Investigating differences of Forward segmentation vs. Whole task practice in a 15-keypress task for Motor Sequence Learning

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Abstract

The following study investigated the differences of practice conditions between forward segmentation and whole task practice for motor sequence learning. Contrary to previous studies, a relatively long sequence of 15 keys was tested. Previous findings and literature could not highlight differences in shorter sequences for keypress tasks with forward segmentation or whole task practice. Based on the Cognitive framework of Sequential Motor Behaviour (C-SMB) and further literature, it was expected that forward segmentation would be more effective as a practice condition compared to whole task practice. Due to limits of the motor buffer and corresponding ability to form motor representations, it was expected that forward segmentation would assist the formation and motor representations to be more easily retrieved and remembered. Participants (n=24) where divided among two different experimental groups, namely forward segmentation practice and whole task practice, and were tested on a 15-keypress sequence with the discrete sequence production (DSP) task after three practice blocks and a second time after one week. No significant difference for reaction times or errors was found in the testing or practice phases between both practice conditions

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Motor skills are fundamental for human interaction with the world; every voluntary action from walking, holding something, to merely pushing a button is an acquired skill. To understand how motor skills can be improved it is crucial to study the benefits and differences in outcomes of different practices for motor skill acquisition and improvement. Abrahamse, Ruitenberg, De Kleine, and Verwey (2013) defined motor sequence learning as “the acquisition of the skill to rapidly and accurately produce a sequence of movements with limited effort and/or attentional monitoring”. To study the acquisition of motor skills and differential effects of training, behavioral measures can be applied to measure differences in motor skill execution with regard to their reaction time and accuracy. Advancements to measure these sequences and their underlying cognitive aspects have been made in the form of sequence acquisition tasks, such as the discrete sequence production (DSP) task (Verwey, 2001). On the basis of the DSP task, the current study focuses on the differences of effects of training with forward segmentation and whole task practice.

Motor sequences

Research on motor sequences has shown that motor skills can vary in their complexity, continuity, and stability (Magill & Anderson, 2010). Continuous motor skills, such as walking or swimming, are composed of and executed by repetitive movements while discrete motor skills are categorized by a definite beginning and end of a particular movement. Miller (1956) proposed that bits of information can be categorized into chunks or sequences with which larger mental representations can be formed to acquire and retain higher loads of information. Correspondingly, motor sequences appear to be combined and retained by combining representations of movement patterns (Verwey, 1996). According to several researchers, the performance of automated and skilled actions, such as writing, typing, or operating a car, are possible due to a practiced combination of sequences into fluid movements (Verwey, 2001).

The Cognitive framework for Sequential Motor Behaviour

The Cognitive framework for Sequential Motor Behaviour (C-SMB) proposes a model for information-processing of motor sequences by a motor processor that includes a central processor (Verwey et al., 2015). Contrary to previous models and research, the C-SMB implies that the execution of motor sequences is not only a motoric but a cognitive task too (Verwey et al., 2015). C-SMB proposes that “knowledge is represented in perceptual, central-symbolic, and motor representations” (Verwey et al., 2015). Equivalent to the formation of a motor representation by bits of information, motor representations can “become part of a multidimensional representation” (Verwey et al., 2015). The acquisition of motor representations is limited by storage of information in short-term memory and the motor buffer (Verwey et al., 2015). With regards to the execution of motor sequences, the central processor activates information for corresponding aspects of motor representations to be used in the execution of an action (Verwey et al., 2015). C-SMB proposes that the central processor loads that information into the motor buffer and short-term memory allowing later retrieval for execution (Verwey et al, 2015). Reaction times in key pressing tasks during initiation phases and concatenation can be explained by these two storage processors of the C-SMB.

In key pressing tasks, such as the DSP task, it has been found that the first key press of a sequence requires more time during a so-called initiation phase in which information about a motor representation is retrieved from memory (Verwey, 1999). An increase of reaction time by processing during the transition of successive chunks is called a concatenation point (Verwey, 2001). Variations in reaction time of concatenation points while processing motor sequences highlight differences in the acquisition of motor skills and can be studied to further gain an understanding of underlying cognitive factors in motor sequence learning and potential benefits of different learning practices.

Forward Segmentation and Whole Task Practice in Motor Sequence Learning

Motor skill practice regimes can be divided into whole task- and part task practice. During whole task practice, a motor skill is carried out in its entirety, while the motor sequence is split into segments during part task practice (Fontana et al., 2009). These practices and their applicability differ in regards to the complexity and organization of tasks (Fontana et al., 2009). Complexity is described by the cognitive demands of a task.

A keystroke would be of low complexity and a dance routine of high complexity (Fontana et al., 2009). Organization describes the relation of different elements in a task; interdependence of elements in a task would involve high organization (Fontana et al., 2009). Naylor and Briggs (1963) propose that tasks with a higher cognitive demand that are at the same time low in organization might benefit from part practice, while tasks with low complexity and high organization might benefit from whole task practice (Fontana et al., 2009). Schmidt and Wrisberg (2000) argue that serial tasks that combine multiple components which are not related benefit from part task practice while serial tasks with elements that are highly organized, and related, benefit from whole task practice (Fontana et al, 2009). In key pressing tasks part practice might be used and most beneficial as organization is low and sequences are not related nor interfering with each other.

A type of part task practice is forward segmentation. Forward segmentation comprises the practice of segments in a consecutive order in which the first motor sequence is practiced at the beginning and later segments after (Ash & Holding, 1990). While some researchers reported fewer errors for forward segmentation than whole task practice in keypress tasks, others found no differences between both conditions (Smith, 1999). Smith (1999) anticipated that effects of training would be highlighted when a longer sequence of behaviour was taught and found that forward segmentation resulted in fewer total errors than whole task practice.

Implications for the present study

After merely responding to key-specific stimuli, it was expected that participants will form motor representations and improve the execution rate for the sequences while performing the DSP task. Shorter reaction times are thus expected to occur in the test and retention phase of the experiment for both practice conditions.

Motor representations have been found to be limited in keypress tasks to 4 or 5 elements (Verwey et al., 2015). Due to the capacity limit of the motor buffer (Verwey et al., 2015), it can be expected that the reaction time during the initiation phase of whole task practice is longer due to the retrieval of a more complex representation rather than shorter segments as in the forward segmentation practice, which can be retrieved and potentially performed faster. Additionally, forward segmentation practice might assist in the formation of longer subsequences, whereas in whole task practice shorter subsequences are concatenated leading to multiple concatenation points and an overall increase in reaction time. These multiple concatenation points might however be concealed at the group level by the fact that participants might use segments of different lengths (Verwey et al., 2015).

Due to the sequence length of 15 keys in whole task practice, it can be expected that overall retention will be worse than for forward segmentation where segmentation is facilitated through structured sequences of 5 keystrokes, comparable to the limited capacity of 4 to 5 elements of the motor buffer. Segmentation is expected to support long-term memory representations (Fontana et al., 2009). Still, extensive practice might outweigh the initial advantages of segmentation in forward segmentation with the formation of sequence representations by increased repetitions in whole task practice.

The present study

In the current study, participants took part in a DSP task in the form of a keypress task. To investigate differences in whole task practice and forward segmentation, participants either practiced a 15-key sequence as a whole or with forward segmentation practice. Participants in the whole task practice group practice a 15-key sequence as a whole in 3 consecutive blocks while participants in the forward segmentation group practice the 15-key sequence in parts that are added per block; in the first block the first 5-keys are practiced and afterwards 5-keys are added per block. Thus, participants in the forward segmentation condition practiced 5 keypresses in the first block, then 10 in the second and the full 15-key sequence in the last practice block. After the 3 practice blocks, participants were tested on the full sequence. One week later, participants took part in a test to measure retention. We tested the hypothesis that forward segmentation would be more advantageous in learning a 15-key sequence than whole task practice.

Methods

Participants

24 Participants (age range 18-31, mean age = 21.3 years, SD=3.04 years; 15 female) partook in the study at the University of Twente in the Netherlands. Most participants were students that were able to partake in the study by signing up on the research studies portal ‘Sona System’ of the University of Twente. Other participants were recruited via personal contact, flyers and through social media. All participants reported being right handed, stated to be non-smokers and to have been sober for at least 24 hours prior to the experiments. Students were compensated for their time with credit points on the university study portal ‘Sona System’. Participants were randomly allocated to the experimental groups. The Ethics Committee of the Faculty of Behavioural, Management and Social Sciences (BMS) of the University of Twente approved the study.

Materials

The experiment was conducted in one of 3 Flexperiment cubicles of the lab for social sciences (BMS lab) at the University of Twente. The Flexperiment cubicles are small (<10sqm) rooms equipped with a desk, chair, monitor, desktop, camera and window. All rooms had the same equipment and layout. The desks, alongside monitors, in the rooms were situated to be facing a wall. The door to enter the room and window were situated at the side of the participant with the blinds of the windows being retracted to about three quarters, to limit external factors that could withdraw the participants’ attention from the experiment. A GoPro camera was mounted above the window, out of the peripheral view of the participants. Participants were seated in front of a 16:9 24 inch 144HZ LCD monitor (AOC G2460PF). The screen was placed approximately 60 cm in front of the participants. A full layout 100% wired QWERTZ keyboard (4World PN:07319) was placed in front of the participants alongside a wired mouse (Dell MS116t). The study was programmed in E-prime and ran on a Dell OptiPlex 7050 PC with Windows 10.

Task

Participants did a variant of the DSP task in which they were instructed to place their hands in front of the keyboard with their left middle finger on C, their left index finger on V, their right index finger on B and their right middle finger on N. During the experiment, four grey squares were shown on the screen horizontally aligned in a row, representing the four keys ‘CVBN’ which participants were asked to lay their fingers on. Once one of the four squares lit up green, participants were supposed to press the assigned key. If the first square in the row lit up green, participants then pressed the corresponding key C, for the second square they pressed V, for the third B and if the last square lit up green the key N had to be pressed. If participants reacted correctly, the next square lit up immediately. If participants made an error by clicking the wrong key, an error message and appeared and a short break occurred before the next stimuli appeared.

The experiment consisted of two sessions with 4 blocks in the first session and two blocks in the second session. The first three blocks in the first session were practice trials and the fourth a test block. The fifth block, which was intended to measure the retention, took part in the second session. After each block participants were informed about their mean performance in response time and number of errors. Participants then had a short break of one minute after which the researcher entered the room and started, if applicable, the next session.

Participants were randomly allocated to one of two different practice condition groups. Namely, forward segmentation and whole task practice. The number of trials and pressed keystrokes were adjusted to be the same for the practice conditions. Participants of both conditions had a total of 360 key presses during the practice blocks, 105 in the test block and 300 in the retention block. Each key of the sequences was followed by a different key, preventing that a key would be pressed twice.

Forward segmentation

The first group of participants was assigned to learn a sequence with the practice condition forward segmentation. Here participants practiced the 15-key sequence segmented into three five key sequences during the first three practice blocks. In the first block participants practiced the first five keys of the full 15-key sequence for 12 trials. Then, in the second block the next five keys of the full 15-key sequence were added where participants then practiced the first ten keys of the sequence for 12 trials. In the third practice block, participants of the forward segmentation condition practiced the full 15-key sequence for 12 trials. Then a test block occurred in which the full sequence was tested for 7 trials. One week later retention was measured for the full 15-key sequence with 20 trials.

Whole task practice

The second group of participants practiced the whole 15-key sequence. In the first three practice blocks, participants practiced the 15-key sequence for 8 trials per block. In the fourth block, participants were tested by executing the 15-key sequence for 7 trials. One week later, participants were tested in their retention of the 15-key sequence for 20 trials.

Procedure

Upon arrival, participants were asked to leave their mobile phones and other potentially distracting devices like smart watches in their belongings outside the experimental room. Participants were then asked to be seated and were facing the monitor; the door and window of the rooms were situated to the participants' sides. Once seated, participants were verbally informed about the keypress task, the procedure during the experiment and the fact that errors would increase the duration of the experiment. Participants were then made aware of the camera above the window and their option to ask questions during the experiment by raising their hand, as well as the option to withdraw from the study at any point. Then participants were handed a consent form (Appendix A) affirming their understanding of their right to withdraw or ask questions, informing them again about the task, associated risks and the use of their data. Once the consent form was signed, the experimenter started the first trial block which followed with further instructions on the screen. After each practice block participants had a short break of one minute after which the researcher entered the room, asked the participant if there were any questions and then started the next block. After completion of the test in the fourth block, participants were thanked for their participation and informed about the next session. Seven days after the first session, the second session took place. Again, participants were asked to leave their mobile phones and other distracting devices outside the room. Then participants were verbally informed about the task again and instructed to lay their fingers on the keys CVBN. When participants felt to be in a suitable state to perform the task, the retention block was started. After the experiment, participants were thanked for their participation.

Results

Reaction Time (RT) was defined and measured by the time it took a participant to respond with the correct keystroke to the stimuli of a green square. The error rate (ER) was defined and measured as the number of incorrect keystrokes in response to appearing stimuli in a block. Analyses focused on the effects of practice schedule on reaction times and errors in the block 4, the testing phase, and block 5, the retention phase. Further, key dependent errors during the practice blocks 1-3 were analysed. All ANOVAs were conducted with transformed arcsine proportions.

Reaction Time

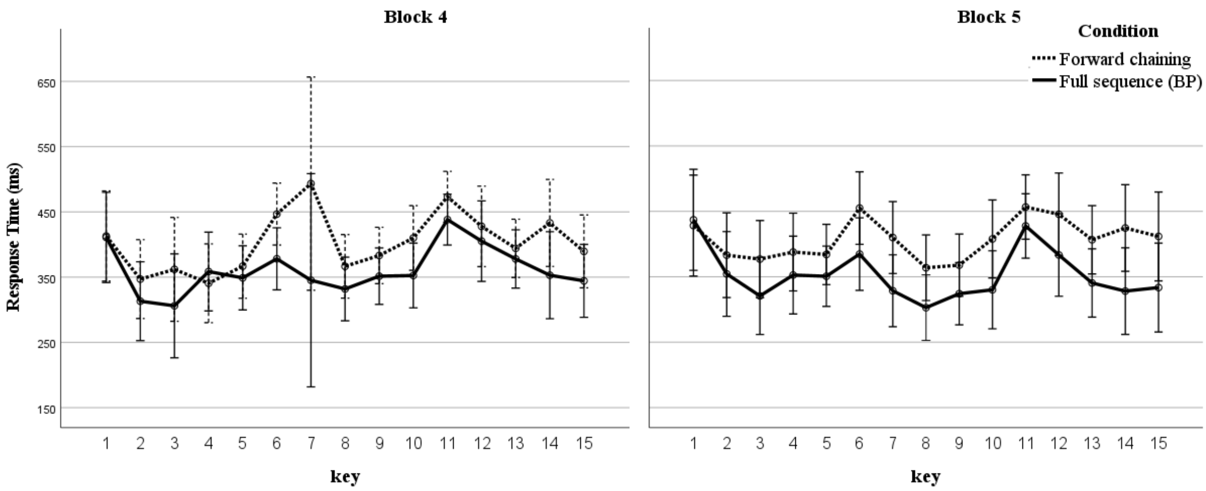
Reaction times were analysed using a 2 (Practice Group) x 2 (Block 4 vs 5) x 15 (Key) mixed design repeated measures ANOVA with practice group as between-subjects variable and Block and Key as within-subject variables. Since Mauchly's test indicated that the assumption of sphericity was violated for Key $\chi2(104)=200.792$, $p<.001$ and Block*Key $\chi2(104)=310.062$, $p<.001$, the Greenhouse-Geisser transformation ($\varepsilon < .75$) was used to correct the degrees of freedom and interpret the data.

The overall mean for RT in the Forward Chaining condition was 405 ms (SD=22 ms) and the mean for Full Sequence 357 ms (SD=22 ms). The mean for Forward Chaining rose slightly from 403 ms (SD=24 ms) to 407 ms (SD=24 ms) and the mean for Full Sequence declined slightly from 361 ms (SD=25 ms) to 353 ms (SD=24 ms). The main effect of Block was not significant ($F(1,22) = .015$, $p = .903$, $\eta p^2 = .001$), whereas the main effect of key was significant ($F(5.011,110.249) = 8.167$, $p < .0.5$, $\eta p^2 = .271$). The Block*Key interaction was not significant ($F(2.382,52.411) = 1.748$, $p = .178$, $\eta p^2 = .074$) which can be seen in Figure 1. The interaction between Block*Key*Condition was not significant as well ($F(2.382,52.411) = .799$, $p = .475$, $\eta p^2 = .035$).

Figure 1 further shows that RT decreased after the first key for both conditions in both blocks. RT rose with key 6 for Forward Chaining in block 4 and declined with key 8. In block 5 RT rose at key 6 for Forward chaining again, but then declined at key 7. For the latter part of the sequence, a peak in RT can be seen with key 10 and 11 for Forward Chaining in block 4 after which it declined again. In block 5 RT rose again at key 10 and 11 for Forward Chaining and declined again after while staying relatively high for the last keys compared to earlier RT. For the Full Sequence, RT rose slightly after the decline in the first keys, at key 4 and 6 in block 4 whereas this increment appeared to lessen for key 4 in Block 5 but stayed for key 6 above the mean. After key 6, RT for the Full Sequence decreased in both blocks and increased considerably at key 11 and declined after, similar to the Forward Chaining condition.

Figure 1

Mean RT (in ms) per Condition and Block



Error Rate Block 1-3

Error Rates in Block 1-3 were analysed using a 3 (Block) x 2 (Practice Group) mixed design repeated measures ANOVA with practice group as between-subjects variable and Block as within-subject variables. As Mauchly's test of sphericity was not violated (p = .901) sphericity was assumed. The overall mean errors for the Full Sequence condition were higher than for the Forward Chaining condition. The mean errors for the Full Sequence condition decreased in Block 2 and increased again in Block 3 while the mean errors for the Forward Chaining condition were the lowest in Block 1, rose in Block 2 and slightly rose again in Block 3. Participants in the Forward Chaining condition practiced 60 keystrokes in the first Block, 120 in Block 2 and 180 in Block 3. The group in the Full Sequence condition practiced 120 keystrokes in all 3 practice Blocks. No significant effect has been found for the interaction between practice condition and errors in Blocks 1-3 ($F(2, 44) = 1.118$, $p = .336$, $\eta p^2 = .048$).

Error Rate Block 4 and 5

A 2 (Block 4 vs 5) x 2 (Practice Group) mixed design repeated measures ANOVA with practice group as between-subjects variable and Block as within-subject variable was used to analyse error rates in Block 4 and 5. In Block 4 and 5 the mean error rate for the Full Sequence condition remained higher than the mean error rate of the Forward Chaining condition. The mean error rate of the Full Sequence practice group declined from 0.963 (SD=0.292) in Block 4 to 0.849 (SD=0.379) in Block 5 while the error rate of the Forward Chaining condition rose slightly from 0.783 (SD=0.402) to 0.811 (SD=0.509). There was no significant interaction between Block and Practice Condition ($F(1,22) = .384$, $p = .542$, $\eta p^2 = .017$).

Discussion

Literature indicates that different types of practices in motor learning are more advantageous depending on the type of the task (e.g., Naylor and Briggs 1963, Schmidt & Wrisberg 2000). Comparing whole task practice and forward segmentation in keypress tasks, some researchers reported better retention for forward segmentation, while others found no differences (Smith, 1999). Segmentation was expected to support long-term memory representations (Fontana et al., 2009), especially for longer sequences as in the current study (Smith, 1999). However, the hypothesis that forward segmentation would be more advantageous compared to whole task practice could not be confirmed as RT and errors were not significantly different during the testing and retention phase.

Reaction Time

While an initiation phase can clearly be seen in figure 1, the reaction time during the initiation phase of whole task practice was not longer than for forward segmentation as expected. This suggests that even though an initially longer sequence was practiced, mental representations for shorter chunks were formed for the whole task practice condition as well. This can further be highlighted by concatenation points at keys 6 and 11 in the testing and retention phase. While these concatenation points can be identified in figure 1 by shorter reaction times for previous and following keys, it appears that a concatenation phase at key 6 and key 11 might not have been the only apparent concatenation points. For whole task practice, the increase in reaction times did not appear to differ for potential mental representations as much in the testing phase as in the retention phase. In the retention phase these concatenation points became more visible at key 6 and key 11. The observation in the testing phase (block 4) of only slight increases at key 6 and key 11 and various other increases in between might confirm the expectation that participants might use segments of different lengths which conceal concatenation points at the group level (Verwey et al., 2015). Though during the retention phase (block 5), it appears that for both practice conditions concatenation points at key 6 and key 11 were more prominent, indicating that mental representations were formed or strengthened in between the first and second session.

After the analysis of reaction times, it could not be confirmed that forward segmentation did assist in the formation of longer subsequences as expected. This might be due to the fact that the length of mental representations that participants form might differ among participants, their ability and approach in remembering said representations.

It could not be confirmed that extensive practice outweighed the initial advantages of segmentation in forward segmentation for reaction times in the testing or retention phase.

Error rate

While it could not be confirmed that extensive practice outweighed the initial advantages of segmentation in forward segmentation for reaction times in the testing or retention phase, there appears to be an effect related to this expectation during the errors in the first three practice blocks. Participants in the forward segmentation group showed less errors in the practice blocks compared to the whole task practice group, even though new sequences were added throughout the practice blocks for forward segmentation whereby participants of the whole task practice group were already presented with the full sequence in the first block. Though, this effect alone cannot confirm the initial benefits of forward segmentation as errors could be lower in a stimuli-response task when participants take more time to react to for example to a new sequence, as introduced in each practice block.

Limitations

Since there are individual differences in the limitation of motor representations to 4 or 5 elements (Verwey et al., 2015), these individual differences pose a limitation to the analysis of the effect of forward segmentation and whole task practice. For individuals with fewer elements than the proposed segmentation of 5 elements in the forward segmentation condition, this could bare disadvantages whereas they might be more favoured with potential shorter segments or whole task practice. Therefore the limited number of participants and probable individual differences might have a larger effect than if a larger sample size would have been tested.

Further, the sample size consisted of mainly students and young adults which might bare an advantage for individual differences affecting the results in each condition, but might limit the generalizability of the data to the population.

Another limitation might be the fact that participants were not aware, before the start of the experiment, that the sequence they were practicing was the same across all blocks.

Forward segmentation might be more advantageous to participants if they are aware of having to practice a sequence and that successive sequences are added in later blocks. If participants were aware of their respective practice regime, there could be an advantage for participants in the whole task practice group, as they could initially choose the length of sequences they intent to actively remember.

Future research

As no significant differences were found between both learning conditions, future research could further investigate probable advantages of both conditions. Forward segmentation might be more favourable for short term learning effects which could be highlighted with less practice or fewer trials in the testing and retention phase. More prominent concatenation points after a break might indicate that there are advantages in the long term for whole task practice and the potentially mere repetition executing the keypress sequence. Though, it is unclear whether participants applied the same strategy or tactics to remember the sequence and form mental representations. Here, it would be interesting to research which meta cognitive strategies were applied, if any.

Since there might be differences in the individual ability to remember different lengths of sequences, individualized segmentation might bare advantages for forward segmentation or part task practice itself. If these individual differences were first investigated, part task practice might bare more advantages while catering to individuals' abilities while potentially highlighting learning effects on these abilities and training for the motor buffer and formation of motor representations.

Conclusion

In conclusion, the study could not confirm the hypothesis that forward segmentation was more advantageous than whole task practice for practicing a 15-key sequence. Reaction times became shorter with extended practice for both conditions with no significant differences between the practice conditions. Both practice conditions showed an improvement in forming motor representations during the testing phase and especially in the retention phase one week later. The relative error rate was lower in during the practice blocks for forward segmentation, indicating potential advantages in short term learning for forward segmentation compared to whole task practice in keypress tasks. Individualized learning practices catered to participants limitations in forming motor representations might bare further advantages for forward segmentation. A clear instruction for the intent of the practice to form motor representations might benefit participants in their learning outcome and accentuate potential differences and benefits of types of practice.

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Appendix A

Consent Form for Investigation into the Learning of Discrete Movements

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	◻	◻
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	◻	◻
I understand that taking part in the study involves me pressing a series of keyboard keys. While doing so, my response time and error rate will be recorded by the computer. First, there will be a part for learning the sequences (120 keypresses), after which my performance will be measured in a test.	◻	◻
I agree to hand my phone to the researcher so that I will not be distracted. The researcher will not do anything with it besides keeping it safe.	◻	◻
Risks associated with participating in the study		
I understand that taking part in the study is not associated with any risks. However, if any complaints emerge I can contact the researcher anytime and know how to.	◻	◻
Use of the information in the study		
I understand that information I provide will be used for a student's bachelor thesis. It will be anonymized and no individual results will be found in the report.	◻	◻
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	◻	◻
Future use and reuse of the information by others		
I give permission for the anonymized data that I provide to be archived on safe University of Twente server so it can be used for future research and learning.	◻	◻

Signatures

______________________	______________________	_________
Name of participant	Signature	Date

I have accurately read out the information sheet to the participant and, to the best of my ability, ensure that the participant understands to what they are freely consenting.

______________________ ______________________ ________

Researcher name Signature Date

Study contact details for further information:

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Contact Information for Questions about Your Rights as a Research Participant:
If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-bms@utwente.nl