Effects of movement practice on task performance

The effects of practice and varying preparation intervals on a sequential motor task

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Abstract

The way movements are planned and executed is a frequently researched topic. The present study is inspired by the findings of an experiment by Adam, Timiniau, van Veen, Ament, Rijcken, and Meijer (2008), who found a difference between the reaching and key-press response types in the way they benefit from time to prepare for the movements. The reaching response experienced adverse effects of additional preparation time, while the key-press response benefitted from extra time. They suggested that these differences were caused by effector selection, which takes some time and was necessary for the key-press response, but not for the reaching response. When no effector selection is necessary the available preparation time is unused and the effort of maintaining visual attention during that time is strenuous and causes the adverse effects. In the present study however, it was proposed that these effects are not the result of effector selection but of the ability to prepare the direction of the movement, which was possible in the reaching task but not in the key-press task. To test this hypothesis the one-effector Flexion-Extension (FE) task (Panzer, Wilde, & Shea, 2006) was used whilst making it impossible to prepare the direction of the movements. The results showed that the reaction time on the FE task reduced following a longer pre-cue, indicating a beneficial effect of additional preparation time on the preparation of the movement. In contrast, movement times increased which showed that additional preparation time did not have an advantageous effect on the actual execution of the movement. These results show that the ability to plan the movement direction is of influence on the speed of movement preparation and movement execution, and that further experimentation with the FE task is warranted to gain more insight into the underlying mechanisms involved in executing the flexing and extending movements.

1 Introduction

Keyterms: motor skills learning, associative learning, motor chunking, motor preparation, discrete sequence.

In everyday life we perform many motor tasks so fluently we hardly notice the intricate sequence of smaller movements that constitute them. For example when opening a door, we do not consciously think about reaching out our arm to the handle and closing our fingers around it, instead these movement patterns have become an automatism through considerable practice resulting in a high level motor skill. The present study is inspired by the international re-Load project which focusses on the ability of elderly people to acquire new motor skills. These skills play an important part in independent living and participation in society. Fast changing technologies make increased demands on people's ability to learn new motor skills which has been found to be more difficult for older people who may be dealing with physical and cognitive decline. The re-Load project studies the underlying mechanisms of learning motor skills and aims to work towards creating methods to improve these skills.

Several tasks have been developed to quantify the speed and accuracy with which people acquire new motor skills. Important as a scientific basis for the current experiment are the Serial Reaction Time (SRT) task, where participants reproduce a non-discrete sequence using four fingers (Nissen & Bullemer, 1987), the Discrete Sequence Production (DSP) task, in which participants reproduce a discrete sequence using four fingers on a keyboard (Verwey, 1994), and the Reaching task (Adam & Pratt, 2004), in which participants use one finger to move to one of four locations to reproduce a sequence. In the present experiment a fourth task was used, the Flexion-Extension (FE) task where people use their elbow to make a flexing/extending motion to move the forearm to certain angles (Panzer, Wilde, & Shea, 2006).

1.1 Motor skill learning

A lot of research has been devoted to understanding the underlying principles of motor learning. What has been found is that there are several modes of executing movement patterns in response to stimuli. The first is the so called 'reaction mode', which is used when a movement pattern has not yet been practiced. Reaction mode means that each movement has to be planned and executed separately in response to a stimulus. This is a slow process which is characteristic for performance on unfamiliar tasks. Following an amount of practice with executing the movement pattern the speed increases, this can happen according to several principles. Verwey and Abrahamse (2012) discussed two distinct types of motor learning which have been demonstrated in previous studies involving various tasks.

The first type of motor learning is the development of motor chunks, that can be used to increase performance on a practiced movement sequence (Verwey, 1994). This has been observed frequently in DSP tasks. Motor chunks are individual movement elements that have been consolidated into sub-sequences which can be executed as a whole. The advantage of developing motor chunks is that complicated movements can be executed faster using less cognitive effort as constant feedback is no longer required. In the original DSP task by Verwey (1994), participants had to practice two sequences for a long period of time so that they learned them by heart. Each sequence is presented following a 500-5000 ms delay acting as a separation between sequences making them discrete. Once the sequences have been learned, the individual movements can be selected as one unit (Verwey, 1996). This eliminates the processing of individual stimuli in reaction mode and allows for much faster processing of the movement pattern. The acquisition of motor chunks can be measured by a reduction of response time during practice.

The second type of sequence learning is called associative learning, which relies on the priming of a response based on the execution of earlier responses. Associative learning occurs when motor chunking is prevented. A commonly used task to demonstrate associative learning is the SRT task where participants have to respond to stimuli by pressing one of four keys (Nissen & Bullemer, 1987). The SRT task displays 4 squares on a computer screen. One of these becomes the target and the participant presses the corresponding key as quickly as possible which makes it comparable to the previously discussed DSP task. However, a difference between the SRT task and the DSP task is that the SRT task does not present discrete sequences but a continuous repetition of sequences with no marked beginning or end. In addition, sequences in the SRT task are longer and a response-to-stimulus interval (RSI) is used to reduce the saliency of the sequences as to only encourage implicit learning. Implicit learning is defined as a measurable change in performance on a task as a result of practice without the participant being consciously aware of the contingencies of the experiment (Shanks, 2005). Thus, whereas the DSP task and SRT tasks are similar, the former allows motor chunking to take place, and the latter aims to reduce the reaction times through associative learning.

The experiment conducted by Verwey and Abrahamse (2012) was a modification of the DSP task in order to investigate both motor-chunk learning and associative learning. In the experiment participants developed motor chunks during a practice phase. However, during the test phase the use of these motor chunks was prevented by replacing stimuli in the practiced sequences with deviant stimuli. Consequently, participants had to again rely on reaction-mode processing to execute the deviant sequences, a process which was thought to involve associative learning. As associative learning was hypothesised to decrease response times, better performance was expected on the familiar sequences with deviants compared to response times on unfamiliar sequences. This was indeed found and supports that even without the availability of motor chunks, practice leads to increased performance on movement tasks.

In short, motor sequence learning naturally happens by forming motor chunks which are selected and executed as one single unit increasing speed and accuracy. When motor chunking is not possible movement skill still increases through the process of associative learning which forms implicit knowledge of the task that increases performance. The present experiment aimed to induce implicit learning and was therefore designed using principles found in the SRT task.

1.2 Preparation time

Preparation time affects the learning of movement sequences. Previous literature shows that the available preparation time affects the way movements are planned before executing them (Adam, Pratt, Hommel, & Umiltà, 2003a). The effect of amount of preparation time, however, is not the same for all types of movements. An experiment by Adam, Timiniau, van Veen, Ament, Rijcken, and Meijer (2008) aimed to distinguish the different effects of preparation time on two response types.

1.3 Response types

The first response type was a key-press response. Four possible target locations were displayed on a screen while participants held four fingers on keys corresponding to the targets. When a target cue appeared the participant had to press the correct key.

The second response type was a reaching response. The task was similar to the one used in the key-press task, except participants did not keep four fingers on the keyboard, but only their index finger in a resting position. When the target cue appeared the participants used their index finger to move to one of the four keys corresponding to the target cue.

1.3.1 Differences between response types

There are fundamental differences between these two response types. The most important is the number of possible effectors. The reaching response always requires one and the same effector to respond to the target cue. The key-press response, however, uses four, which requires effector selection to take place before the movement can be initiated.

Effector selection is the process in which the correct effector is selected as a parameter for a particular movement. Rosenbaum (1980) and Schmidt (1975) argued that for a movement to be initiated, its parameters have to be specified. These parameters are specified serially but not in a particular order, and include effector selection, direction, and distance of the movement. It appeared that effector selection took a relatively long time.

Because effector selection takes some time, key-press responses benefitted from additional time to prepare the correct response, i.e. longer preparation times, which resulted in a shorter reaction time (RT) (Adam et al., 2008). In contrast, the reaching response was found to be negatively affected by longer preparation times. This adverse effect was explained by Adam et al. (2008) as being the result of the effort required to maintain visual attention for a prolonged amount of time. Because no effector selection is necessary there is no need for additional preparation time. The resulting extra effort of maintaining visual attention reduces vigilance, increasing RT. For the key-press response the preparation time had an advantageous effect because it offered the possibility to prepare the effector for the upcoming movement.

1.4 Types of pre-cue

It was found that the effect of preparation time was influenced by the type of pre-cue that was given. A pre-cue is a stimulus which gives advance information regarding the upcoming cue. There is a difference in the way performance on the response types varied as a result of different types of pre-cues. Adam et al. (2008) aimed to shed some light on this difference. The types of pre-cues that were used in their experiment are called ‘partial’ and ‘full’. The partial pre-cue gave some information about the upcoming target stimulus by highlighting two out of four possible targets, limiting the amount of possible response options but not specifying exactly which would be the correct response. This allowed participants to form an idea about the upcoming movement, but did not provide enough information for them to prepare the movement completely. The full pre-cue specified exactly which location would become the target stimulus, allowing participants to use the time of the pre-cue to prepare the required movement. It was found that providing the participant with more advance information through the pre-cue led to a greater reduction of RT on the key-press response. The reaching response was also affected by pre-cue type but only following a long pre-cue duration and to a lesser extent than the key-press response (Adam & Pratt, 2004; Adam et al., 2008).

1.4.1 Types of pre-cue & movement planning

The performance differences between the two pre-cue types is the result of the extent to which movement preparation is possible. Schmidt (1975) proposed that movements are controlled by a motor program. A motor program is responsible for initiating the beginning of a movement by specifying the class of movements and specifying a movement by defining its parameters. RT can be decreased by pre-specifying parameters such as which effector and movement direction to use (Adam et al., 2008; Rosenbaum, 1980), and by limiting the spatial distance of response choices (Bock & Eversheim, 2000). Once the parameters have been defined the movement can be initiated. The pre-cue types differ in the way they provide the participant with info to specify movement parameters.

The difference between the reaching and key-press responses in the way they are influenced by pre-cue type has to do with the fact that the reaching response requires less movement planning. Regardless of the pre-cue type and exact response location most parameters of the movement are already known. For example the general movement direction at the onset of the movement is similar for all target stimuli; lifting the finger and moving forward, before having to change direction to one of the target locations (Adam et al., 2008).

For the key-press response, however, this is different. The four possible responses are inherently different in that they require different effectors. This means that when a partial pre-cue is used, specifying two possible locations, movement planning can still not fully occur because the necessary effector is unknown (Adam et al., 2008). Nevertheless, partial preparation is possible. For example, Adam et al. (2008) used a partial pre-cue where the two left-most targets were highlighted. This allowed the participants to preselect the hand, and be aware of the fact that the target cue would occur to the left, allowing them to pre-direct spatial attention (Bock & Eversheim, 2000).

In conclusion, the reaching response is less affected by the type of pre-cue because the first part of the movement, lifting the finger and moving forward, is always the same regardless of the exact response location. This means that no matter how many possible response locations are suggested by the pre-cue the onset of the movement is always the same. In contrast, with the key-press response each response location requires an entirely different set of movement parameters and is therefore influenced by different pre-cue types.

1.5 Present experiment

The effect found by Adam et al. (2008) regarding the way the reaching and key-press responses are influenced by pre-cue duration forms the basis for the present experiment. They proposed that the adverse effect of pre-cue duration on the reaching response is the result of having to fixate visual attention for longer because no effector selection is necessary, and that this adverse effect did not occur on the key-press response because participants needed that time to prepare the correct finger. For the present study however, it was proposed that the effect may be due to the fact that movement direction planning was always possible in the reaching task, but not on the key-press task where each response location required the use of a different finger preventing movement direction from taking place before the required finger was known.

The goal of the present experiment was to find out whether the adverse effect of longer pre-cue duration that was found on the reaching task by Adam still occurs when movement direction planning is not possible. This was done using the one-effector FE task with young participants while making it impossible to prepare the movement direction by using a pre-cue that highlights two possible target locations on either side of the present cursor position.

Additionally in the present experiment two fixed sequences of movements were used. This made it possible for participants to learn the movements and improve their response speed. Participants were kept unaware of the presence of fixed sequences to induce only implicit learning. The aim was to determine whether the adverse effects of pre-cue duration were the result of effector selection, in which case the one-effector FE response should also be adversely effected by a longer pre-cue duration. In contrast if the effect was due to movement direction planning the FE response should be beneficially affected by a longer pre-cue duration.

2 Method

2.1 Participants

Thirty people (4 male, 26 female) of ages 18-25 (mean – 20.4) participated. Participants were volunteering students of the University of Twente in the Netherlands from the faculty of behavioural sciences who received a small compensation in the form of course credits. All participants were right-handed and had normal or corrected vision. Before participating the participants signed an informed consent form regarding the nature of the task, but they were unaware of the presence of a sequence or the goal of the experiment. The research was reviewed and accepted by the local ethics committee.

2.2 Apparatus & Stimuli

The experiment was conducted in a quiet room where it was completed in solitude (see Appendix I for a picture of the set-up). Participants were aware that they were being monitored via a camera by an observer in an adjacent room. The observer made sure participants executed the task correctly, kept track of the progress they were making, and made a note if something unexpected happened.

The task was executed by moving a lever supporting the right forearm, which allowed for a low-resistance rotating motion in the horizontal plane. Participants were instructed to rest their arm comfortably on the lever keeping their elbow on the rotation point. An adjustable handle at the end of the lever was moved closer or further from the rotation point so the participant could comfortably grab it, making sure their elbow remained on the rotation point of the lever throughout the experiment.

Participants sat approximately 80 cm from the screen on a height-adjustable chair which was adjusted to each participant to allow for an ergonomically friendly completion of the experiment, i.e. the participant could sit up straight and didn't have to reach up or down to rest their arm on the lever. Due to the duration of the experiment and the monotonicity of the movements it had to be ensured that the participants were strained physically as little as possible. The chair did not have armrests in order to not interfere with the motion range of the apparatus.

Movement was recorded by an analogue potentiometer in the rotation point. The signal was processed by an AD converter and transmitted via a USB connection to a laptop running Windows 7 and Matlab 2013b software. The input signal had an accuracy of 0.35º within a range of -50º and 40º from the centre position, i.e. keeping the lever perpendicular to the screen pointing straight forward as seen from the participant. This rotational range of the lever was chosen once according to what felt most comfortable and was kept the same for all participants. The position of the lever was sampled and recorded at 500 Hz, the displayed cursor position was based on the average of 70 ms of buffered measurements, i.e. 35 samples. The program ran at a refresh rate of 60 Hz.

Stimuli were presented on a 22" flat-screen monitor with a resolution of 1680x1050 pixels and a response time of 5ms. A horizontal row of 9 target squares (39 mm x 39 mm on screen, and 7.2° wide within the rotational range of the lever), separated by 13.4 mm (2.5°) was continuously displayed in dark red on a black background. When considering the centre position of the lever to be at an angle of 0°, the relative angles corresponding to the centres of the targets numbered 1 through 9 are -43.9° (1), -34.2° (2), -24.5° (3), -14.7° (4), -5.0° (5), 4.7° (6), 14.5° (7), 24.2° (8), 33.9° (9).

The pre-cue consisted of changing the filling of the pre-cued targets to yellow. One of these squares would turn to a green colour and all the others would return to a dark red colour, indicating the location to which the participant had to move a round white cursor 8.7 mm in diameter. When the cursor was in the centre of a target, it had some freedom, of 15.2 mm on screen and 2.8° with the lever, to move both left and right within the target without leaving it.

2.3 Task

Participants were required to practise two fixed sequences of 6 aiming movements. Each sequence of six movements was considered to be one trial. A set of 6 different sequences was created that all had the same cumulative movement distance. With the targets numbered 1-9 from left to right, the cued targets for each sequence were [2 7 8 5 6 3], [3 2 7 2 3 5], [4 6 3 8 5 7], [6 4 8 4 2 5], [7 6 8 2 6 5], [8 3 8 7 6 7]. Each participant was assigned a combination of 2 out of the 6 mentioned sequences. It was chosen to have a set of 6 sequences to choose from in order to counterbalance possible effects of differences between sequences (for details on sequence allocation consult Appendix II).

All sequences started from the centre position (target 5), but the first element of each sequence was different, this was done to allow participants to recognise the sequence by the first element. In addition the targets 1 and 9 were excluded. This was done because if the participant had the cursor on one of these left-most or right-most targets the next movement direction would have been certain. Now the participants were only able to pre-determine the movement direction after gaining some knowledge of the movement sequences, i.e. to know that targets 1 and 9 do not appear.

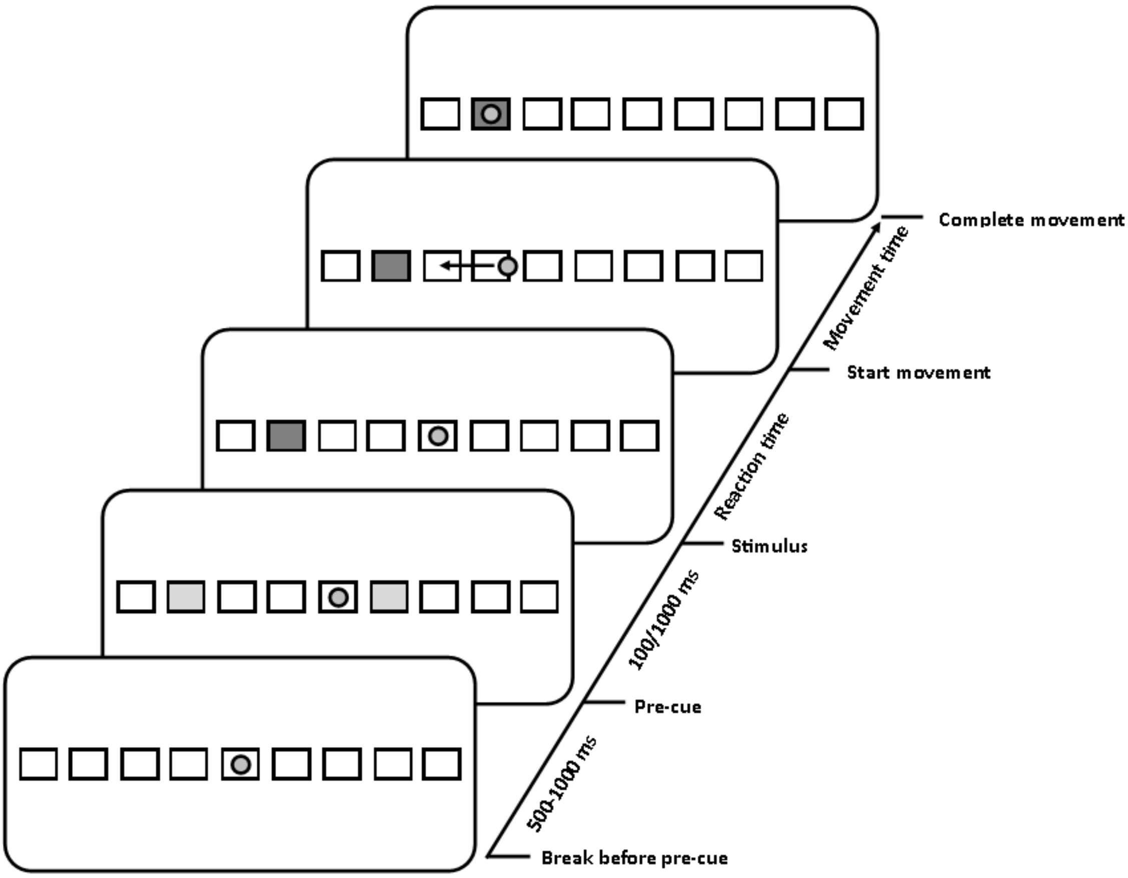

Figure 1. Stages of responding to one sequence element

Figure 1 provides an overview of the stages of responding to one sequence element. At the onset of a sequence they were instructed to have the cursor on the centre target, to ensure each sequence of movements was initiated from the same position. Before each movement two squares changed colour to yellow to act as the partial pre-cue. This pre-cue was intended to provide advance information regarding the possible location of the target stimulus, which was always one of the two yellow squares. The alternative pre-cue location was randomly selected, but, relative to the participant's current cursor position, always occurred on the opposite side of the target stimulus. This was done so the direction of the upcoming movement remained ambiguous. If both pre-cue locations occurred on the same side relative to the current cursor position the participant would already be able to initiate the movement before knowing which exact location was the target. In addition it would eliminate the possibility to observe whether participants learned the direction of the upcoming movements as a result of practice.

Preceding the pre-cue a short period of rest was given in which nothing happened. The duration of this break was randomly selected between 500 ms and 1000 ms at 100 ms increments. This response-to-stimulus interval was implemented to clearly mark the beginning and ending of a movement. The duration of the pre-cue itself was also randomly selected for each movement and was either 100 ms or 1000 ms, as was the case in Adam et al. (2008). Pre-cue durations were randomly presented but balanced within each block. After the pre-cue one of the yellow squares changed colour to green, and the other changed back to red, indicating the location to move the cursor to.

For each movement the reaction time and movement time was recorded. Reaction time (RT) was defined as the time between stimulus onset, and the cursor being completely outside the current target. Movement time (MT) was defined as the time between the cursor completely leaving the current target, and the cursor being completely inside the cued target.

The participants were told to execute the movements as fast as possible without making any errors. To register as a 'correct response' the participant had to keep the cursor on the target stimulus for 500ms. If the cursor left the target before this time the movement was considered an error. Another possible error was to prematurely leave the current position before the target stimulus had turned to green. Upon making an error the sequence was immediately aborted and a new one started. The sequence in which the error was made was repeated at a later stage in the same block.

2.4 Procedure

Participants performed the experiment in one session that lasted two hours. Upon entry they were required to sign the informed consent form. Before the start of the experiment the participants were granted some time to familiarise themselves with moving the lever and with the way lever movements translate to cursor movements. The familiarisation period ended when 5 trials of 6 random movements had been completed successfully. Following the familiarisation period a brief recap of the instructions was given and the experiment started. The experiment consisted of 10 blocks of movements separated by 1 minute breaks in which participants received feedback on their average reaction time during the last block. Each block was made up of 20 trials. In each block two different sequences were practiced, resulting in each sequence being administered 10 times in one block. The order of sequence presentation was random.

The experiment consisted of two phases. Phase 1 was the practice phase which consisted of 8 blocks of trials in which two sequences were repeated. Each of the two sequences was presented 10 times in random order, so each sequence was practised for a total of 80 times. After completion of the practice phase participants were required to fill out a questionnaire regarding whether or not they had noticed the two practiced sequences and what they thought the sequences had been. The questionnaire is included in Appendix III. First they were asked to write down from memory what they thought the sequences were. They were told that the sequences consisted of 6 elements, and they were given a screenshot of the computer screen displaying the target locations which were numbered 1 through 9. In six empty boxes, representing the six elements of the sequence, participants were required to write down the corresponding number of the target cue in each of the six boxes. Consequently they were asked to indicate how sure they were about the sequence they wrote down. This procedure was the same for both sequences. Afterwards, on the next page, a list of 18 sequences was given. Amongst these sequences were the 6 sequences that were created for the experiment, so the participants could select the two sequences they had practised. The other 12 listed sequences did not occur in the experiment but were similar in that they had similar endings and that targets 1 and 9 never occurred. Participants were asked to, out of the 18 options, select the two sequences they thought they had carried out during the practice phase of the experiment. This was done to get an idea of the level of explicit knowledge participants had acquired about the presented sequences. After completing the questionnaire the test phase began.

In the test phase two blocks of trials were administered. In one of the test-blocks the same two sequences were presented as in the practice phase. In the other test-block two unfamiliar sequences were presented. The unfamiliar sequences were chosen from the set of 6 sequences. Whether the unfamiliar block was presented first or second was counterbalanced by reversing the order across participants (see Appendix II).

2.5 Data analysis

Before performing the statistical analyses the data were checked for measurement errors, i.e. RT's of less than 20 ms, which were removed (0.03%). Measurement errors were caused by a slight jitter of the cursor which sometimes caused the cursor to leave the target if the participants kept it exactly at the border of the current target location.

Furthermore all outliers were removed, i.e. RT's and MT's that fell outside +/-3 standard deviations from the mean across all blocks. Outlier removal was done for RT and MT separately which resulted in slightly different numbers of data points for both measures. Across all 30 participants a total of 36,000 movements was recorded for both measures. Based on this outlier analysis and exclusion of measurement errors, for RT and MT respectively a total of 599 (1.7%) and 391 (1.1%) measurements were excluded from further analysis.

A linear mixed effects model was used to analyse the data. Due to multiple measurements per participant the independence assumption was violated. To resolve this the subject identifier variable was included in the analysis as a random effect so the analysis assumes a different baseline for each participant. In addition a Bonferroni adjustment for multiple comparisons was used.

Throughout the results section no standard deviations have been reported. This was done because the standard deviations do not accurately represent the variation of responses within the analysed effects. When analysing the fixed factors of Block and Pre-cue duration the wide distribution of performance within those groups was for a large part due to the influence of other random factors, which will be discussed in the following paragraphs. This was also one of the reasons to choose for a linear mixed effects analysis rather than a repeated measures anova, as the repeated measures anova would look at the means of the analysed groups without considering interacting effects of other random factors that were not experimentally controlled resulting in the subtle differences as a result of the fixed factors not being detected. The linear mixed effects model was able to correct for these random influences and filter out the influence of the fixed factors and thereby detecting significant effects. The practice phase and test phase were analysed separately. The following paragraphs describe the procedure for each phase.

2.5.1 Practice phase

The main effect of independent variables ‘block’ (only practice phase, therefore 8 levels), and ‘pre-cue duration’ (100 ms vs. 1000 ms), and their interaction were analysed using the linear mixed effect model, resulting in a 8x2 factor design. In addition, the covariates ‘movement distance’ and ‘distance between two pre-cue locations’ were included as random effects, as they were not empirically manipulated but could possibly affect the influence the fixed factors have. Including them as random effects corrects for any influence these covariates may have on the main effects.

2.5.2 Test phase

The goal of this analysis was to find an interaction between familiarity (familiar vs. unfamiliar) of the performed sequence and the duration of the pre-cue (100 ms vs. 1000 ms). These were included as fixed factors resulting in a 2x2 factor design. In this analysis the covariates ‘movement distance’ and ‘distance between pre-cue locations’ were also included as random effects. For this analysis the last two blocks of the experiment were used. By including only the two test phase blocks the performance on the two practiced sequences and the two new sequences were compared.

2.5.3 Questionnaire

On the question where the participants had to reproduce the sequence by heart the answers were scored as either being a) incorrect, b) 50% of movements in the correct direction, c) 100% of movements in correct direction, d) 50% of movements to correct target location, e) 100% correct recall. This was done in case the participants were unable to fully recollect the sequence to still get an idea of certain aspects of the sequence they may have noticed such as direction.

2.5.4 Errors

During the experiment the two types of errors were recorded per block per participant. The first possible error was to move prematurely, i.e. allowing the edge of the cursor to cross the edge of the current target location before the target cue appeared. The second type of error was to under- or overshoot the target cue, meaning once the cursor was completely within the cued target that any part of the cursor crossed the target border again within the 500 ms timeframe to register a response as 'correct'. The two types of errors were analysed individually using a generalized linear model Poisson analysis.

3 Results

3.1 Practice phase

3.1.1 Performance increase

For this analysis only the data for the first 8 practice blocks were used in the linear mixed effects model in order to determine the effect of Block on RT and MT. RTs and MTs during the practice phase are depicted in Figure 2.

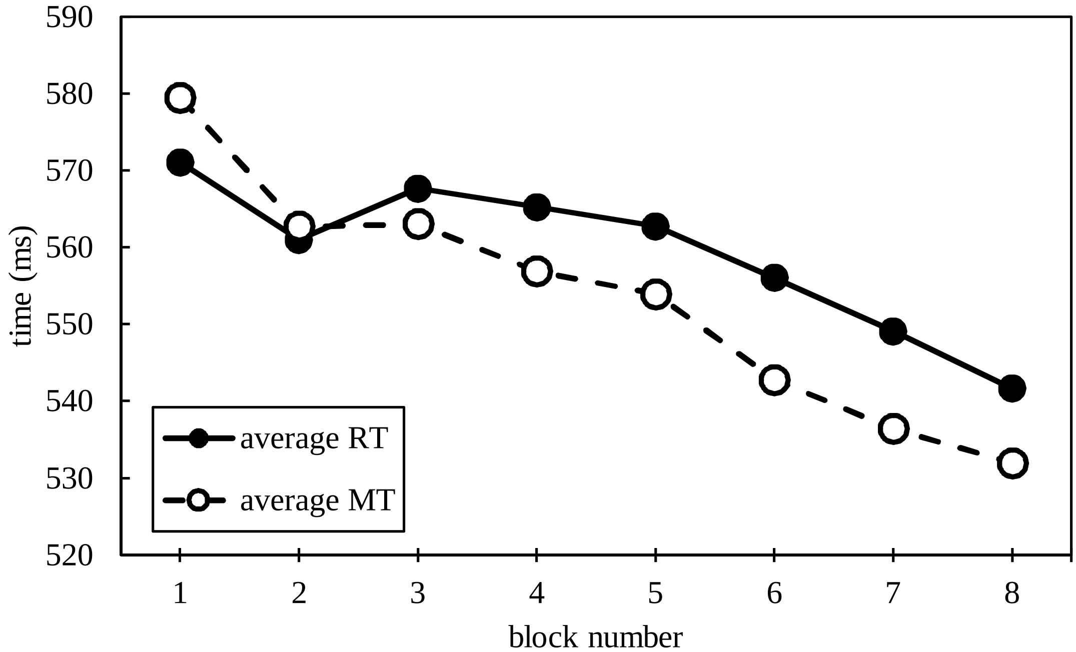

Figure 2. Gradual improvement of RT and MT during practice

For reaction time a significant effect of Block was found, F (7, 28244.914) = 60.243; $p < .0005$. A decrease of RT was observed in the second block, but this trend did not continue into the third block, where RT increased again. After the third block performance continued to gradually decrease. This is an indication that learning did not start to improve reaction times until after a few blocks of practice. The rapid improvement of performance on the second block and the relative deterioration of performance on the third block may have been the result of using different response strategies. The overall improvement between the first and last blocks of the practice phase was 25ms (a 4.4% increase of performance).

For movement time there was also a significant difference between movement blocks, *F* (7, 28339.634) = 65.040; *p* <.0005. In comparison to the first block of movements a significant decrease in MT was found immediately from the second block onwards. In contrast to RT, improvements in MT appear to already occur after just a short amount of time practising. However, a similar relapse in performance was observed in the third block, although not as severe as with RT. The overall improvement of MT between the first and last blocks of the practice phase was 49ms (a 8.5% increase of performance).

3.1.2 Influence of pre-cue duration

One of the questions of this study was whether pre-cue duration would influence performance on the task. The results show that the duration of the pre-cue does in fact cause a notable difference in performance (Figure 3).

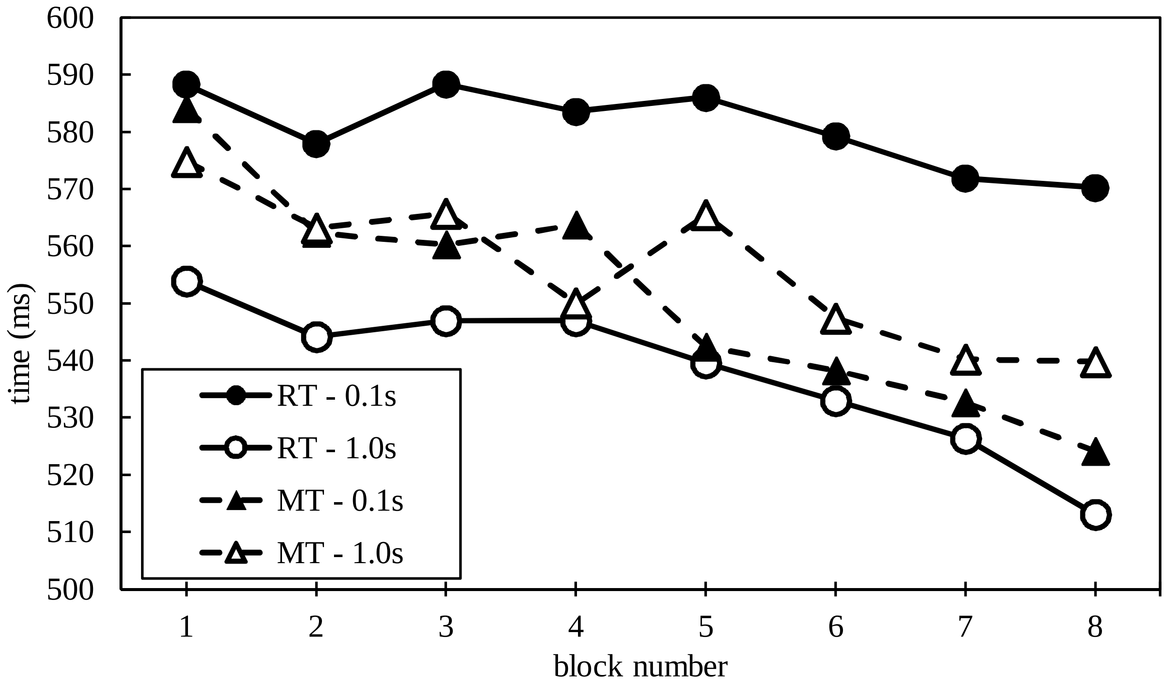

Figure 3. Average RT and MT following a 0.1s and 1.0s pre-cue duration

For RT the result was that longer pre-cue durations consistently led to shorter reaction times, i.e. better performance. The mean difference across the practice phase between 0.1 and

1.0 second pre-cue durations was 43 ms, F (1, 28246.3) = 2353.3; $p < .0005$. This is a similar result to what was found in Adam et al. (2008) on the key-press response. For MT there was also a significant effect of pre-cue duration on performance, F (1, 28350.0) = 44.7; $p < .0005$. Contrary to RT, however, MT experienced an adverse effect of pre-cue duration from about halfway through the practise phase. When looking at the first half of the practice phase there was an insignificant estimated difference between the 0.1 s compared to the 1.0 s pre-cue durations of 4.6 ms, t(14128) = -1.046, $p = .296$. When looking at the second half though, there was a significant difference of -11.5 ms, t(21310) = -2.693, $p = .007$ between pre-cue durations.

3.1.3 Interaction effect of pre-cue duration and practice

As learning is possible because of the use of fixed sequences the interaction between pre-cue duration and amount of practice has been analysed. The interactions can be observed in Figure 3. A significant interaction was found between amount of practice and the duration of the pre-cue for both RT, F (7, 28246.9) = 6.2; $p < .0005$ and MT, F (7, 28347.4 = 3.3; $p <$ .0005. Interestingly, the difference in RT between the two pre-cue conditions increases as a function of practice. In addition it can be noticed in Figure 3 that performance on the short pre-cue remains fairly constant, and that it appears to be the long pre-cue condition where performance improves as a result of practice. The difference of MT following a short or long pre-cue is fairly small during the first half of the practice phase, it is not until the second half that the difference in performance between pre-cue durations increases. This might be an indication that halfway through the experiment a sudden change in knowledge about the sequences affects the influence of the pre-cue and causes the sudden change in the difference between performance on a short and long pre-cue.

3.2 Test phase

3.2.1 Difference in performance

The first analysis on the test phase revealed a significant difference in performance between the familiar and unfamiliar sequence for both RT, F (1, 6970.0) = 28.5; $p < .0005$ and MT, F (1, 7088.0) = 72.1; $p < .0005$. Reaction times were on average 10 ms (1.7%) faster in familiar sequences, and movement times were on average 20 ms (3.7%) faster in the familiar sequence.

3.2.2 Influence of pre-cue duration

A significant difference was found between the execution of a movement following a short and long pre-cue for both the familiar and unfamiliar sequences (Figure 4).

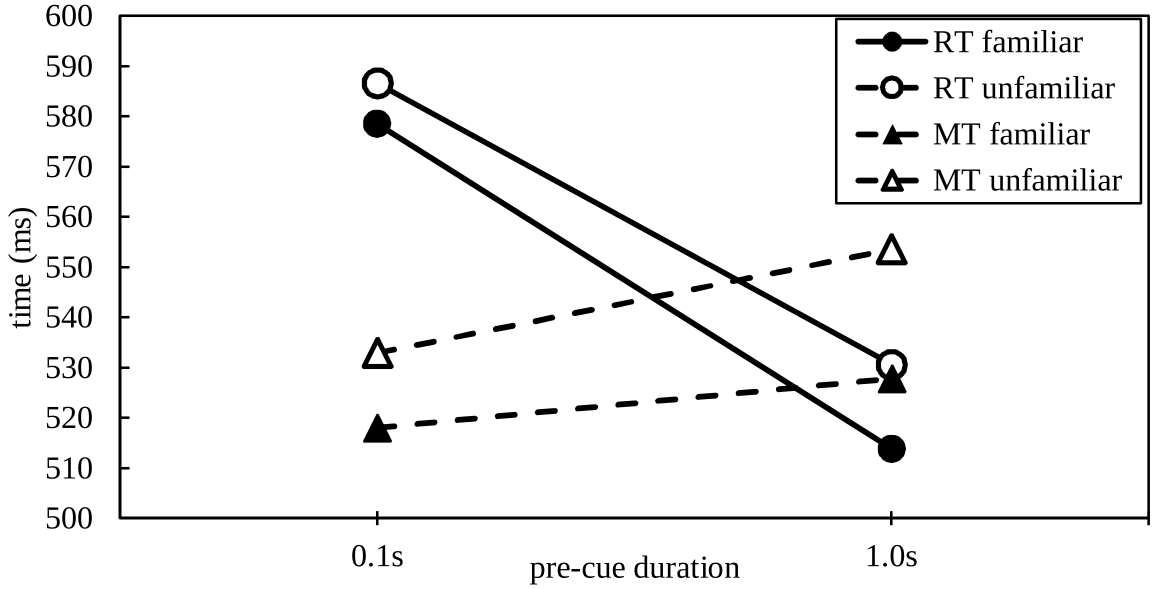

Figure 4. Average RT and MT following a 0.1s and 1.0s pre-cue on a familiar and unfamiliar sequence

Reaction times were slower following the 1.0 second pre-cue, this was true on both the familiar sequences where the difference was 64.4 ms, F (1, 3429.677) = 431.552; p <. 0005 and the unfamiliar sequences where the difference was 56 ms, F (1, 3473.817) = 420.310; $p < .0005$.

For movement times longer pre-cue durations had adverse effects, this was also the case on both the familiar sequences, where MT was 9.8 ms slower, F (1, 3514.8) = 4.4; p = .035, and the unfamiliar sequences where MT was 20.6 ms slower, F (1, 3524.7) = 4.8; p = .029.

3.2.3 Interaction effect of pre-cue duration and practice

The linear mixed effects model analysis was performed on the data of the two test phase blocks in order to observe the RT and MT differences between pre-cue durations on the well-practiced sequences and the unfamiliar sequences. For both RT, F (1, 6972.410) = .373; p = .542 and MT, F (1, 7101.369) = .002; p = .965 no significant interaction was found, revealing that the difference between pre-cue conditions was not significantly different between the familiar and unfamiliar sequences.

3.3 Errors

Figure 5 displays the average percentages of errors per block for each of the two error types.

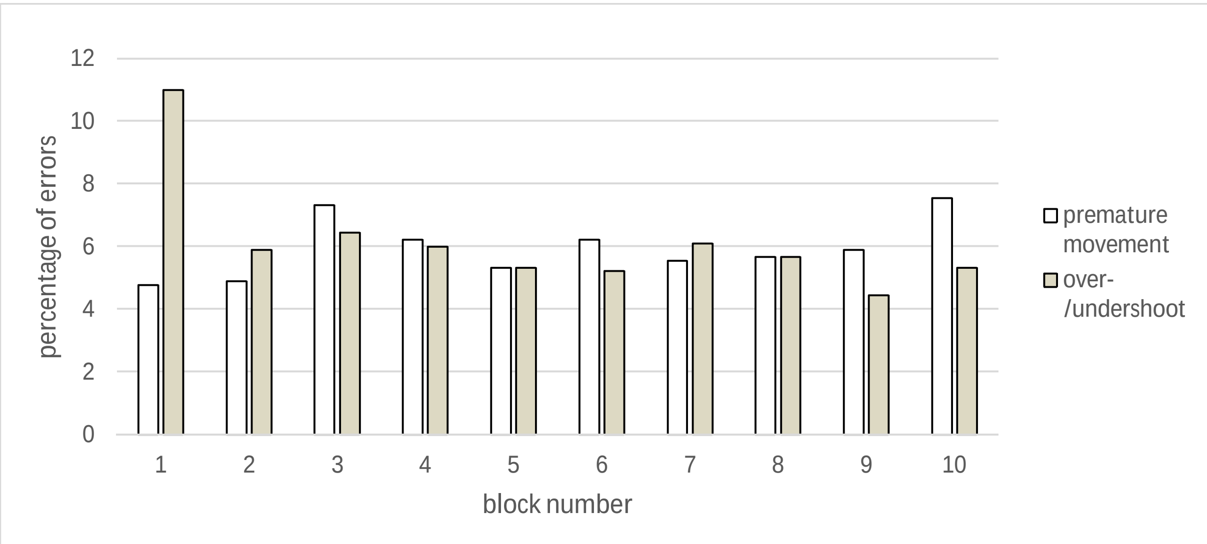

Figure 5. Percentage of both types of errors per block

No significant differences were found between premature movement errors across movement blocks during the practice phase, χ^2 (7, N = 240) = 7.544, p = .375. For over-

/undershoot errors it was found that the first block yielded significantly more errors than the subsequent blocks; on average 11% vs. 5.6% respectively, χ^2 (7, N = 240) = 33.265, p < .0005. Across blocks 2 through 8 no significant difference was found, χ^2 (6, N = 210) = 1.745, p = .942. No significant differences were found during the test phase between errors made on the familiar and unfamiliar sequences for both error types; premature movements, χ^2 (1, N = 60) = 1.850, p = .174 and over-/undershoots, χ^2 (1, N = 60) = .725, p = .394.

3.4 Questionnaire

The first question that was asked involved participants writing down what they thought the two practiced sequences were. The maximum number of correct answers is 60, 2 sequences for all 30 participants. Figure 6 displays the distribution of the answers that were given on the sequence recollection question across all participants.

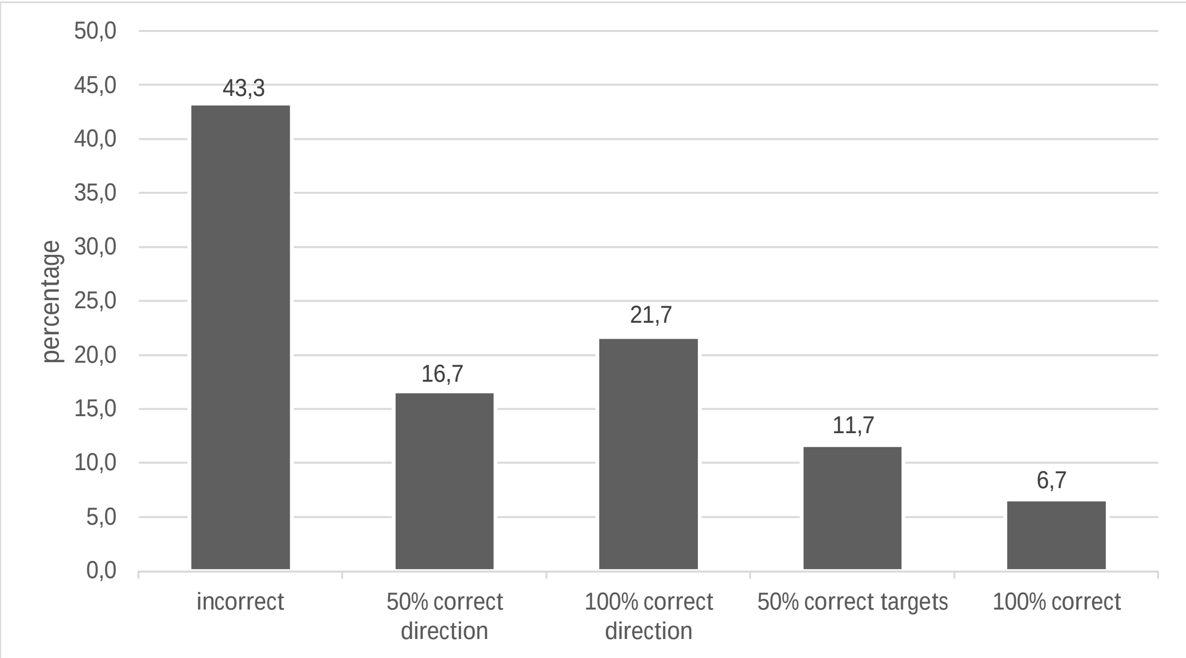

Figure 6. Distribution of answers (%) on sequence recollection across all participants

It can be noted that while a large portion of the answers was incorrect the majority of answers that were given indicated that some level of knowledge was acquired. In 4 (of 60 = 6.7%) cases the sequence was remembered correctly including exact target locations.

Additionally, when the ‘100% correct’, the ‘50% correct targets’, and ‘100% correct direction’ responses are combined it can be concluded that in 24 (40.1%) cases the directions of the entire sequence could be recollected. The fact that the directional aspects of the sequence could be recollected without, in most cases, knowing the exact sequence, is evidence of implicit learning.

As the previously mentioned percentages are regarding the entire set of 60 answers it does not provide information about the distribution of correct answers among participants. A difference was found between participants in their ability to recognise and recall sequences. For the purpose of this analysis an answer was considered correct if the participant could recall 100% of movement directions. Using this criteria it was found that 5 (of 30 = 16.7%) of participants recollected both sequences correctly, 14 (46.7%) recalled one of the two sequences, and 11 (36.7%) did not recall either of the sequences. This shows that some people were better able to notice and distinguish the sequences. Nevertheless, a majority of 19 (63.4%) participants noticed at least one sequence and were able to recall the direction of each movement.

The second question involved recognition of the sequences from a list of options. Interestingly, the percentage of correct recognitions is 37%, roughly the same as the percentage of answers on question 1 where people were able to recall the correct direction of the movements (40.1%). Correlating the answers of participants on questions 1 and 2 yielded a significant correlation of $r(28) = .613$, $p < .0005$, indicating a strong relationship between recalling the sequences by heart, and selecting them from a list of options.

Participants were also required to indicate what strategy they used to recollect the sequences. 66.6% claimed they recalled the sequences because they remembered the order in which the target cues appeared. 26.7% said they repeated the movements with their arm to deduct the sequence and 6.7% of participants used a different approach, namely, simply guessing, or trying to deduct the sequence based on perceived regularities in the sequence order, e.g. movements to the left and right were always alternating. This indicates that over a quarter of the people reconstructed the explicit sequence from their implicit knowledge.

4 Discussion

Adam et al. (2008) found an adverse effect of preparation time on RT and MT when performing the reaching task. Whereas they argued this was the result of having to maintain visual attention due to effector selection not being necessary, the present study was based on the hypothesis that this effect was related to all movements in the reaching task being in the same direction. Since on the reaching task the general direction of all movements was the same participants were able to prepare the onset of the movement before the exact response location was known. Movement preparation before knowing the exact response location was not possible on the key-press task. In the present experiment the one-effector FE task was used, but in such a way that movement direction planning was never possible due to two pre-cued target locations appearing on either side of cursor. The goal of the present study was to find out whether the adverse effects of pre-cue duration on a one-effector task would still occur when preventing movement direction planning before the appearance of the target stimulus. If the adverse effect does not occur it is a strong argument against the explanation of Adam et al. (2008) that the effect is due to effector selection.

Consequently, if the effect of pre-cue duration on the reaching task found by Adam et al. (2008) is in fact due to effector selection, the FE task was expected to behave similarly to the reaching task as both make use of just one effector. Therefore the FE task would be negatively affected by pre-cue duration as well. In contrast, if the present study was correct in assuming that the effect of pre-cue duration is the result of being able to prepare movement direction, it was expected that the FE task behaves similarly to the key-press task where movement direction planning was also not possible.

The present data showed that the FE task indeed seems to be affected by pre-cue duration similarly to the key-press task, as longer pre-cue durations led to shorter reaction times instead of longer ones. This indicates that even though the FE task is a one-effector task, it is not affected by pre-cue duration in a similar way to the one-effector reaching task. Instead it appears to be affected more similar to the multi-effector key-press task. This finding supports the view that the effect of preparation time was likely not the result of effector selection itself, but of the ability to prepare movement direction since movement preparation was not possible in the FE task, and it still only required the use of one effector.

Another interesting finding was that the difference between reaction times following a 0.1 s and 1.0 s pre-cue increases as a function of practice, suggesting an interaction between the effect of pre-cue duration and the familiarity with the practiced sequences. As Figure 3 showed it appears that the increasing difference is the result of RT following a 1.0s pre-cue improving more rapidly than RT following a 0.1s pre-cue. Therefore it appears that participants were able to benefit more from longer pre-cue durations as a result of more practice.

In addition, for movement times there was also an effect of practice on performance. Starting halfway into the experiment longer preparation times actually led to longer movement times which is contrary to what was expected. It appears that movement execution is influenced differently by pre-cue duration than movement preparation, and that the additional time which benefitted the preparation of a movement did not have beneficial effects on the execution of that movement. As the negative effect of longer pre-cue duration did not appear until halfway through the practice phase it would appear this is the result of sequence learning.

A possible explanation for this phenomenon is the changing role of the pre-cue in movement preparation. Schmidt (1975) discussed the role of movement parameters in the preparation and execution of movements. He stated that in order to prepare a movement all movement parameters such as required distance, direction, speed and force have to be known.

The pre-cue used in this experiment served to provide the participant with a limited number of movement parameters. In the beginning of the experiment when the sequences were still completely unknown, the pre-cue provided little information such as the distances to two pre-cued locations without specifying which would be the target location. It is hypothesised that as participants get more familiar with the presented sequences when they have had more practice they are able to complement the movement parameters provided by the pre-cue with their own knowledge regarding the upcoming movements. At the end of the practice phase 63.4% of participants were able to reproduce the movements of at least one of the two practiced sequences. If the participant was aware of the direction of the movement, and then two locations on either side of the cursor were highlighted as the pre-cue, the participant would have known which one of the pre-cued locations would turn into the target location. This means that the participant supplemented the information given by the pre-cue with his own to form a complete set of movement parameters. This would make the partial pre-cue used in this experiment start to act as a full pre-cue specifying exactly where the participant had to move to. Adam et al. (2008) found adverse effects of pre-cue duration on MT on the reaching task with a more pronounced negative effect following a full pre-cue compared to a partial pre-cue. Assuming the hypothesis of changing pre-cue roles is correct, it would make sense that in the beginning of the practice phase when the pre-cue is partial the negative effect is small, and later following more practice the effect becomes larger when the pre-cue provides full information.

It must be noted that throughout the experiment the reaction times were quite slow. It is expected that this is the result of the requested accuracy of the movements. Salthouse and Hedden (2002) discuss how there is a trade-off between speed and accuracy. They state that demanding speed and accuracy are incompatible requirements. When speed is required participants are prone to make more errors, in addition when accuracy is required precautions have to be taken resulting in slower RT. They do, however, also acknowledge that such a trade-off function varies per task and also per participant, so no real judgment can be made as to the effects demanding high accuracy has had on participants' reaction times in the present experiment. It must, however, also be acknowledged that in the present experiment it was not reaction time to the stimulus that was being measured, but rather the combined time of noticing the stimulus, directing visual attention, preparing the movement, and leaving the present target position. This may have contributed to RT's being higher than in classical reaction time experiments where the task and response type are usually simpler.

With regards to the data-analysis the use of the linear mixed effects (LME) model has proven most useful with this type of data. Where many reaction time experiments make use of a repeated measures anova this was found to be undesirable in the present experiment. As there were several random variables such as movement distance and distance between pre-cue locations that were not experimentally controlled for but did influence performance these needed to be controlled for in the analysis. However not every participant encountered exactly the same set of conditions on these random variables. When these random-effect variables were included in a repeated measures anova not all participants had complete datasets and the analysis failed. Using only the fixed factors of pre-cue duration and block would have been a waste of data as a total of 960 measurements in the practice phase for each participant would have been reduced to 16 average scores per participant. In addition this approach would have resulted in the inclusion of the influences of the random effects, obscuring the effects of the fixed factors. The LME model allowed all measurements to be included in the analysis by not having to average measurements within the different conditions. It also allowed for the inclusion of the influencing factors that were not experimentally controlled as random effects. This enabled the analysis to filter out the effects of the fixed factors and allowed for the detection of much subtler differences with higher accuracy.

4.1 Conclusion

Based on the results from this experiment it seems that the FE task has things in common with both the reaching and the key-press tasks. Due to the adverse effects of longer pre-cue duration on RT it seems that movement preparation on the FE task happens in a similar fashion to the key-press task. It is proposed that this is because movement direction planning was not possible on either task. This result contradicts the finding of Adam et al. (2008) who state that the differences in performance following short or long pre-cue durations is due to effector selection. Hereby the main research question is answered and we can conclude that the adverse effects of longer pre-cue durations found on the reaching task did not in fact occur on the FE task while movement direction planning was not possible. Additionally for movement time the results showed that the FE task resembles the reaching task in the way movement times are influenced by pre-cue duration. In sum, movement planning of the FE response happens similarly to the key-press response, as on neither tasks movement direction planning was possible and movement planning could not occur until the target stimulus appeared. In contrast movement execution in the FE task happened similarly to the reaching task which is likely the result of both using only one effector. Therefore it can be concluded that even though the FE task is also a one effector task, it is not influenced by pre-cue duration the same way as the reaching task, which is a strong indication that it is movement direction planning that is at the basis of the effects of pre-cue duration.

4.2 Recommendations

Further research with the FE task is recommended to get more insight into the underlying mechanisms of executing flexing-extending movements. The present study was intended as an exploratory experiment to examine how the FE task reacts to several constructs regarding movement planning and execution found in previous literature. From the results of this experiment several questions have arisen that would be worth exploring in further research.

It was found that the inability to prepare for movement direction apparently causes the FE task to be influenced differently than the reaching task. In future research it could be attempted to allow participants to also prepare movement direction on the FE task. This could be done by presenting the two pre-cue locations on just one side of the cursor position instead of one on either side. It would be interesting to see if in that case the effect of pre-cue duration found on the reaching task also appears on the FE task.

Furthermore, an unexpected result was obtained regarding the increasing influences of pre-cue durations on RT and MT as a function of practice. It was hypothesised that this is the result of the partial pre-cue starting to act as a full pre-cue as the missing movement parameters are supplemented by the participants as a result of increased knowledge about the sequences. Further research could attempt to test this hypothesis by for example using random sequences of movements to prevent learning taking place, and then alternatingly administering partial and full pre-cues to see if the difference in performance between the short and long pre-cue durations would also be more pronounced in the full pre-cue condition. If that is the case it would suggest that the increasing benefit of longer pre-cue durations on RT in the present experiment are indeed the result of participants supplementing the pre-cued information with their own acquired knowledge about the sequences.

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6 Appendixes

6.1 Appendix I

6.2 Appendix II

Sequence allocation

Sequences:
1: 2 7 8 5 6 3
2: 3 2 7 2 3 5
3: 4 6 3 8 5 7
4: 6 4 8 4 2 5
5: 7 6 8 2 6 5
6: 8 3 8 7 6 7

			Practice phase; Block								Testphase; Block	
Conditions	**Participants**	**Sequences**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**
Condition 1	1,7,13,19,25	1,3,4,5	1&5	1&5	1&5	1&5	1&5	1&5	1&5	1&5	1&5	3&4*
Condition 2	2,8,14,20,26	2,3,4,5	3&5	3&5	3&5	3&5	3&5	3&5	3&5	3&5	2&4*	3&5
Condition 3	3,9,15,21,27	2,3,4,6	3&4	3&4	3&4	3&4	3&4	3&4	3&4	3&4	3&4	2&6*
Condition 4	4,10,16,22,28	1,2,4,6	2&4	2&4	2&4	2&4	2&4	2&4	2&4	2&4	1&6*	2&4
Condition 5	5,11,17,23,29	1,2,5,6	2&6	2&6	2&6	2&6	2&6	2&6	2&6	2&6	2&6	1&5*
Condition 6	6,12,18,24,30	1,3,5,6	1&6	1&6	1&6	1&6	1&6	1&6	1&6	1&6	3&5*	1&6

Figure 7. Sequence allocation, *=unfamiliar sequences

6.3 Appendix III

Questionnaire

VRAGENLIJST “SEQUENTIËLE ARMBEWEGINGEN”

PROEFPERSOONNUMMER (invullen door proefleider): ______

GESLACHT:

NAAM:

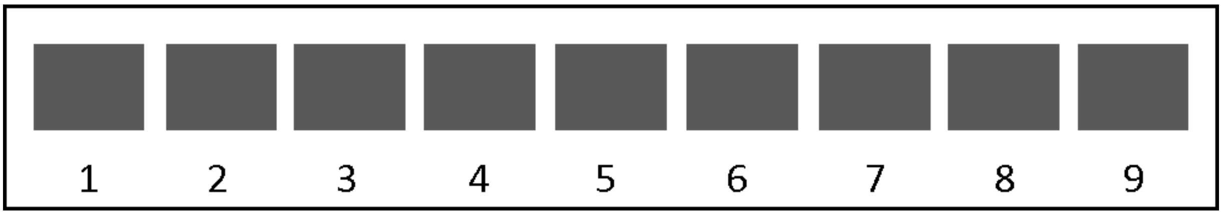
LEEFTIJD:

LINKS OF RECHTSHANDIG:

Let op: alleen het blad omslaan als u klaar bent. Teruggaan naar een vorige vraag is NIET toegestaan.

VRAAG 1.

In dit experiment heeft u steeds door het bewegen van uw arm gereageerd op een oplichtend blokje. Gedurende de trainingsfase waren er continu twee vaste series waarin de blokjes oplichtten, en dus ook twee vaste volgordes van armbewegingen.



Figuur: de doelposities die in het experiment getoond werden.

De serie armbewegingen had altijd een lengte van zes. Kunt u hieronder proberen aan te geven welke ***twee*** series van armbewegingen u gedurende het experiment moest uitvoeren? Zet de nummers van de blokjes in de juiste volgorde! Geef bij beide series ook aan hoe zeker u bent van uw antwoord.

Serie 1.

- Volgorde van armbewegingen:

- Zekerheid over serie 1 (kruis het juiste antwoord aan):

Helemaal niet zeker	Een beetje zeker	Behoorlijk zeker	Helemaal zeker

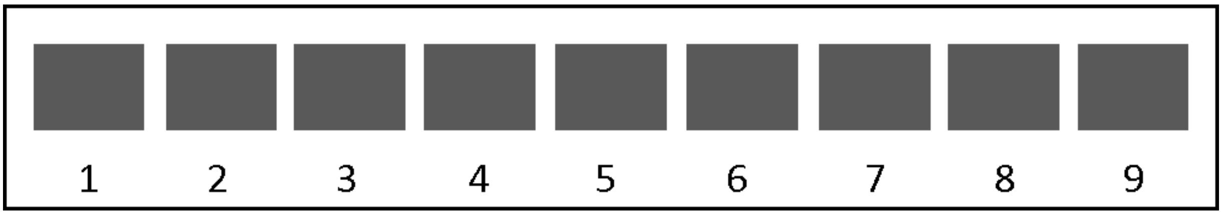
Serie 2.

- Volgorde van armbewegingen:

- Zekerheid over serie 2 (kruis het juiste antwoord aan):

Helemaal niet zeker	Een beetje zeker	Behoorlijk zeker	Helemaal zeker

VRAAG 2.
In de tabel hieronder staan 18 mogelijkheden van armbewegingen. Kies hieruit de twee series waarvan u denkt dat deze zijn voorgekomen in het experiment. Zet een 1 achter de volgorde waarvan u het meest zeker bent, en een 2 achter de serie waarvan u iets minder zeker bent. Kies dus ALTIJD *twee* mogelijkheden, niet meer of minder!



Figuur: de doelposities die in het experiment getoond werden.

A	**7 6 3 4 3 7**	
B	**6 2 7 6 2 3**	
C	**3 2 7 2 3 5**	
D	**8 4 5 4 8 5**	
E	**3 8 4 8 6 2**	
F	**7 6 8 2 6 5**	
G	**2 5 7 3 6 4**	
H	**4 6 3 8 5 7**	
I	**4 6 2 6 5 7**	
J	**8 3 8 7 6 7**	
K	**3 6 5 2 3 6**	
L	**7 2 8 3 6 5**	
M	**8 5 3 8 3 2**	
N	**2 7 8 5 6 3**	
O	**4 2 4 8 7 5**	
P	**6 7 6 2 4 5**	
Q	**6 4 8 4 2 5**	
R	**2 6 2 3 6 3**	

VRAAG 3.

Hoe herkende u ‘uw’ bewegingssequenties in de vorige twee vragenlijsten. Omcirkel het meest passende alternatief.

a) doordat ik mij de volgorde herinnerde van de blokjes op het scherm

b) doordat ik met mijn arm de bewegingssequentie in gedachte uitvoerde

c) doordat ik mij de posities van de vierkantjes en toetsen herinnerde

d) anders, namelijk:

VRAAG 4.

Hebt u verder nog opmerkingen over dit experiment?