recognized their 6-key-sequence correctly (100%). However, in the limited practice group 22 participants (92%) recalled the 3-key-sequence correctly and in the extended practice group 23 participants recalled the 3-key-sequence correctly (96%). The 3-key-sequence was correctly recognized by 23 participants (96%) in the limited version and 23 participants in the extended version (96%). Recall and recognition were not better after extended than after limited practice ($X^2(df=1)=.356$, $p=.551$ for recall on 3-key-sequence and $X^2(df=1)=.0$, $p=1$ for recognition on 3-key-sequence).

4. Discussion

The phenomenon of context-dependent learning is known for quite some time in verbal learning (e.g. Godden & Baddeley, 1975) and has been successfully extended to the domain of motor tasks (Wright & Shea, 1991; Anderson, Wright & Immink, 1998; Abrahamse & Verwey, 2008). Recently these findings were further extended to the preparation of motor movements where context-effects in a switched context condition have been found (Ruitenberg et al., under review).

The present study aimed to reproduce and deepen knowledge concerning the question whether and in which way context-dependencies develop in motor tasks which are purely memory based. A motor task that is suitable for this purpose is the Go-/No-Go DSP task which separates preparation and execution of motor movements (de Kleine & Van der Lubbe, 2011). We used two sequences of different length, a three-key and a six-key sequence, and two kinds of context manipulation – a switched context condition in which colors of the two to be learned sequences switched, and a novel context condition in which the sequences were presented in a new color. Furthermore we divided participants in two practice groups; one with extended and one with limited practice. We made the predictions that (a) the context-effect will be greater for the longer six-key sequence than for the three-key sequence, (b) both context manipulations will cause an attenuation of performance and (c) the amount of practice will mediate the development of context-dependencies. In the following these predictions will be dealt with in detail one by one.

As predicted, we found context dependencies for the three-key sequence in both the switched and the novel context manipulation. In other words, the manipulation of the incidental stimulus, sequence color, had a significant influence on participants' performance as response times slowed down when sequence color and thus the context changed. This is in line with Tulving and Thomsons *encoding specifiy principle* (1973), which states that memory is facilitated if information available at encoding is also available at retrieval; related to the present study this means that the sequence color that was presented during practice and therefore during encoding functioned as a cue that facilitated memory when it was present at retrieval. Consequently, participants performed better in the same context condition than in the switched and the novel context condition. Furthermore it is noticeable that in the novel context condition one color for both sequences was used. In comparison to the other two conditions participants could not link a color to a specific sequence, but instead one color to both the long and the short sequence. It is therefore possible that the absence of this distinguishing aid had an influence on the forming of the context-effect in the novel context condition.

However, for the longer six-key sequence neither the novel nor the switched context manipulation affected participants' performance. Consequently, the finding that performance did not change for the six-key sequence falsified also our second prediction that the context-effect will be greater for longer sequences. At first sight this is quite remarkable as longer sequences have a higher cognitive work load than shorter sequences (Verwey, 2003); therefore we assumed in the introduction that with increased difficulty context dependencies would increase as a mediator role of task difficulty manipulated by sequence length has already been suggested by other studies (Wright & Shea, 1991). Wright and Shea found that participants' performance, measured in terms of correctly executed key presses (PC), decremented in a switched context manipulation for the four-key sequence but not for the shorter three-key sequence (it should be noticed that the present study, despite the fact that PCs were also registered but were generally very low, focused on RTs which are more sensitive for performance measurements than PCs). How is it thus possible that in the present study context-dependencies were found for the three-key sequence and *not* for the six-key sequence?

We assume that this finding can be explained due to participants' expectations, which were probably shaped by the incidental stimuli and the associated sequence length, and consequently affected motor preparation. Verwey (2001) postulates a *dual processor model* which states that two different components, a cognitive and a motor processor, guide the execution of discrete motor sequences. The cognitive processor prepares the sequence items and loads them into a motor buffer; subsequently the motor processor reads these items and executes them immediately. With practice sequences become familiar and instead of individual sequence elements motor chunks are loaded into the motor buffer so that consequently processing load on the cognitive processor is reduced. In the case of the short sequence the context manipulations shaped participants expectations in the way that maybe a longer sequence than the three-key sequence was expected by participants. Context dependencies developed therefore due to the fact that the cognitive processor had insufficient time to identify and prepare the correct sequence and load it into the motor buffer so that performance impaired in this case. On the basis of this possible explanation we assume that in the Go-/No-Go DSP task mainly the cognitive processor is affected by context manipulations. This explanation could especially be accurate for the switched context; the switched incidental stimulus primed the participants' expectations in the way that a longer sequence was expected because in the practice phase the color has been associated with the six-key sequence. In the case of the six-key sequence, in turn, we assume that the cognitive processor had sufficient time to identify and prepare the correct sequence elements so that context manipulations could not influence participants' performance. In other words, in the case of the six-key-sequence the changing incidental stimulus did not have the surprise effect that would be necessary to influence response times on the six-key sequence. Obviously, these findings stand in contrast to the predictions that have been made in the introduction. To address the question what role sequence length plays in the development of contextual dependencies in memory-based motor tasks further research could include different sequence lengths than those used in the present study. To check if the mentioned explanation is true, sequences of e.g. five and seven key presses can be used; on the basis of the given explanation context dependencies for the five-key sequence should be greater than for the seven-key sequence. Furthermore if in an experiment with three- and six-key sequences contextual dependencies develop for the three-key sequence, what effect would an even greater difference in sequence length, e.g. with three- and seven-key sequences, cause? It can be assumed that the magnitude of the context-effect would be even greater, as in the execution of the shorter sequence – after incidental context manipulation – an even longer sequence can be expected.

A closer look at the response times on the individual keys reveals that in the switched context condition of the three-key sequence *only* the first key was affected (319ms same vs. 347ms switched) by the changing context. Within DSP sequences Verwey distinguishes between *sequence initiation*, the response time on the first key, the *concatenation phase*, which represents the transition from one to the next motor chunk and the *execution phase* in which the remaining elements of a motor chunk are executed (Verwey, 2010). In terms of this division of sequence execution the switching context did only affect the initiation of the sequence, whereas the execution phase was unaffected. This finding can also be connected to a model postulated by Sternberg, Monsell, Knoll and Wright (1987) which states that two independent stages are involved in the execution of a sequential motor skill. In the first stage sequence elements have to be identified and loaded into the motor buffer – in the second stage these elements can subsequently be executed. According to this model external factors such as context manipulations should not affect sequence elements past the first (thus past the sequence initiation). In the case of the present study this prediction is true, but *only* for the switched context as in the novel context the second key was also affected. Further research could address the question whether switched context manipulations for short sequences in motor preparation tasks mainly affect sequence initiation whereas the execution phase stays mostly unaffected. It is also noteworthy that in both context manipulations the last sequence key was nearly unaffected which shows that during the execution of earlier sequence elements later sequence elements still have to be prepared by the cognitive processor (Verwey, 2001). Due to the fact that this is not the case for the last sequence element the third key was unaffected.

Another issue this paper addressed was whether the amount of practice mediates the development of contextual dependencies. In this respect it is crucial to know in how far participants rely on visual information when preparing a sequence, because when sequences can be executed without the need of visual stimuli it can be assumed that context conditions should have less effects on performance. Hikosaka et al. (1999) propose that motor sequences are first learned in terms of visual-spatial coordinates and become mostly motor based with practice. De Kleine and Van der Lubbe (2011) noticed that the load on visual-working memory is increased in unfamiliar sequences as compared to familiar sequences. Furthermore Verwey (2001) noticed that with the development of motor chunks the need for the cognitive processor to prepare every single key press or (visual) stimulus diminishes. Since context manipulations in the present study are of visual nature, it could be predicted that with practice context-effects would diminish. On the other hand we mentioned the assumption that since contextual dependencies are assumed to develop through associations between intentional and incidental stimuli, these associations could be greater after extended practice. However, neither the first nor the second assumption was proved right as both practice conditions showed similar context effects for the three-key sequence. In other words, the amount of practice did not mediate the development of these context effects. A possible explanation might be that the participants reliance on visual stimuli diminished to early, as performance in terms of RT of the limited practice group was not significantly worse than performance of the extended practice group (it should be noticed that were was an effect of practice through practice blocks, but statistically practice groups still did not differ in performance in the test phase). This is remarkably because the extended practice group executed five more practice blocks than the limited practice group. The assumption that the sequences were probably very easy to master is supported by the fact that (a) all participants recalled and recognized the six-key sequence correctly, (b) 92% participants recalled the thee-key sequence correctly (recognition: 96%) and (c) recall and recognition did not differ for both practice group.

In summary, the present study successfully demonstrated context effects in both a switched and a novel context condition for three-key-sequences in the execution of a purely memory based motor task, the Go/No-Go DSP task. However, these findings could not be confirmed for six-key sequences. The results were explained in terms of Verwey's dual processor model by the assumption that the cognitive processor had insufficient time to identify and prepare the short sequence elements. After the incidental context manipulation the participants' expectations were probably shaped in the way that a longer sequence than the three-key sequence was expected. On the other hand the execution of the six-key sequence was unaffected due to the fact that the whole sequence is presented in advance and could be easily prepared by the cognitive processor. These findings stand in contrast to our hypothesis that the preparation of a longer sequence and therefore more difficult task would cause greater contextual dependencies. Recommendations for future research in this respect have been made. Furthermore practice did not mediate the contextual dependencies that have been found, as it could be assumed that both practice group switched relatively fast to a state where they could execute the sequences without the aid of visual stimuli.

5. References

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