Forward Chaining, Backward Chaining and Whole Task Practice in Motor Sequence Learning

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Bachelor Thesis

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Date of Delivery: 13. July 2021

Abstract

Different types of learning can influence the efficiency and proficiency of acquisition and retention of motor behaviours. Previous research could not identify general guidelines on whether whole task practice, forward chaining or backward chaining is most beneficial for learning. This paper argues that with backward chaining, compared to the other two practice types, mental representations at the end of a sequence can develop quicker. In line with the Cognitive framework for Sequential Motor Behaviour (C-SMB), these mental representations help overcome the limits of the motor buffer in early learning. Thus, backwards chaining is assumed to show faster reaction times (RT) than forward chaining or whole task practice. Participants (n=36) were divided across three experimental groups and practised one 9-key sequence with the discrete sequence production (DSP) task. The experiment was designed as a two-part study to compare the retention one week later. There was no significant difference in RT between the practice groups. However, after retention and in certain key locations, backward chaining was more error-prone than the other two conditions. A potential explanation for the results is that mental representations were not yet sufficiently established to cause differences. Also, backward chaining appears to be more demanding considering that the natural sequence order needed to be reassembled.

Keywords: Motor sequence learning, discrete sequence production task (DSP), backward chaining, forward chaining, whole task practice

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Motor learning plays an important role in everyday life. Every movement we perform has been learned. This starts with basic motor skills such as a child learning how to sit, stand or walk and continues throughout our life (Magill & Anderson, 2010). Magill and Anderson (2010) define motor skills as "activities or tasks that require voluntary control over movements of the joints and body segments to achieve a goal" (p.3). Motor learning concerns its acquisition, its improvement possibilities or its reacquisition. Finding out how to train motor skills best can help learners acquire the skills most advantageously (e.g. Roessger, 2012; Wightman & Lintern, 1985). Few advances have been made to compare differences in practice methods to explore characteristics of the underlying cognitive structure during the learning process. Laboratory research to assess cognitive processes can be done with, for example, a key pressing task such as the discrete sequence production task (DSP; Verwey, 2001) which was also employed in the current research. Literature makes several distinctions and recommendations for optimal motor learning. However, few guidelines show clear results, such as with whole task practice, backward chaining and forward chaining (see below). Therefore, this paper investigates the difference between backward chaining and forward chaining relative to whole task practice with the DSP task while considering the cognitive processes involved.

Results from the DSP task show that after having a sequence of movements extensively practised, making the first movement is relatively slow because the participant needs to recall information about the sequence. This is called the initiation phase and it gets longer relative to the number of subsequent movements (Schröter & Leuthold, 2009; Verwey, 1999). After people execute the first stimulus, they carry out the series of movements more rapidly. This is possible because, through practice, participants develop motor representations that bundle multiple single movements into one representation. These motor representations are considered to be so-called motor chunks (Verwey, 1999; Wymbs et al., 2012). These can be retrieved more easily because the responsible processors can initiate a motor chunk instead of single movements (Magill & Anderson, 2010; Verwey, 1996) and the execution of a movement will be faster and can eventually become automatic (Immink et al., 2020; Verwey & Wright, 2014).

The Cognitive framework for Sequential Motor Behaviour (C-SMB) by Verwey et al. (2015) states that in the preparation of the sequence of movements the so-called motor buffer is involved. This buffer holds the elements of a movement available after a central processor has loaded it from memory. This is comparable to what short term memory (STM) does with perceptual information (Abrahamse et al., 2013; Verwey, 1996; Verwey et al., 2015). Once loaded in the motor buffer, a motor processor executes the movement. This makes the central processor no longer needed and thus, the demand on the brains' cognitive load capacity is decreased (Immink et al., 2020; Logan, 1985; Verwey, 1996; Verwey, 2001; Verwey et al., 2015).

Similarly to the STM, the motor buffer has a limited capacity (Abrahamse et al., 2013; Verwey et al., 2015). Therefore, when having a relatively long sequence (e.g. > 4 key-presses), not the whole sequence can be loaded initially. When one has developed motor chunks, these chunks can be loaded instead of the single movements which demand less motor buffer capacity. Thereby, more movements can be held available simultaneously and movements can be executed fluently (Verwey et al., 2009; Verwey & Eikelboom, 2003). Hence, motor chunks help to overcome the limits of the motor buffer.

Motor chunks are also assumed to have a limited capacity to bundle single movements (Verwey et al., 2009; Verwey & Eikelboom, 2003). Thus, in a relatively long sequence, even if chunks have already developed the motor processor has to reload the later movements or chunks into the motor buffer (Abrahamse et al., 2013; Verwey et al., 2015). Through that, a concatenation point emerges which is the transition point from executing one motor chunk to another. This concatenation is visible in individual reaction time (RT) data through a temporary increase in RT (Abrahamse et al., 2013). Like the initiation phase, concatenation is assumed to be involved in loading and initiating the next movements (Verwey, 2003). Thus, similarly to the initiation, concatenation is considered to take longer when it is followed by more individual movements. In conclusion, the capacity of the motor buffer is limited and long sequences require the cognitive processor to reload information. This raises questions about the optimal way to support our cognitive systems in practising motor sequences.

Part Task and Whole Task Learning

Practising motor skills can be done in different ways. A first distinction can be made between whole task and part task training. Whole task training is practising an entire task at once, whereas part task training means that the task is split into several segments which are then practised individually[1] (Fontana et al., 2009; Smith, 1999; Wightman & Lintern, 1985).

Part task training is supposed to have several advantages over whole-task training. First, it can simplify the training process as complex sequences of behaviour may be split up into less complex ones and these can then be learned individually (Ash & Holding, 1990; Fontana et al., 2009; Holding, 1965). Moreover, it can improve performance on the whole task with comparably less practice. This can improve the cost-efficiency of training (Brydges et al., 2007; Wightman & Lintern, 1985). Third, it can have a greater reinforcement effect because part tasks reach their end, and with that temporal goals, more often (Leslie & O'Reilly, 1999; Holding, 1965). In contrast, part task practice can be disadvantageous because the structure or function of a movement is changed which makes it difficult to later combine the partial movements (Fontana et al., 2009).

The nature of the task can determine which kind of learning is favourable (Fontana et al., 2009; Magill & Anderson, 2010). Naylor and Briggs (1963) proposed to classify the nature of the task by its level of complexity and organization. Complexity refers to a task having a high or low number of components, and how much attention they require. Following their hypothesis, a relatively uncomplex

[1] Whole task training is also referred to as whole task practice or whole practice (e.g. Brydges et al., 2007). Part task training is also named part practice (e.g. Brydges et al., 2007; Fontana et al., 2009), chaining (e.g. Leslie & O'Reilly, 1999; Walls et al., 1981) or segmentation (e.g. Wightman & Lintern, 1985).

task does not need to be practised in parts whereas it might be advantageous for a highly complex task. This further depends on the organization of a task. This is the dependency of the components on each other in a temporal and/or spatial dimension. High in organization means that the components of the tasks are highly interrelated and, thus, should be learned as a whole. Conversely, if a task is low in organization the single components are rather independent and it might be more beneficial to learn the task in parts (see also Brydges et al., 2007; Fontana et al., 2009; Magill & Anderson, 2010). Although a single keypress can be reproduced independently, the spontaneously developed motor chunks that assemble a sequence might represent highly organized patterns (Verwey et al., 2009; Verwey & Eikelboom, 2003). Furthermore, it is not known yet if determining these patterns by pre-segmenting a sequence causes disadvantages. Thus, it is not clear yet if a complex keypress sequence should be practised with part or whole task practice.

Backwards and Forwards Chaining

Part task learning may take the form of forward chaining and backward chaining. Forward chaining involves practising the first segment of a behaviour first and then the later segments of the skill are added to the sequence (e.g. A - AB - ABC). Backward chaining involves practising the last segment of the behaviour first and adding the prior segments to the segments practised earlier[2] (e.g. C - BC- ABC; Smith, 1999).

Backward chaining's advantage as compared to forward chaining and whole task practice has been explained by operant conditioning by Skinner (1938). Accordingly, "it allows the learner to receive terminal reinforcement many times while learning the steps of the chain and helps the perception of how each part is related to the final product" (Wilcox, 1974, p.175). Importantly, it is different to forward chaining because the end product is kept prominent constantly which serves as reinforcement. Yet, operant conditioning may generally account for advantages for part task practice. When considering humans' goal-directedness, it may be "that the human learner can hold a long-term goal in mind and that this can act as a reinforcer for each stage in a task which the learner perceives as leading to that goal" (Wilcox, 1974, p.181). Moreover, it could be argued that with any type of part task training, reinforcement comes into play. Since, as by definition part task practice presents shorter segments that reach their goal quicker, a learner gets reinforced timelier and more often (Leslie & O'Reilly, 1999).

One disadvantage for backward chaining compared to forward chaining and whole task practice is that the natural sequence order may be distorted which may be more demanding when reassembling the segments (Ash & Holding, 1990). In conclusion, both types of chaining have advantages and disadvantages but there is no evidence to support the superiority of one approach over the other. This

[2] There are different ways of part task learning; the current study employs repetitive part learning because it has shown superiority to pure part and progressive part learning (Briggs & Naylor, 1962). Pure part learning means that the learner practices every sequence of a behaviour after each other and at the end combines them (e.g. A - B - C - ABC; Wightman & Lintern, 1985). Progressive part learning means that "each new part is practiced in isolation before it is added to any parts that have already been practiced" (e.g. A - B - AB - C - ABC; Wightman & Lintern, 1985, p.270).

may be because the advantages and disadvantages that got discussed in previous literature were highly dependent on that specific task and context (compare e.g. Ash & Holding, 1990; Smith, 1999; Wightman & Lintern, 1985; Wilcox, 1974). Hence, it should be explored which of these factors are more prominent for a serial motor task such as the DSP.

Current Research

Considering earlier results from DSP studies, when learning a sequence from the start to the end, the motor processor prepares the first parts of a sequence together and then the subject responds with individual responses to later stimuli. Thereby, connections within the first segments are more extensively practised and later segments are not prepared as a whole. With backward chaining, the last part is loaded in the motor buffer as a whole in the beginning and it is most extensively practised. Therefore, associations between the keys may develop sooner and mental representations are likely to develop quicker (Verwey et al., 2015). From that, it could be argued that because the last segment is more familiar, these representations of the last segments may then be prepared by the motor processor by loading it into the motor buffer with the first initiation already or, the concatenation might be quicker. Because of that, the overall RT is expected to be shorter in backward chaining compared to forward chaining and whole task practice.

In the current study, the differences between these practice types were investigated using the DSP task (Verwey, 2001; see also Abrahamse et al., 2013). The DSP task is a RT task based on a keyboard pressing task, with which underlying cognitive processes of motor learning can be explored (Abrahamse et al., 2013). To create a relatively complex task, participants practiced a 9-key sequence with forward chaining, backward chaining and whole task practice. To also assess later retention, participants got tested a second time one week later.

Methods

Participants

In total, 36 participants (Age: *M*=21.7 years, *SD*=1.8 years) took part in the experiment (17 male, 18 female, 1 non-binary). They were equally and randomly distributed over the experimental groups. All participants did not consume alcohol 24 hours prior to the experiment, had full control of their hands and were no heavy smokers. All subjects participated voluntarily and signed informed consent before the experiment (see Appendix A). The experiment was approved by the Ethics Committee of the Faculty of Behavioral, Management, and Social Sciences (BMS) at the University of Twente. Students of the BMS faculty could receive course credits (SONA points) for participation.

Materials

The experiment was conducted at the University of Twente, in a Flexperiment cubicle of the BMS lab. A computer running on Windows 10 was used and the DSP task was programmed in E-Prime 2.0. All unnecessary programmes and services were turned off so that the computer would have the best capabilities for measuring RT. The keyboard was QWERTY using a PS/2 connection. Unnecessary items were removed from the table. The screen was an AOC screen with a 144 Hz refreshing rate. Participants looked at the screen from approximately 50 cm distance. The windows and door were closed so that only minimal sound deflection could occur. The top light was always turned on to ensure the same lighting for every participant. Moreover, the curtain was closed by approximately three quarters so that some sunlight would come in but that differences in light could not distract the participants. With a GoPro camera, the participants were observed from outside the cubicle.

DSP Task

The computer screen displayed four boxes of 23 mm by 23 mm with a distance of 46 mm as representatives of the c, v, b, and n keys. These boxes lit up green as visual stimuli to indicate that the respective key should be pressed. The response-to-stimulus interval (RSI) was zero, meaning that once the key was pressed the new stimuli got presented immediately. In case an error was made, the participant needed to wait five seconds and the next trial started. If a key was pressed too early the participant was warned and could then continue with that trial.

The task consisted of a 9-key sequence constituted by the keyboard keys c, v, b, and n. Every sequence consists of 3 segments with 3 keys. The middle finger and index of the participants' left hand and right hand were assigned to the respective key on the keyboard. The subjects were explicitly asked to rest their fingers on these keys during the whole task. The fingers used for the sequence were counterbalanced among the sequence and the participants so that no individual finger difference could account for differences in RT.

As displayed in Table 1, the sequence was practised differently in every experimental condition. Each subject executed five blocks. To make sure that not a more extensive amount of practice per segment would account for differences in the learning effect the whole group received less practice in the first three blocks which, as in the other conditions, resulted in 120 repetitions per segment.

Table 1.

Visualization of an Example Sequence in Every Condition

Condition		Block 1: Practice	Block 2: Practice	Block 3: Practice	Block 4: Test	Block 5: Retention
	Repe-titions	20	20	20	5	15
Forward Chaining		vnb	vnb nvc	vnb nvc bcn	vnb nvc bcn	vnb nvc bcn
Backward Chaining		bcn	nvc bcn	vnb nvc bcn	vnb nvc bcn	vnb nvc bcn
	Repe-titions	13	14	13	5	15
Whole Task Practice		vnb nvc bcn	vnb nvc bcn	vnb nvc bcn	vnb nvc bcn	vnb nvc bcn

Procedure

Upon entrance into the lab, the participants were seated in front of the computer. First, they needed to fill out a form confirming that they followed the SARS-CoV-2 regulations which applied at that point in time. It was a reciprocal form ensuring them that the researcher also followed these measurements. Next, the participants received written and verbal information about the study. Then, they signed the informed consent form (see Appendix A). Following, they handed their phones and if applicable smartwatches to the researchers. After that, the first block was started by the experimenter and she then left the room. The participants were not informed about the experimental manipulations. At the beginning of the first block, the computer gave clear instructions about what the participant should do (see Appendix B). After completion of every block, the participants got to see their average response time in that block and the number of errors made. Then, every participant had a break of 60 seconds for which they were instructed to stay inside the room. Following that, the experimenter came back to turn on the next block until the first four blocks were finished. Seven days later (in exceptional cases six to eight days), the subjects came back for the fifth, retention, block. Interested participants received a debriefing.

Results

Reaction Time

Outliers were calculated and removed. The threshold for being an outlier was 2.5 SD from the mean. In total 2.2% of the data was removed. Furthermore, the trials in which an error was made were removed. Block one to three were excluded from the analysis because not all segments were practised in all conditions and thus, a comparison would not yield comparable results.

A 3 (Practice Group) x 2 (Block 4 vs. 5) x 9 (Keys) mixed design was analysed using a repeated measure ANOVA. Practice Group was measured as between-subject variables whereas Block and Key were within-subject variables. Since the Mauchly's Test of Sphericity was significant for the variable Key, $\chi^2(35)=102.420$, $p<.001$, and the Block*Key interaction, $\chi^2(35)=108.537$, $p<.001$, the sphericity assumption was violated, and thus, the degrees of freedom were corrected using the Greenhouse-Geisser transformation (Greenhouse & Geisser, 1959; Sheskin, 2011).

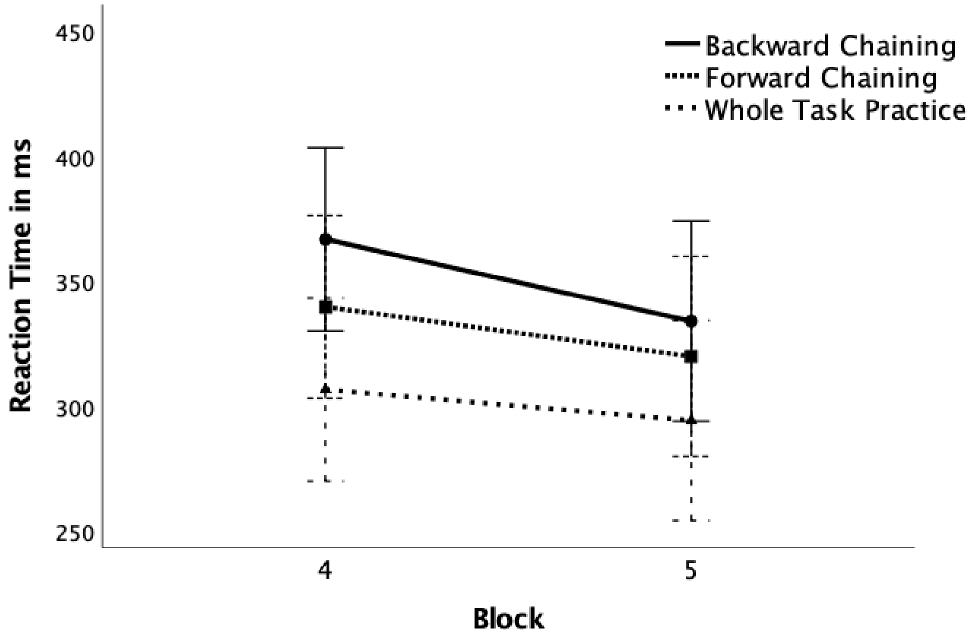
The main effect of Block showed that participants were significantly faster, $F(1,33)=13.32$, $p<.001$, $\eta_p^2=.29$, in the retention test (Block 5: *M*=338 ms, *SE*=10.57 ms) compared to the immediate test (Block 4: *M*=316 ms, *SE*=11.55 ms). The RT decrease in Block 5, relative to Block 4, was not different for the three Practice Groups, $F(2,33)=1.01$, $p=.375$, $\eta_p^2=.06$. This interaction is shown in Figure 1.

As the main effect of Key was significant, $F(4.574,150.951)=6.86$, $p<.001$, $\eta_p^2=.17$, the key location in the sequence affected the RT. The difference between Keys was not significant for the three Practice Groups, $F(9.149,150.149)=0.95$, $p=0.484$, $\eta_p^2=.05$. The Block*Key interaction was significant, $F(3.981,131.389)=3.18$, $p=.016$, $\eta_p^2=.09$, meaning that the effect of Key differed for the two blocks.

The main effect of PracticeGroup showed no significant difference between the practice groups, $F(2,33)=1.85$, $p=.17$, $\eta_p^2=.101$. The mean for Backward Chaining was 350.397 ms (*SD*=110.869 ms), for Forward Chaining 329.84 ms (*SD*=110.869 ms) and for Whole Task Practice 300.45 ms (*SD*=110.869 ms). Lastly, the interaction between Block*Key*PracticeGroup indicates that there was no significant difference between the conditions when accounting for the differences in Blocks and Keys, $F(7.963,131.389)=1.20$, $p=.30$, $\eta_p^2=.07$. Although not significant, Figure 2 shows a different pattern for Backward Chaining compared to the other two conditions. More specifically, Backwards Chaining had a peak in RT at Key 6 whereas the other conditions had the peak at Key 7.

Figure 1

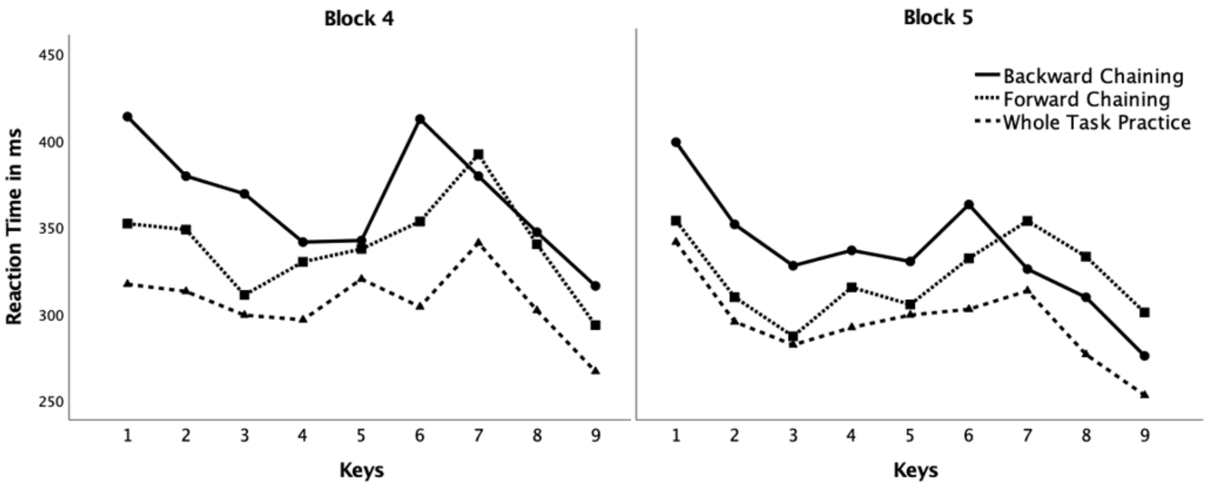
Mean RT (in ms) per Condition and Block



Note. The error bars show the Standard Error of the Mean.

Figure 2

Interaction of RT (in ms) for Practice Condition, Block and Key



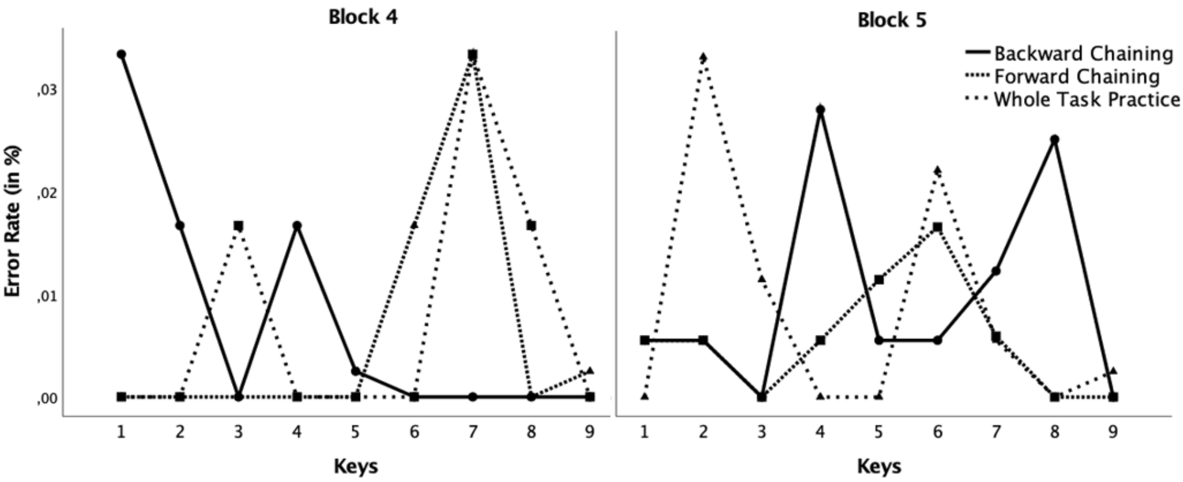
Note. Error bars are omitted to allow better visibility of the segmentation patterns used by the participants.

Error Rate

The error proportions were analysed after an arcsine transformation to normalize the distribution of the data. Besides that, the same analysis was conducted as with the RTs. Also here, Mauchly's Test of Sphericity indicated that the assumption of sphericity was violated, for Key, $\chi^2(35)=98.646$, $p<.001$, and Key*Block, $\chi^2(35)=75.359$, $p<.001$, and thus, a Greenhouse-Geisser transformation was used. Figure 3 shows the significant effect in the Block*Key*PracticeGroup interaction, $F(11.382,187.796)=2.05$, $p=0.025$, $\eta_p^2=.11$. Post hoc analysis revealed that there were fewer errors made with Whole Task Practice and Forward Chaining compared to Backward Chaining in Block 5 at Key 4, $F(2,33)=5.05$, $p=.012$, $\eta_p^2=.23$, and in Block 5 at Key 8, $F(2,33)=5.48$, $p=.009$, $\eta_p^2=.25$. Furthermore, although also not significant, Figure 3 indicates that participants in the Backward Chaining Condition made more errors in the beginning and fewer at the end compared to the other two conditions. However, this pattern vanished in the retention test.

Figure 3

Error Percentage per Practice Condition, Block and Key



Note. Error bars are omitted to allow better visibility of the interaction.

Discussion

Different types of practice have been found to affect the learning outcome (e.g. Fontana et al., 2009; Naylor & Briggs, 1963; Roessger, 2012; Wightman & Lintern, 1985; Wilcox, 1974). The present experiment tested the differences in learning between forward chaining, backward chaining and whole task practice. Considering the limits of the motor buffer, it was hypothesized that backward chaining would cause faster RT compared to forward chaining and whole task practice. Inconsistent with the hypothesis, the findings of the experiment showed no difference in RT between backward chaining, forward chaining and whole task practice.

Reaction Time

First, the RT results will be considered. Motor representations allow faster execution of motor movements (Verwey & Wright, 2014) and thus, it is likely that those would be required to account for differences between the practice groups. Hence, one reason for the non-significant difference may be that with the employed sequence and limited amount of practice, motor representations for the segments were not yet established. This confirms the notion that motor chunks only develop with extensive practice (Wymbs et al., 2012). Instead, it may be argued that central-symbolic representations have been established (Verwey et al., 2015). These representations are present long before motor chunks develop (Kovacs et al., 2009; Verwey et al., in press) because they are not grounded in slowly developing motor representations but rather "based on … low-level perceptual and/or motor representations" (Verwey et al., 2015, p.57). Kovacs et al. (2009) argue that multiple kinds of representation combined cause learning effects. Since in the current experiment no motor representations could develop, it can be argued that representations at the perceptual level alone (i.e. central-symbolic representations) were not sufficient to account for differences between the groups.

Moreover, the data for this sequence with this little amount of practice appears not to apply to the Naylor and Briggs (1963) hypothesis. On the one hand, the current results seem neither complex enough nor too complex so that whole or part task practice would be beneficial. Furthermore, it cannot be infered about the sequence's organization. It may have been that a key pressing sequence is high in organization because of the interrelation within motor chunks. The current results indicate that in early practice, the movements are not interrelated. This also indicates that no motor chunks were built yet. Taken together, the current research does not allow recommendations on whether whole or part task practice is beneficial for a nine-key sequence with the employed amount of practice.

Error Rate

Even though not predicted, it was found that the error rate was significantly different depending on the condition, key location and test phase. More specifically, participants performed better with whole task practice and forward chaining at key locations 4 and 8 compared to Backward Chaining after consolidation.

The current findings are somewhat in line with earlier findings. Smith (1999) found that forward chaining leads to fewer errors at the beginning of a task whereas backward chaining resulted in fewer errors at the end of the task. The number of errors was highest in the middle part, no matter if the outer segments were less or equally difficult. This somewhat contradicts our research because this experiment found that backward chaining showed equal error rates in the immediate test and higher error rates in the retention test especially in the middle (Key 4) and outer segment (Key 8). Thus, in short-term learning, people should consider that if the beginning should be flawless, forward chaining or whole task practice should be employed. If the end is considered more important, backward chaining should be employed.

Furthermore, literature commonly supports the view that consolidation enhances performance (e.g. Diekelmann & Born, 2010). Surprisingly in the present research, the accuracy remained mostly equal and even worsened in the Backwards Chaining Condition for Key 4 and 8. A potential explanation is that with backward chaining the natural order of the sequence was distorted and thus, participants could not develop a holistic picture of the sequence (Ash & Holding, 1990). Reconstructing the natural order of the sequence may be an additional demand on cognitive processes and may have caused that certain keys were not remembered. An indication of that is the significantly higher number of errors made at Key 4 only in the Backward Chaining Condition, which is the start of the second segment.

Moreover, a study by Watters (1990) found that in a keying sequence task, part task training with forward chaining resulted in fewer errors than with backward chaining. Whole task practice resulted in the most errors. These differences disappeared after 20 minutes but after another 5 days, participants in the Backward Chaining Condition showed worse results compared to both the Forward Chaining and Whole Task Condition (Watters, 1992). These latter results are in line with the present findings. This indicates that backward chaining may be generally more error-prone in the long term.

Hence, the already discussed results may be explained in two ways. It may be that the current amount of practice did not suffice to cause significant differences and/or the distortion of the natural sequence order may have caused a higher mental load. The latter would be a considerable disadvantage for backward chaining whereas the amount of practice can be subject to change.

Limitations and Suggestions for Further Research

Limitations of the two part task practice groups were that the whole sequence was only introduced relatively late, namely in the third block. According to van Merriënboer et al. (2003), part task practice alone is not enough if the information cannot be associated with the whole task. In a future experiment, the sequence should first be introduced as a whole in every condition so that the participant can form a holistic picture. For this approach, the participants should be informed about their practice group so that they can relate better to the whole sequence. In this way, participants may have a greater learning effect from forward and/or backward chaining (van Merriënboer et al., 2003). Furthermore, this way operant conditioning may be more effective for backward chaining because the participants have a better impression of what their ultimate goal is (Skinner, 1938).

Furthermore, it may be that the task itself was not complex enough so that significant differences between the conditions could appear. Part task practice is said to be only beneficial in complex tasks (Naylor & Briggs, 1963). The current sequence may still have been too simple. Thus, in a similar experiment, participants should practice a longer sequence with for example 16 or more key presses. Additionally, although the effect was not significant, Figure 2 indicates that the segments should be longer than three keys. The imposed segmentation pattern of three key segments was not found in the RT. Instead, segmentation seems rather spontaneous with a peak in RT at Key 6 in backward chaining but at Key 7 in the other two conditions which indicates relatively late concatenation. This indicates that in all conditions there were associations between the earlier keys, but the limit of the motor buffer was not yet reached with three keys per segment. Thus, future research should make use of four or even five key segments.

Additionally, Figure 2 shows a pattern that leaves room for speculation. Previous experiments indicated that a concatenation point usually indicates the start of a new motor chunk by a temporal increase in RT. In pre-segmented sequences, the increased RT occurs at the beginning of the predetermined subsequence (Verwey et al., 2009). Thus, it would be likely that concatenation occurs at the key at which a familiar sequence begins (i.e. for backward chaining at key 7). However, this was not the case for backward chaining. This may imply that backward chaining was more demanding and therefore, concatenation needed to occur earlier. Future research should investigate this unexpected finding more thoroughly.

Moreover, as argued above, with the limited amount of practice no motor representations could have developed yet and central-symbolic representations alone were not sufficient to account for differences between the practice groups. Concerning the error rate, the representations seemed at least not sufficiently established in the backward chaining condition to be retained after one week. This is also supported by the non-significant pattern in Figure 3 which indicates that backward chaining led to fewer errors at the end of the sequence whereas the reverse was the case for the other two conditions. As this pattern vanished in the retention test, it may be that the current amount of practice was not sufficient to create stable mental representations for the sequence. These would also be needed for significant differences between the conditions. Therefore, a further experiment should employ a higher number of repetitions per segment.

Despite the suggestions to improve this study design, these results may not be generalizable to other tasks. Almost any real-life task is more complex than a simple motor task such as the DSP (Rogers et al., 2001; Wulf & Shea, 2002). Additionally, the results are dependent on “characteristics such as chain type and chain length” (Wilcox, 1974, p. 2) and hence, it is expected that the proposed changes to the experiment would yield different results. Furthermore, these tasks usually do not regard the applied context and environmental influences that have shown to be relevant for learning (Brydges et al., 2007). Hence, the ideas presented above are limited to simple RT tasks.

Conclusion

In conclusion, this study could not confirm the hypothesis that backward chaining is more advantageous than forward chaining and whole task practice. Instead, backward chaining showed to be more error prone after consolidation at two key locations. The results are likely to be explained by the notion that no motor representations could form with the limited amount of practice employed. Furthermore, the central-symbolic representations were not sufficient for significant differences in RT to occur. Another explanation may be that the expected superiority of backward chaining was restricted because the reassembling of the segments was more demanding compared to learning the sequence in a natural order. There are several limitations associated. Thus, a follow-up study should be conducted in which participants in all conditions are first exposed to the whole sequence so that they can form a holistic picture of it. Additionally, they should be informed about their experimental condition to place the relationship between the segments better. Moreover, the sequence and segment length should be extended to create a more complex practice task. Lastly, the amount of practise should be increased so that more mental representation can develop. Still, the presented results and implications are limited to a simple RT task such as the DSP with a 9 key sequence with 3 key segments and a limited amount of practice.

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Appendix A.

Consent Form for Motor learning with discrete sequence procedure
YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**
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, whereby after 100 keystrokes my performance will be measured. Afterwards, I am allowed to take a break of 5 minutes. At the end, a final recording of my performance will be made. After the experiment I will have to fill out a survey with my experience in similar skills and my demographics.	□
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.	□
Use of the information in the study	
I understand that information I provide will be used for a students bachelor thesis. They 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 my name or personal characteristics, will not be shared beyond the study team.	□
Future use and reuse of the information by others	
I give permission for the deindividualized 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 potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

__Carolin Schneider__________ _____________________ ________

Researcher name Signature Date

Study contact details for further information: Carolin Schneider, c.h.c.schneider@student.utwente.nl

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

Appendix B.

Screen Instructions of the DSP task

Welcome to this experiment!

--> Read this instructions carefully

The goal of this experiment is investigating how people practice a key pressing sequence. To that end, you will practice in 4 successive blocks, and return next week for some further testing.

Please remain seated until the experimenter says otherwise…

(press the SPACE bar to continue)

Now, rest your fingers on the following keys

Left middle and index fingers, right index and middle fingers on keys C, V, B, en N, respectively

Do not use other fingers.

During each block, leave your fingers on the keys when you are not pressing

(press the SPACE bar to continue)

This is how the squares look like. Here, the letters indicate the keys to press (these will not be displayed).

If one square gets a color, press the corresponding key. Do NOT press before the square lights up.

(press the SPACE bar to continue)

The experiment starts now.

Be fast but limit your errors: More errors means more waiting so that the experiment will take longer for you.

Now, make sure the indicated fingers are resting on the CVBN keys….

(press the SPACE bar to continue)