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## Chapter 5

### **Interference effects in learning similar sequences of discrete movements**

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**Abstract**

Three experiments were conducted to examine pro- and retroactive interference effects in learning two similar sequences of discrete movements. In each experiment, the participants in the experimental group practiced two movement sequences on consecutive days (one on each day, order counterbalanced across participants) followed by retention tests on the third day. Two out of eight target locations differed between the two sequences. Experiment 1 established the nature of the interference effects in the current set-up. Clear evidence was found for button-specific pro- and retroactive interference effects. Experiments 2 and 3 further probed the mechanisms underlying those effects, by varying the numbers of repetitions (50 or 250) of the first and second sequence (Experiment 2) and the hand, dominant or non-dominant, with which the sequences were practiced (Experiment 3). Experiment 2 showed that after a mere 50 repetitions the representation of the movement structure was strong enough to evoke the effects observed in Experiment 1. Experiment 3 revealed that learning with the dominant hand did not result in more pronounced interference effects compared to learning with the non-dominant hand. In combination, these results suggest that changes in the representation of the movement structure are primarily responsible for the observed interference effects.

## Introduction

In human motor behavior, many skilled actions require the sequential planning and execution of a series of movements. This is not only the case for inherently sequential actions like typing, speaking or writing, but also for everyday tasks like picking up a cup of coffee or athletic performances such as taking a basketball free throw or doing a Fosbury flop. Research on sequential learning has focused on various aspects, including underlying knowledge structures (e.g., Brown & Robertson, 2007; Willingham & Goedert-Eschmann, 1999), movement dynamics (e.g., Sosnik, Hauptmann, Karni, & Flash, 2004), and transfer to other configurations (e.g., Dean, Kovacs, & Shea, 2008; Wilde Braden, Panzer, & Shea, 2007; Wilde & Shea, 2006). An important phenomenon in sequence learning is that similar sequences may interfere with each other. For example, when someone is used to typing on an English qwerty-keyboard, switching to the French azerty- or the German qwertz-keyboard can lead to great frustration. After having typed for a while on one of the alternative keyboards, returning to the qwerty-keyboard can also give rise to problems. Thus, performance on one task can lead to suboptimal performance on a slightly different task as a result of interference between competing movement responses. This effect can be highly undesirable in situations where two similar movement sequences have to be performed without interference, such as playing similar parts in music, typing words with similar begin letters, or employing different techniques in sports. In addition, when a certain movement sequence leads to suboptimal performance, such as when new materials, instruments, or regulations are introduced, the influence of the old sequence on learning and performing a new sequence may also be undesirable. In spite of the theoretical and practical importance of studying interference effects in perceptual-motor sequence learning, research on the mechanisms underlying those interference effects has been relatively scarce (Panzer & Shea, 2008; Panzer, Wilde, & Shea, 2006).

Interference effects in cognitive tasks have been studied since the 1950s by among others Underwood (1957), Brown (1958), and Peterson and Peterson (1959). It is generally assumed that interference is the result of the limited capacity of the brain for consolidating and retrieving processed information. Broadly speaking, two types of interference effects are distinguished, proactive interference (also referred to as anterograde interference) and retroactive interference (or retrograde interference). Proactive interference is the influence of existing information (or knowledge structures) on consolidating new information, for example when familiarity with the position of certain keys on the qwerty-keyboard interferes with learning to type on an azerty-keyboard. In most cases this influence will be facilitative as keys that are in the same position are typed faster by experienced

typists compared to absolute beginners. Proactive interference can also be debilitating, as is the case when keys on different locations cause slower or incorrect performance. For instance, certain automated words, such as names or passwords, may be performed incorrectly when switching to an unfamiliar keyboard. Retroactive interference is interference from new information on the retrieval of existing information, for example when returning to a qwerty-keyboard after a period of typing on an azerty-keyboard. In most cases this would have a debilitating effect, as two different responses (different key locations) are coupled to the same stimuli (typing the same word). Adaptation of certain keys to new locations could result in incorrect or slower performance on a task that was previously performed with ease and without errors.

In early work on perceptual-motor interference it has been argued that the occurrence of retroactive interference is dependent on the time interval between the learning of two similar tasks (Bunch, 1946) and the amount of learning of the second task (Lewis & Miles, 1956). Conversely, Adams (1987) argued that increasing the amount of learning of the first task leads to increased sensitivity to retroactive interference. Recently, Panzer and colleagues (Panzer & Shea, 2008; Panzer et al., 2006) studied interference effects in learning similar movement sequences. In the study of Panzer et al. (2006) participants learned a first sequence consisting of sixteen subsequent movements between several target lights using the right arm holding a lever. On the next day, two movements within the sequence were reversed, while on a third day the sequences learned on the first and second day were performed. Panzer et al. found that learning the second sequence resulted in retroactive interference effects in retention performance of the first sequence with respect to the changed movements between the sequences. They concluded that the memory structure supporting the production of a movement sequence is essentially overwritten when another, similar movement sequence is learned.

Using essentially the same experimental set-up, Panzer and Shea (2008) found that when the first sequence is learned with twice the number of repetitions spread out over two days, this movement-specific retroactive interference effect is no longer observable. Apparently, the additional practice prevented the first sequence from being overwritten. Similarly, Panzer et al. (2006) showed that learning the second sequence was only facilitated by having learned the first sequence for a very short period of learning and that the facilitative effect was washed out in retention performance on the third day. Panzer and Shea (2008) found that two days of learning the first sequence with twice the number of repetitions resulted in a lasting proactive facilitative effect on the learning of the second sequence. To explain these findings Panzer and Shea (2008) concluded that “the stronger of two similar movement sequences exerts an influence on the weaker sequence and not vice

versa” (Panzer & Shea, 2008, p. 886). The logical next step would be to uncover when, where, and how such influence would be exerted. As it stands, however, little is known about how the underlying memories of similar movement sequences interact and what elements of sequential movement execution are responsible for the observed interference.

Therefore, in the current study we sought to shed more light on when, where, and how pro- and retroactive interference effects between similar movement sequences occur. As regards the production of single movement sequences, it has been argued that sequential performance is hierarchically structured and that sequence information pertaining to the structure of the movement sequence (in short, movement structure) is stored independently of the actual production of the movement, which is represented in effector-specific information (in short, movement dynamics; Bernstein, 1996; Lashley, 1951; Park & Shea, 2002; Rosenbaum, 1990). The structure of a single movement sequence appears to be coded in a relatively abstract way and controlled and executed on a higher neural level than the actual forces produced by the effector system. It has been argued that the structure of the movement sequence (i.e., the abstract, effector-independent representation) must be developed before enhancing the movement dynamics so as to refine movement execution (Lai, Shea, Wulf, & Wright, 2000; Wilde Braden et al., 2007).

In learning two or more similar movement sequences, the movement structures are largely similar yet different in a number of respects, either spatially, for instance through differences in target location, or temporally, for instance through differences in overall timing, such as when playing a musical piece at different tempi. As a result, the movement structures may interfere either because the structure of the sequence learned first is overwritten by the second structure or because the second structure is more salient than the other as it was more recently practised (Panzer et al., 2006; Panzer & Shea, 2008). The theoretical framework used for single sequences (the distinction between structure and dynamics) might provide theoretically and practically relevant insights into the occurrence of interference effects between two (similar) sequences. Theoretically, it would extend our understanding of how similar movement sequences are consolidated and retrieved from memory. Practically, insight into the underlying mechanisms of learning similar sequences may provide starting points for teaching and instructing how to learn similar movement sequences in an optimal way, whether it be in the fields of music, sports, rehabilitation, ergonomics, or in other settings.

In each experiment of the present study participants practised two sequences of discrete movements to large buttons on a panel, with the notable exception of the control group in Experiment 1 who practised only one sequence. In the studies of

Panzer et al. (2006) and Panzer and Shea (2008) the sequences learned on the first and second day were not counterbalanced. It is therefore conceivable that their results were confounded by the possibility that one of the sequences was easier to perform than the other. Close inspection of absolute movement times of the first and second learned sequences in Panzer et al. (2006) reveals that the control group performing only the second sequence (S2) performed it faster than the control group who only practiced the first sequence (S1), which may suggest that S1 was indeed more difficult. Panzer and Shea (2008) tested the same sequences and in the same order. Strikingly, the ‘difficult’ sequence of Wilde Braden et al. (2007) was exactly the same as S1 in the studies of Panzer et al. and Panzer and Shea (2008), while the ‘easy’ sequence was conspicuously similar to S2 of those studies. By counterbalancing both to-be-learned sequences between S1 and S2 possible effects of differences in difficulty were eliminated in the present study.

Furthermore, by using discrete button-press movements rather than continuous movements we could easily and unambiguously determine the movement durations from one button to the next. The aim of the first experiment was to establish how similar movement sequences interfere using a sequence of discrete movements, thereby providing an empirical foundation and reference point for Experiments 2 and 3. In Experiment 2 we sought to gain more insight into how an asymmetrical distribution of practice (i.e., learning the two sequences with unequal numbers of repetitions) influences the interference effects in learning and performing similar movements, thus picking up on a major theme from the studies of Panzer et al. (2006) and Panzer and Shea (2008). The purpose of Experiment 3 was to explore the possible differential roles of movement structure and movement dynamics in the occurrence of interference effects. To this end, we included two different groups; one group who learned with the dominant hand and another group who learned with the non-dominant hand, thereby manipulating the effector dynamics indirectly as the dominant arm is known to be a more proficient effector than the non-dominant arm (Sainburg, 2002; Sainburg & Kalakanis, 2000). Admittedly, this does not fully separate the effects of structure and dynamics as it is possible that dominant hand learning is also accompanied by a stronger internal representation of the structure than learning with the non-dominant hand. However, there have been several studies indicating that the acquisition of abstract motor representations generalizes across hands, which renders this possibility less likely (Park & Shea, 2002; Wilde, Magnuson, & Shea, 2005).

The hierarchical structure for the production of single movement sequences would predict that the movement structure is leading in the occurrence of interference effects and that the effector dynamics plays a subordinate role. More specific predictions regarding the respective roles of movement structure and

movement dynamics in interference effects are provided locally in the introduction of each experiment.

## **Experiment 1**

The main aim of Experiment 1 was to establish the nature of the proactive and retroactive interference effects in learning two similar, discrete movement sequences with an equal amount of practice. Following the results of Panzer et al. (2006), we expected to observe short-term proactive facilitation effects. For the retroactive interference effects we also expected to find retroactive interference effects similar to those found by Panzer et al. (2006), that is, movement-specific interference effects on the changed movements.

## **Method**

### *Participants*

Twenty-four individuals (10 men, 14 women), between 18 and 27 years of age ( $M = 20.6$ ,  $SD = 2.2$ ), participated in the experiment after having given their written informed consent. The participants had no previous experience with the experimental task and were all self-reported right-hand dominant. The study was approved by the ethics committee of the research institute before it was conducted.

### *Apparatus*

The apparatus consisted of a specially designed wooden panel ( $0.70 \times 0.40 \times 0.11$  m) with thirteen large buttons ( $\varnothing 63$  mm  $\times$  18 mm height; Buddy Button, RDG Kompagne, Enschede, the Netherlands), with a small Light Emitting Diode (LED) under each button. Twelve blue buttons were possible target buttons and one red button was the start/stop button (see Figure 5.1). The panel was connected to a standard PC and ran on a Labview 8.0 application controlling the LEDs to independently light up. Furthermore, the moment at which a specific button was pressed was registered at 1000 Hz and processed further using custom made software (Matlab 6.5) to compute movement times between buttons, that is, the times between the onset of one button press and the onset of the next button press in the sequence.

### *Design*

Participants were randomly divided into two groups, an Experimental Group (EG) and a Control Group (CG). The EG practised a first sequence (S1) on the first day, a similar second sequence (S2) on the second day and performed both sequences on the third day to establish retention performance and interference between the sequences learned on the first two days. The CG only performed S1 on the first and



### *Interference effects in learning*

on the third day. Comparing performances of the EG and CG allowed for the delineation of the retroactive interference effect of learning the second sequence on reperforming the first sequence from the effects of the elapsed time between consecutive performances.

#### *Procedure*

Participants were instructed to perform a movement sequence as fast as possible without making errors by hitting the button that corresponded to the illuminated LED. After a signal from the experimenter, the participants initiated the movement sequence by hitting the start button. After hitting the start button, the first LED in the sequence immediately went on. Only after hitting the correct target button this LED was switched off and the LED corresponding to the next target button switched on. Participants of both groups learned S1 on Day 1 by executing 5 blocks of 30 repetitions and 5 extra ‘last block’ repetitions, for a total of 155 repetitions. We calculated average movement times of the first 5 trials of each block and of trials 151-155. Participants of the EG learned S2 on the next day (Day 2) following the same procedure as on Day 1. On Day 3 participants of the EG were tested on both sequences, first on S2 and then on S1 (each test consisting of five repetitions). Participants of the CG were not active in the experiment on Day 2 and performed only S1 on Day 3. As participants of the EG performed a block of five repetitions of S2 before S1 on Day 3, the CG received five warm-up trials before commencing with the actual retention test.

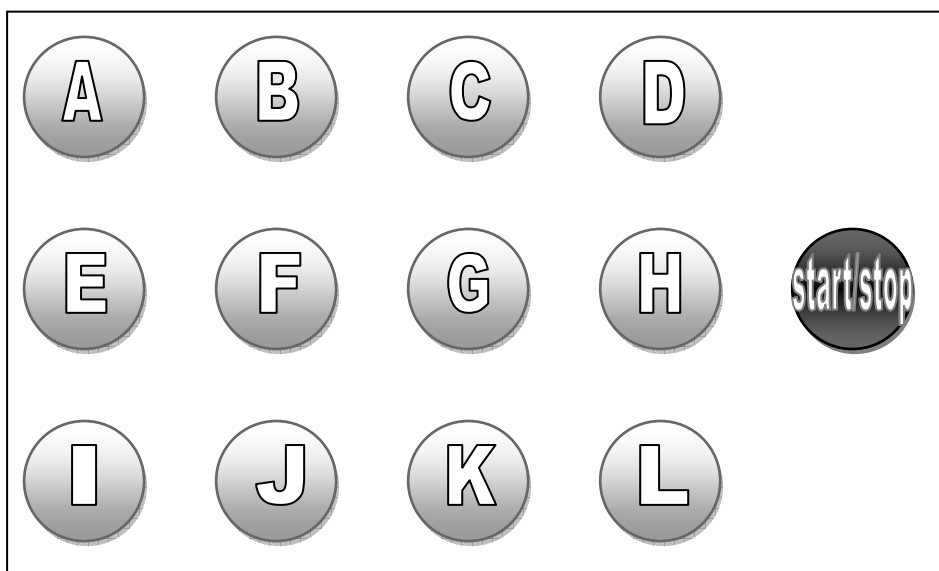


Figure 5.1. The experimental set-up and buttons with corresponding letters.

### *Sequences*

Participants of the EG were required to learn two different movement sequences. Both sequences consisted of consecutively pressing eight target buttons resulting in eight consecutive movements, with the first movement being the movement from the start button to the first target button (referred to as Button 1 in the remainder of the text and in all figures), the second movement being the movement from Button 1 to the second target button (Button 2), and so on, up to the movement from Button 7 to 8. The sequences differed on two buttons, that is, Buttons 4 and 5, effectively changing the movements to Buttons 4, 5, and 6. Although in the movement to Button 6 the target button remained the same, the button from which the movement had to be initiated was different. The two changed buttons were mirrored to keep the between-button distances equal over the sequences and to create two sequences of comparable difficulty. Figure 5.1 shows the locations of the target buttons. One sequence consisted of subsequently pressing buttons I-D-F-B-K-H-A-L, whereas the other sequence consisted of pressing buttons I-D-F-J-C-H-A-L. These two sequences were counterbalanced with regard to which sequence was learned on Day 1 (S1) and which sequence was learned on Day 2 (S2). Participants of the CG performed only S1 on Day 1 and on Day 3. The two possible to-be-practised sequences were counterbalanced within the CG.

### *Dependent variables and measurements*

The movement times between hitting consecutive buttons were the dependent variables. Button times were averaged over the five recorded trials for each block and test. To test for proactive effects the recorded button times of the six acquisition blocks for both sequences of the EG were compared. To test for retroactive interference effects, we compared retention performance of the EG and CG of S1 on Day 3 with that of S1 at the end of Day 1 as this comparison was informative about the retroactive effects of having learned S2 on the renewed execution of S1. Effect sizes were calculated using Cohen's  $f$  (Cohen, 1988). By convention, a Cohen's  $f$  of 0.10 represents a small effect, an  $f$  of 0.25 a medium effect, and an  $f$  of 0.40 a large effect (Cohen, 1988). To evaluate differences between blocks and tests, ANOVAs with repeated measures on block and test were performed. If the sphericity assumption was violated, either the Huynh-Feldt correction (if Greenhouse-Geisser's epsilon < .75) or the Greenhouse-Geisser correction (if Greenhouse-Geisser's epsilon > .75) was used (Girden, 1992). Post hoc pairwise comparisons on the main effects were all Bonferroni corrected.

## Results

### Proactive interference

To test for proactive effects for both sequences the button times over the six acquisition blocks were compared. To this end, a Sequence (S1, S2)  $\times$  Block (1-6)  $\times$  Button (1-8) ANOVA was performed on button times with repeated measures on all three factors. It yielded significant main effects of sequence,  $F_{1,12} = 41.33$ ,  $p < .001$ ,  $f = 1.85$ , block,  $F_{1.82, 21.86} = 198.710$ ,  $p < .001$ ,  $f = 3.96$ , and button,  $F_{73.13, 37.57} = 40.89$ ,  $p < .001$ ,  $f = 1.85$ , as well as significant Sequence  $\times$  Block,  $F_{2.21, 26.52} = 64.39$ ,  $p < .001$ ,  $f = 2.29$ , Sequence  $\times$  Button,  $F_{4.67, 57.22} = 6.17$ ,  $p < .001$ ,  $f = 0.72$ , and Block  $\times$  Button,  $F_{4.26, 51.18} = 6.46$ ,  $p < .001$ ,  $f = 0.73$ , interaction effects. All these effects were superseded by a Sequence  $\times$  Block  $\times$  Button interaction,  $F_{4.77, 57.22} = 5.13$ ,  $p < .001$ ,  $f = 0.65$ . Post hoc comparisons on the Sequence  $\times$  Block  $\times$  Button interaction indicated that on Block 1 all button times, except that for Button 5, were significantly faster on S2 than S1 (see Figure 5.2 for short-term proactive interference effects). This tendency of Button 5 to show no facilitative effect on learning S2 was repeated on the following blocks. Thus, the proactive facilitation effect did not apply equally to all buttons, implying that the proactive effects were button-specific.

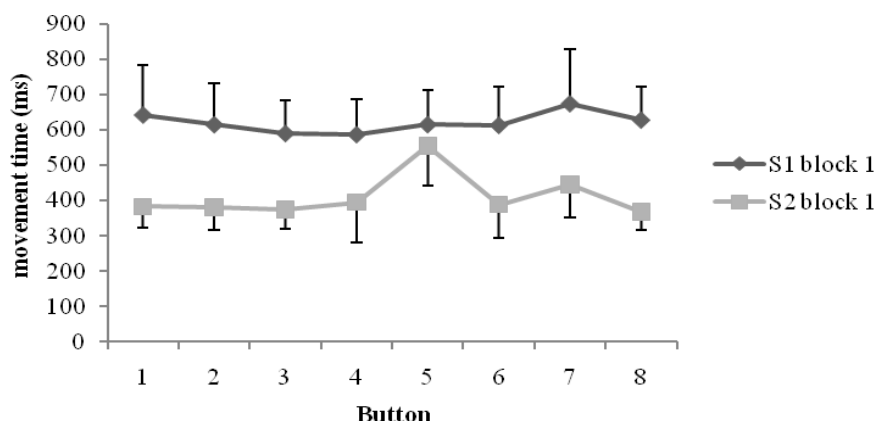


Figure 5.2. Averages and standard deviations across subjects of movement times of Blocks 1 of both S1 and S2 for the EG to illustrate the short-term proactive effects.

### Retroactive interference

To test for retroactive interference effects, we compared retention performance of S1 on Day 3 with performance of S1 at the end of Day 1 across groups. This comparison sheds light on the retroactive effect of S2 on the renewed execution of S1. Therefore, a Group (EG, CG)  $\times$  Sequence (S1 Day 1 last block, S1 Day 3)  $\times$  Button (1-8) ANOVA was performed on button times with repeated measures on both factors. It yielded significant main effects of sequence,  $F_{1,22} = 11.60$ ,  $p < .01$ ,  $f$

= 1.14, and button,  $F_{3.44, 75.62} = 28.33$ ,  $p < .001$ ,  $f = 0.72$ , a significant Sequence  $\times$  Button interaction,  $F_{3.69, 81.15} = 3.34$ ,  $p < .05$ ,  $f = 0.32$  and near-significant interactions between group and sequence,  $F_{1, 22} = 2.92$ ,  $p = .10$ ,  $f = 0.36$  and group and button,  $F_{3.44, 75.62} = 2.10$ ,  $p = .08$ ,  $f = 0.30$ . However, all these effects were superseded by a significant Group (EG, CG)  $\times$  Sequence  $\times$  Button interaction,  $F_{3.69, 81.15} = 2.94$ ,  $p < .05$ ,  $f = 0.36$ .

Pairwise comparisons revealed that movements to Buttons 3, 4, 5, 6 and 7 were significantly slower on Day 3 ( $ps < .05$ ) compared to Day 1 for the EG, whereas all movements for the CG were performed equally fast on Day 1 and Day 3 (all  $ps > .17$ ). This suggests button-specific retroactive interference effects caused by the learning of S2 on the changed buttons, but also on the buttons directly before and after the changed buttons (see Figures 5.3a and 5.3b).

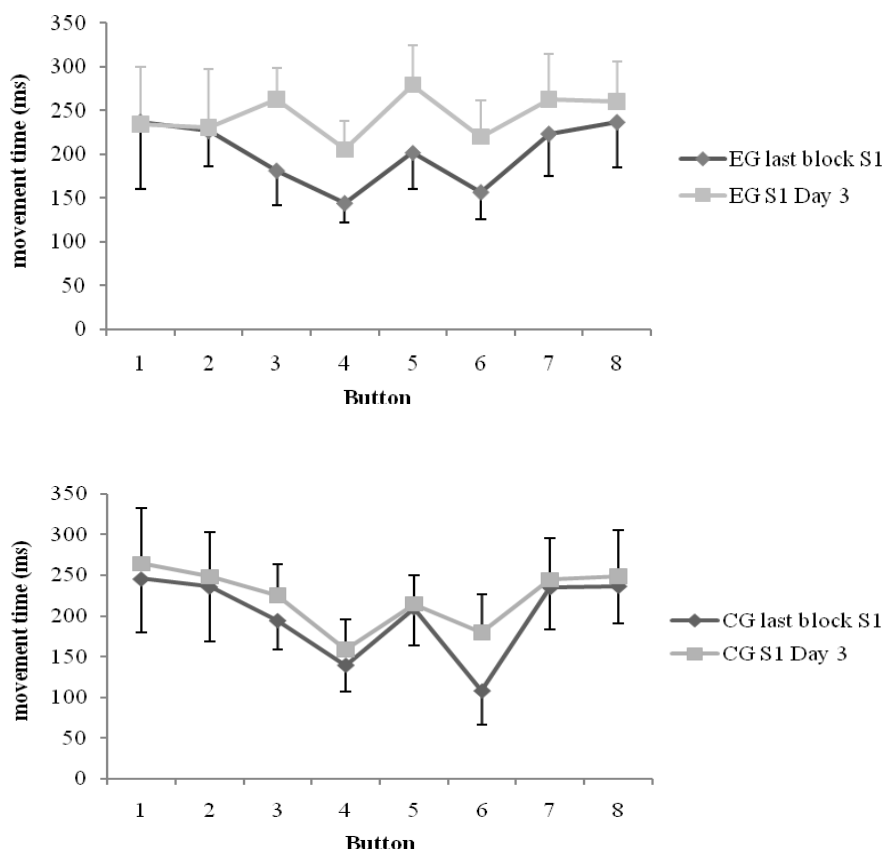


Figure 5.3a and 5.3b. Averages and standard deviations across subjects of movement times of S1 Block 6 Day 1 and S1 Day 3 for the EG and CG to illustrate the retroactive effects.

## Discussion

The results of Experiment 1 revealed a button-specific proactive effect of having learned S1 on learning S2 as the movements to all but one buttons were executed faster when learning S2. Interestingly, this button-specific proactive effect was not

limited to the unchanged parts of the sequence but extended to the changed movements to Buttons 4 and 6 that were unexpectedly also performed faster without previous practice. It appears therefore that this proactive effect cannot be fully attributed to changes in the representation of the movement structure. One possibility is that the dynamics of the effector system also contributed initially to this facilitative effect. Thus, the button-specific proactive facilitative effect was probably caused by a general facilitative effect, countered by button-specific interference on some of the changed movements.

We also found button-specific retroactive interference effects for the experimental group, but in contrast to the findings by Panzer et al. (2006) these effects were not restricted to the changed movements between the first and second sequence. As expected, button times to Buttons 4, 5, and 6 were slower on Day 3, in line with the movement-specific interference effects found by Panzer et al. Surprisingly, also movement times to Buttons 3 and 7 were slower for S1 on Day 3, suggesting that not only the movements to the changed buttons, but also performance of the movements to buttons that were pressed right before and right after the changed buttons degraded as a result having learned the second sequence. Furthermore, we found a significant main effect of Button in the ANOVAs testing for proactive and retroactive interference effects. Different distances between subsequent buttons within a sequence are likely to account for this effect.

It can be concluded that our discrete task seemed to yield similar interference effects as were observed in the continuous task employed by others (Panzer et al., 2006; Panzer & Shea, 2008) in the sense that changing the movement structure resulted in movement-specific interference effects. In the case of the retroactive effects, these effects were not restricted to the changed movements but also involved movements to unchanged buttons that were pressed right before and right after the changed buttons. Inclusion of a control group showed that the retroactive effects were indeed caused by the learning of the second sequence and not by potentially confounding factors such as the elapsed time between execution of S1 on Days 1 and 3. In the case of proactive effects, they did not only involve unchanged movements but also changed movements. A plausible explanation for these findings is that subsequent movements were chunked (Jimenez, 2008; Koch & Hoffmann, 2000; Povel & Collard, 1982; Verwey, 1994; Wilde, Magnuson & Shea, 2005). As a result of chunking, some movements from one button to the next have stronger links than other movements between consecutive buttons in the sequence. Therefore, trying to break up the sequence can result in a disruption at a weaker link before or after the actual change. Evidence of chunking within the current retroactive interference effects provides further support for the suggestion that the movement structure is leading in performance degradation when re-performing an

old movement sequence after having learned a similar new one.

## **Experiment 2**

In Experiment 1 we found button-specific pro- and retroactive interference effects similar to those found by Panzer et al. (2006). The aim of Experiment 2 was to examine the effect of an asymmetrical distribution of practice (i.e., learning the two sequences with unequal numbers of repetitions) on the observed proactive and retroactive interference effects. Note that the combined results of the studies of Panzer and Shea (2008) and Panzer et al. (2006) suggest that a relatively small amount of additional practice may have marked influences on the observed interference effects (i.e., for the retroactive effect overwriting vs. full access of the first sequence and no lasting proactive facilitation vs. clear long-lasting proactive facilitation). Similarly, Ghilardi, Moisello, Silvestri, Ghez, and Krakauer (2009) demonstrated that prolonged training of a first sequence increased resistance to interference by a second learned sequence. To examine those influences in greater detail in a single experiment, we included an experimental group who learned the first movement sequence with a relatively large number of repetitions (250), followed by a relatively small number of repetitions (50) for the second sequence. We compared this group with a second experimental group who learned the first sequence with a relatively small number of repetitions (50) and the second with a relatively large number of repetitions (250). When a sequence is learned with few repetitions, this is likely to result in a relatively weak memory representation compared to a sequence learned with markedly more repetitions. In view of the findings of Panzer and Shea (2008), we expected that learning a first sequence with a large number of repetitions would result in a stronger memory representation compared to learning a sequence with a small number of repetitions. Under such conditions retroactive interference effects would be minimal compared to when a weaker representation (small number of repetitions) is followed by a relatively large number of repetitions. For the proactive effects we expected that longer initial learning would lead to more proactive facilitation when learning a second sequence compared to a short period of initial learning. As we were primarily interested in the comparison between the two experimental groups, we did not include a control group. After all, the results of Experiment 1 already demonstrated that retroactive interference effects occur in the experimental set-up used and that comparing the last block of S1 with performance of S1 on Day 3 is a suitable method to for establishing those effects.

## **Method**

### *Participants*

Twenty-four individuals (12 men, 12 women), between 18 and 27 years of age ( $M = 22.6$ ,  $SD = 2.6$ ), participated in the experiment after having given their written informed consent. The participants had no previous experience with the experimental set-up. They were randomly assigned to either the Long-Short (LS) group or the Short-Long (SL) group.

### *Apparatus*

The experimental set-up was the same as in Experiment 1.

### *Design, Procedure and Sequences*

The design was changed slightly compared to that used in Experiment 1. We used a different sequence to extend the findings of Experiment 1 by changing movements to Buttons 4 and 7 between the sequences. By altering the sequence we avoided capitalizing on effects that might have been specific to a certain set of movements within a particular sequence. The sequences consisted of sequential movements to button locations I-D-F-C-E-G-J-H and I-D-F-K-E-G-B-H (see Figure 5.1). These sequences were again counterbalanced according to which sequence was learned on Day 1 and Day 2. The LS group performed S1 on Day 1 for a total number of 250 repetitions in 10 blocks of 25 trials. The average movement times of the first five trials of Block 1 and the average movement times of the last five trials of each block were analyzed (11 blocks in total). The LS group learned S2 on Day 2, but only two blocks of 25 trials for a total of 50 trials. Again the average of the first five trials and the last five trials of each block were used for analysis. The SL group followed the reverse protocol, with 2 blocks of 25 trials of learning S1 and 10 blocks of 25 trials for S2. On Day 3, participants first performed five trials of S2 and then five trials of S1. Otherwise the procedure was identical to Experiment 1.

### *Dependent variables and measurements*

Data were gathered and analyzed in a similar manner as in Experiment 1.

## **Results**

### *Acquisition*

As we had a disproportional number of learning blocks, we were not able to perform a full ANOVA over all learning blocks of both groups. To establish that the 200 more repetitions indeed led to improved movement dynamics as hypothesized, we compared the first block of S1 with the last block of S1 for both groups. Therefore, a Group (LS, SL)  $\times$  Sequence (S1 Block 1, S1 last block)  $\times$  Button (1-8)

ANOVA was performed on average button times with repeated measures on sequence and button. It yielded significant main effects of sequence,  $F(1, 22) = 429.06$ ,  $p < .001$ ,  $f = 4.36$  and button,  $F(5.10, 112.19) = 8.19$ ,  $p < .001$ ,  $f = 0.61$ , as well as a significant Sequence  $\times$  Button interaction,  $F(5.65, 124.31) = 7.28$ ,  $p < .001$ ,  $f = 0.58$ , a marginally significant Group  $\times$  Button interaction,  $F(5.10, 112.19) = 2.15$ ,  $p = .064$ ,  $f = 0.31$ , and, importantly, a significant Group  $\times$  Sequence interaction,  $F(1, 22) = 6.05$ ,  $p < .05$ ,  $f = 0.52$ . Pairwise comparisons for the latter interaction revealed that on Block 1 both groups performed equally well (LS:  $M = 623$ ,  $SD = 105$ ; SL:  $M = 598$ ,  $SD = 111$ ) but that at the end of Day 1 the LS group performed significantly faster than the SL group (LS:  $M = 185$ ,  $SD = 36.0$ ; SL:  $M = 253$ ,  $SD = 49.6$ ). Indeed, 200 more repetitions led to faster performance and thus improved movement dynamics.

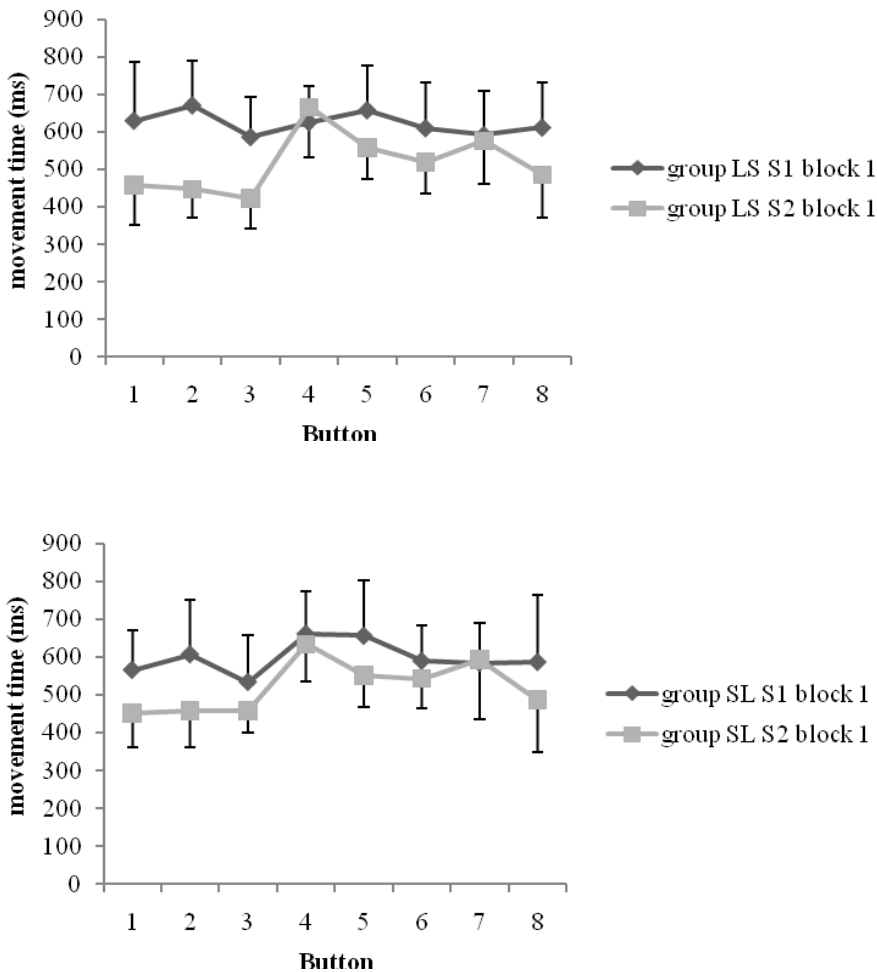
### *Proactive interference*

Again, the disproportional number of learning blocks did not allow conductance of a full ANOVA over all learning blocks of both groups. Therefore, we only compared the first block of S1 and S2 to test for immediate proactive effects. By comparing Block 1 of Day 1 with Block 1 of Day 2 of both groups we could study the effect of a stronger memory representation, that is, 200 extra repetitions of learning, on the acquisition of a similar sequence. A Group (LS, SL)  $\times$  Sequence (S1 Block 1, S2 Block 1)  $\times$  Button (1-8) ANOVA was performed on average button times with repeated measures on sequence and button. It yielded significant main effects of sequence,  $F(1, 22) = 34.61$ ,  $p < .001$ ,  $f = 1.25$ , and button,  $F(4.77, 104.94) = 21.51$ ,  $p < .001$ ,  $f = 0.98$ , which were qualified by a significant Sequence  $\times$  Button interaction,  $F(4.08, 89.27) = 9.62$ ,  $p < .001$ ,  $f = 0.79$ . Pairwise comparisons revealed that all button times were faster for S2 compared to S1 (all  $ps < .01$ ), except movements to Buttons 4 and 7 ( $ps = .805$  and  $.917$ , respectively). Buttons 4 and 7 were the buttons of S2 that were different from the corresponding parts of S1.

Thus, the results demonstrated a button-specific proactive facilitative effect for the movements that remained unchanged from S1 to S2, but not for the two buttons that were different from S1 to S2. Surprisingly, no effect of group was present, indicating that these proactive effects were not different when 200 more repetitions of S1 were performed (see Figures 5.4a and 5.4b). Additional analyses demonstrated that the proactive facilitative effects remained similar over Blocks 2 and 3 of both S1 and S2 between both groups.



## Interference effects in learning



Figures 5.4a and 5.4b. Averages and standard deviations of movement times across subjects of Blocks 1 of both S1 and S2 for the LS- (5.4a) and SL group (5.4b) to illustrate the short-term proactive effects.

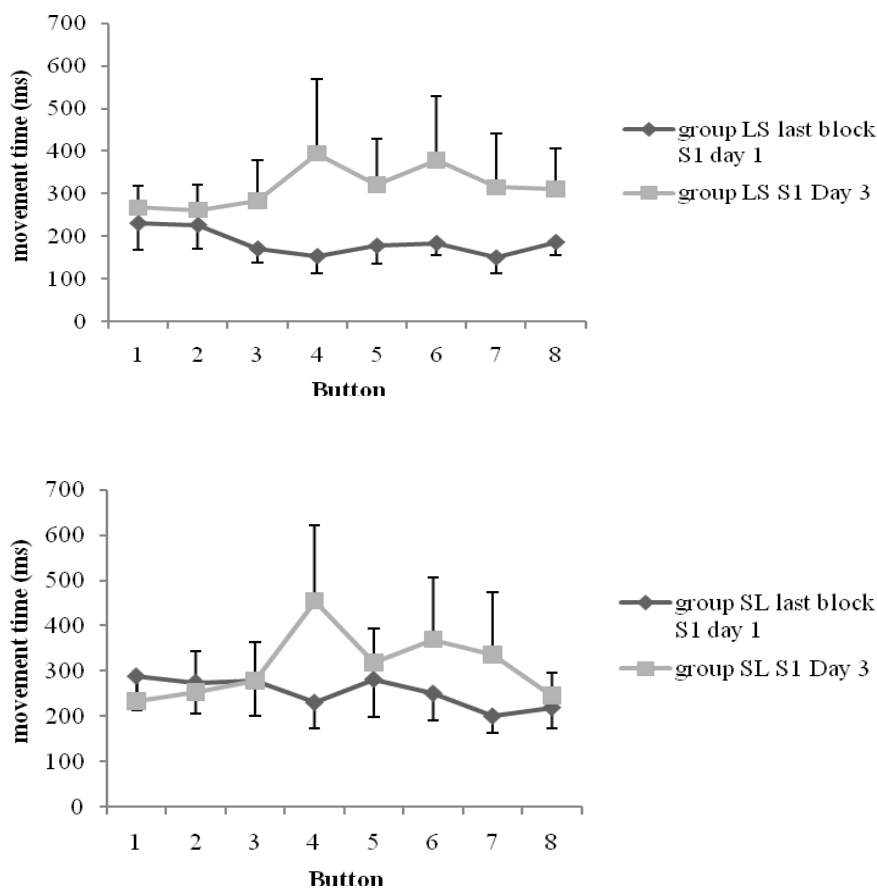
### Retroactive interference

To test for retroactive interference effects, we compared retention performance of S1 on Day 3 with that of S1 at the end of Day 1, similar to the comparison in Experiment 1. A Group (LS, SL)  $\times$  Sequence (S1 Day 1 last block, S1 Day 3)  $\times$  Button (1-8) ANOVA was performed on button times with repeated measures on the last two factors. It yielded significant main effects of sequence,  $F_{1, 22} = 31.26$ ,  $p < .001$ ,  $f = 1.19$ , and button,  $F_{3.66, 80.52} = 6.91$ ,  $p < .001$ ,  $f = 0.56$ , as well as significant Group  $\times$  Sequence,  $F_{1, 20} = 4.62$ ,  $p < .05$ ,  $f = 0.46$ , Group  $\times$  Button,  $F_{7, 154} = 2.08$ ,  $p < .05$ ,  $f = 0.31$ , and Sequence  $\times$  Button,  $F_{3.79, 83.47} = 23.12$ ,  $p < .001$ ,  $f = 1.03$ , interactions. Pairwise comparisons on the Group  $\times$  Sequence interaction revealed that on Day 3 both groups performed equally well (LS:  $M = 317$ ,  $SD = 83.1$ ; SL:  $M = 311$ ,  $SD = 83.1$ ) but that at the end of Day 1 the LS group performed significantly faster than the SL group (LS:  $M = 185$ ,  $SD = 36.0$ ; SL:  $M = 253$ ,  $SD = 49.6$ ). This was not surprising because at the end of Day 1 the LS group had

performed 200 repetitions more (see Figures 5.5a and 5.5b).

Pairwise comparisons on the Group  $\times$  Button interaction revealed that on average the movement to Button 3 was performed significantly faster ( $p = .028$ ) for the LS group compared to the SL group. In addition, movements to Buttons 4 and 5 tended to be performed faster for the LS group compared to the SL group ( $p = .080$  and  $p = .058$ , respectively) as a result of 200 more practice repetitions. All other comparisons were not significant.

Pairwise comparisons on the Sequence  $\times$  Button interaction revealed that only movement times to Buttons 1 and 2 did not differ significantly between the last block of Day 1 and Day 3 ( $p = .39$ ,  $p = .61$ , respectively). All other button times were performed significantly slower on Day 3 compared to Day 1 (all  $ps < .05$ ). Thus, we found button-specific retroactive interference effects, similar to those found in Experiment 1. The lack of a significant three-way interaction suggests that these button-specific retroactive interference effects did not differ between the LS group and the SL group.



Figures 5.5a and 5.5b. Averages and standard deviations across subjects of movement times of last block of S1 Day 1 and S1 Day 3 for the LS- (5.5a) and SL group (5.5b) to illustrate the retroactive effects.

## **Discussion**

In Experiment 2 we examined how an asymmetrical distribution of practice influenced the interference effects in learning and performing similar movements by including two groups with different protocols. Similar but not identical to Experiment 1 we found button-specific proactive facilitative effects on the movements that remained the same between S1 and S2 and no facilitative effects for the movements to the buttons that were changed (in Experiment 1 also some of the changed movements were performed faster at the start of learning S2). Interestingly, no effect of group was present, indicating that proactive facilitative effects were not different when more repetitions of S1 were performed, although, unsurprisingly, the LS group performed significantly better at the end of Day 1. Apparently, the representation of the movement structure was already strong enough after 50 repetitions to evoke movement-specific interference effects. The improvement in the dynamics of the effector system of the additional 200 repetitions, evidenced by the finding that the LS group performed significantly faster at the end of Day 1 than the SL group, was not a determining factor. Apparently, the effector dynamics no longer played a significant role in proactive interference effects once the movement structure had been established.

As in the experimental group in Experiment 1, we found button-specific retroactive interference effects that were not limited to the changed buttons. Only the first two movements of the sequence were performed equally fast between performances on the third day compared to the end of the first day. The extra 200 repetitions did not lead to differences in retroactive interference effects, despite a clear improvement in the effectiveness of the movement dynamics; at the end of 250 repetitions the sequence was performed significantly faster than after 50 repetitions. This is in contrast with earlier work by Panzer and Shea (2008) who found that prolonged practice with S1 increased resistance to retroactive interference by S2.

As in Experiment 1 the retroactive effect was also clearly present one movement before and one movement after the changed buttons, providing further evidence for the interpretation that movements are chunked and function as a unit under interference conditions. Furthermore, even the SL group showed remnants of the first learned sequence when re-performing the first sequence on Day 3, suggesting that there was at least some memory trace representing the sequence available for movement execution. This supports the idea that although the salience of retrieving the first sequence diminishes over time, it remains present and available for movement execution.

### Experiment 3

The first two experiments demonstrated that changing the structure of the movement by changing the target buttons in a sequence resulted in strong proactive and retroactive interference effects on and around the changed target buttons. The data of Experiment 2 suggested that this movement structure is already established after 50 repetitions. It appeared that changing the movement structure was primarily responsible for the occurrence of interference effects. The additional development of the dynamics of the movement with extended training, that is, the faster performance of the sequence after another 200 repetitions, did not have an influence on the interference effects. In Experiment 3 we further investigated the respective roles of movement structure and movement dynamics in the observed interference effects. For this purpose, we again included two different groups; one group learning with the dominant hand and another group learning with the non-dominant hand.

In previous studies, it has been suggested that the dominant hand is a more proficient effector than the non-dominant hand, as evidenced by quicker movement times and movements with greater spatial and temporal accuracy (Sainburg, 2002; Sainburg, 2005; Sainburg & Kalakanis, 2000). Furthermore, from experiments on transfer from the dominant hand to the non-dominant hand and vice versa it is evident that there is intermanual transfer of motor learning. Movements learned with one arm or hand affect the learning of movements with the other arm or hand (e.g., Parlow & Kinsbourne, 1989; Taylor & Heilman, 1980; Thut, Cook, Regard, Leenders, Halsband, & Landis, 1996). Thut et al. (1996) demonstrated in a drawing task that learning with the dominant (right) hand led to a positive transfer to the non-dominant hand in terms of movement times, while such an effect was not observed in the opposite direction. Similar results have been reported by Parlow and Kinsbourne (1989) and Parlow and Dewey (1991). It has been argued that during learning a weaker duplicate of the movement structure is formed in the contralateral hemisphere, with the dominant hand forming a stronger engram in the non-dominant hemisphere than vice versa (Lazlo, Bagulay, & Bairstow, 1970; Parlow & Kinsbourne, 1989; Thut et al., 1996).

In Experiment 3 we sought to gain more insight into the respective roles of the strength of the movement structure and the influence of improved movement dynamics by testing two groups, one learning the movement sequences with the dominant hand and one with the non-dominant hand. Similar to Experiments 1 and 2, after learning the two sequences, participants performed retention tests to examine the presence of (retroactive) interference effects. In addition to that participants now also performed transfer tests during which they performed the sequences with the other hand than the hand with which they had learned the

## *Interference effects in learning*

sequences (i.e., the dominant hand if they had learned with the non-dominant hand and vice versa). If the movement dynamics would prevail, the transfer from the non-dominant hand to the dominant hand would be facilitated more as this would mean a transfer to a more efficient effector, in spite of a weaker engram. Conversely, if movement structure is the crucial factor, the transfer from the dominant to the non-dominant hand would be facilitated more as this would mean a transfer to the stronger movement structure (the contralateral engram), despite performing with the less proficient effector. As in Experiment 2, a control group was omitted because the primary interest of the experiment was to compare interference and transfer effects in the dominant and non-dominant hand learning groups.

### **Method**

#### *Participants*

Twenty individuals (8 men, 12 women), between 19 and 24 years of age ( $M = 20.9$ ,  $SD = 1.76$ ), participated in the experiment after having given their written informed consent. The participants had no previous experience with the experimental set-up. An adaptation of the Edinburgh Handedness Questionnaire (Oldfield, 1971) was used to determine hand dominance. All participants were right-hand dominant and were randomly assigned to either the Dominant hand (D) learning group or the Non-Dominant hand (ND) learning group.

#### *Apparatus*

The same experimental set-up as in the first two experiments was used.

#### *Design, Procedure and Sequence*

To examine the movement-specific interference effects we now varied the movements to Buttons 3 and 7 between the sequences. To make sure that the locations of the buttons in the sequence relative to the start/stop button were exactly the same for the D and ND groups, we rotated the panel 180 degrees for the ND group. The sequences for the D group consisted of the movements to the following locations (see Figure 5.1): K–F–L–H–B–E–A–G and K–F–D–H–B–E–I–G. For the ND group the sequences consisted of movements to the following locations: C–F–D–H–J–E–I–G and C–F–L–H–J–E–A–G, essentially creating mirror images of the sequences. As the panel was rotated 180 degrees, this resulted in the same physical movement pattern as for the D group. Both sequences were again counterbalanced between the sequences learned on Day 1 and on Day 2. Both ND and D groups performed S1 and S2 for a total of 140 trials in four blocks of 35 trials. The average movement times of the first five trials of Block 1 and the average of movement times of the last five trials of each block were used for the analyses (five blocks in

total). On Day 3, participants were required to first perform five trials of S2 followed by five trials of S1 (i.e., the same interference retention tests as in Experiments 1 and 2). After that, participants were required to perform two transfer tests with the contralateral hand, first S1 then S2. For an overview of the design, see Table 5.1.

#### *Dependent variables and measurements*

Data were gathered and analyzed in a similar manner as in Experiments 1 and 2.

*Table 5.1.* Overview of the experimental design of Experiment 3.

	Day 1	Day 2	Day 3			
	140 learning trials	140 learning trials	retention tests 5 trials each		transfer tests 5 trials each	
D-group	S1-D	S2-D	S2-D	S1-D	S1-ND	S2-ND
ND-group	S1-ND	S2-ND	S2-ND	S1-ND	S1-D	S2-D

*Note:* S1 = sequence 1; S2 = sequence 2; D = dominant hand; ND = non-dominant hand.

## **Results**

### *Proactive interference*

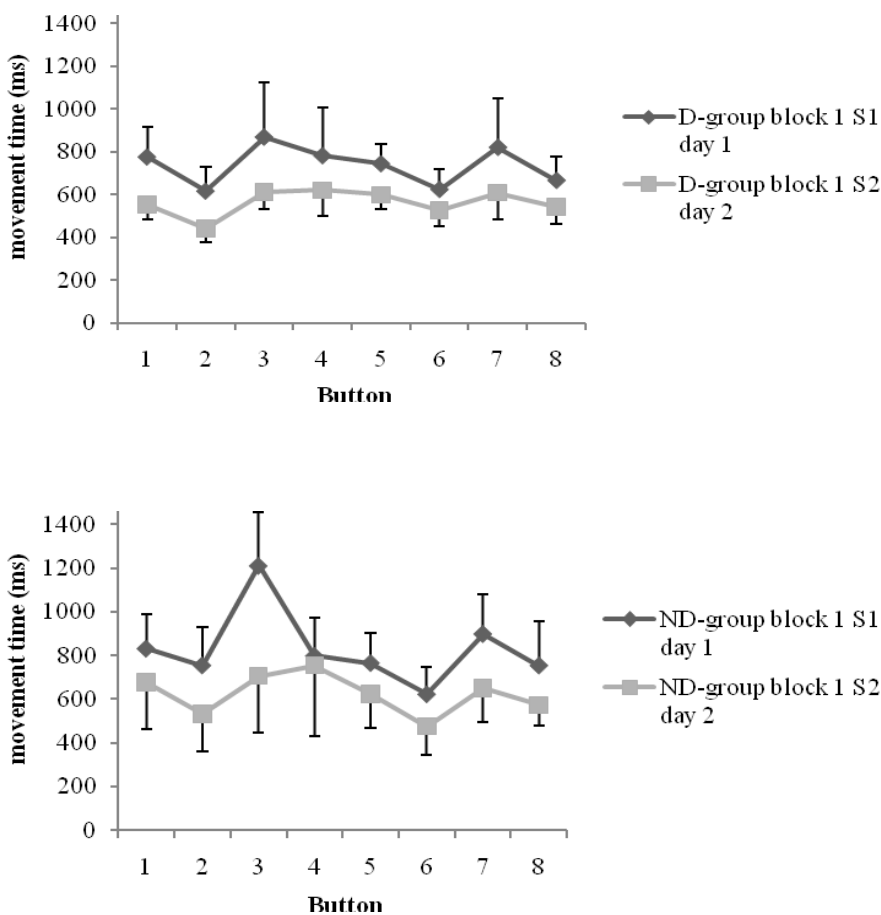
To test for button-specific differences between the groups on learning the second sequence after having learned the first sequence, a Group (D, ND)  $\times$  Sequence (S1, S2)  $\times$  Block (1-5)  $\times$  Button (1-8) ANOVA was performed on button times with repeated measures on the last three factors. It yielded significant main effects of sequence,  $F(1, 18) = 109.25, p < .001, f = 2.47$ , block,  $F(1.36, 24.39) = 428.97, p < .001, f = 4.90$ , and button,  $F(4.28, 86.86) = 80.43, p < .001, f = 2.10$ , as well as significant Sequence  $\times$  Block,  $F(1.67, 30.05) = 32.62, p < .001, f = 0.66$ , Sequence  $\times$  Button,  $F(5.52, 99.32) = 6.82, p < .001, f = 0.54$ , and Sequence  $\times$  Block  $\times$  Button,  $F(6.65, 119.73) = 1.82, p < .001, f = 0.50$ , interactions. All other comparisons, including effects of group, were non-significant ( $ps > .05$ ), although the Group  $\times$  Sequence, Group  $\times$  Button, and Group  $\times$  Sequence  $\times$  Block  $\times$  Button interactions suggested mild trends towards significance ( $ps = .095, .085$  and  $.092$ , respectively). The significant interactions will be detailed below to further scrutinize the proactive effects.

Post hoc comparisons on the significant Sequence  $\times$  Block interaction indicated that S2 was performed significantly faster on all five blocks compared to S1 on the same blocks (all  $ps < .05$ ). Follow-up pairwise comparisons on the Sequence  $\times$  Button interaction revealed significantly faster movements in S2 ( $ps < .05$ ) compared to S1 to all buttons except for Button 4 ( $p = .11$ ). This button-specific proactive facilitative effect was probably caused by a general facilitative

## Interference effects in learning

effect, countered by button-specific interference on the movement to Button 4.

Post hoc comparisons on the Sequence  $\times$  Block  $\times$  Button interaction indicated that on Block 1 all button times ( $p < .001$ ), except for Button 4 ( $p = .11$ ), were significantly faster on S2 than S1 for both groups (see Figure 5.6a and 5.6b for short-term proactive interference effects for both groups). The finding that the movement to Button 4 showed no facilitative effect on learning S2 had disappeared on all further blocks. Interestingly, on all further blocks of performing S2, movements to all buttons remained facilitated by having learned S1, with the exception of the movement to Button 7 for Blocks 3, 4, and 5. This implies that the proactive effects were button-specific but not in a one-to-one fashion with changes in the movement structure as one would expect this effect to be on the changed movements and not on one of the unchanged movements.



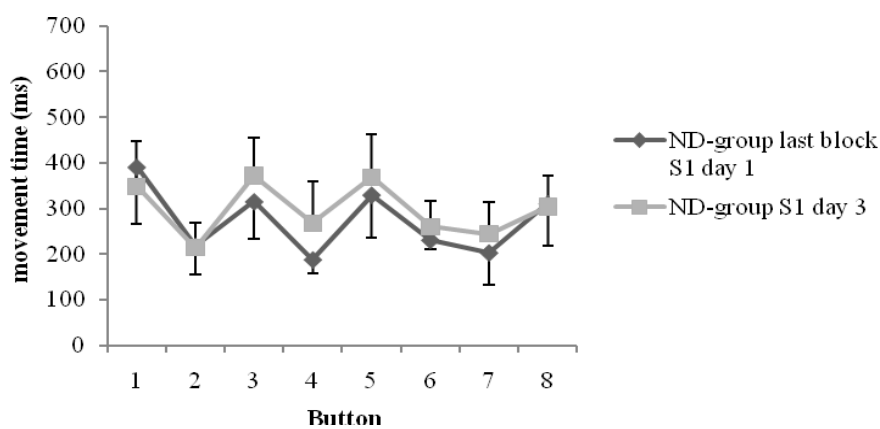
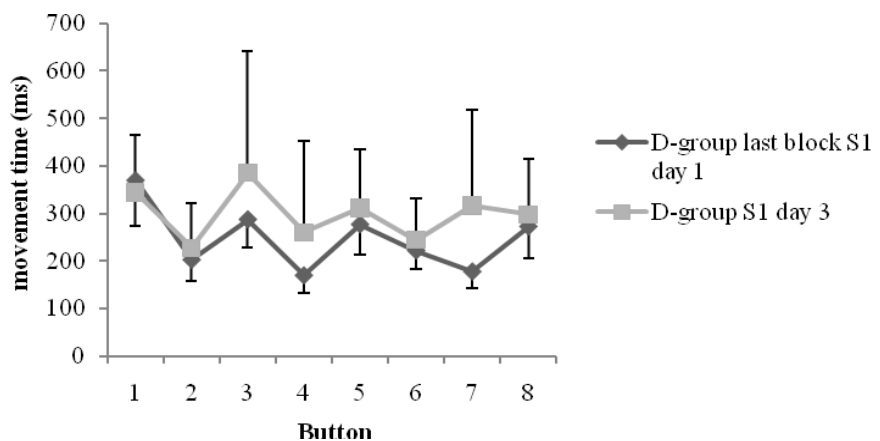
Figures 5.6a and 5.6b. Averages and standard deviations of movement times across subjects of Blocks 1 of both S1 and S2 for the D- (5.6a) and ND group (5.6b) to illustrate the short-term proactive effects.

It appeared that although some differences on a button-specific level were present between learning with the D- and the ND hand these differences were not consistent with the differences in movements between the sequences, suggesting

that learning with either the dominant hand or non-dominant hand resulted in the same proactive interference effects. Despite slightly faster movement times, the lack of a main effect of group ( $p = .15$ ) suggests that in the current task, the dominant hand cannot be considered a more proficient effector system than the non-dominant hand.

### *Retroactive interference*

To test for retroactive interference effects, we compared performance on Day 3 of S1 with that of S1 at the end of Day 1, which is S1 Block 5. A Group (D, ND)  $\times$  Sequence (S1 last block, S1 Day 3)  $\times$  Button (1-8) ANOVA was performed on button times with repeated measures on the last two factors. It yielded a significant main effect of button,  $F(2.81, 30.64) = 33.60, p < .001, f = 1.36$ , and a marginally significant main effect of sequence,  $F(1, 18) = 3.89, p = .064, f = 0.89$ . These main effects were superseded by a significant Sequence  $\times$  Button interaction,  $F(2.57, 46.32) = 7.04, p < .001, f = 0.62$  (see Figures 5.7a and 5.7b).



Figures 5.7a and 5.7b. Averages and standard deviations of movement times across subjects of last block of S1 Day 1 and S1 Day 3 for the D- (5.7a) and ND group (5.7b) to illustrate the retroactive effects.



### Interference effects in learning

Pairwise comparisons revealed that movements to Buttons 4 and 7 were performed significantly slower on Day 3 than on Day 1 ( $p$ s < .05), while movements to Buttons 3, 5, and 6 showed tendencies to be performed slower on Day 3 than on Day 1 ( $p$ s = .07, .09 and .07, respectively), suggesting a button-specific retroactive interaction effect on and around the changed buttons. It also appeared that the movement to Button 1 was performed significantly faster on Day 3 compared to Day 1, which may not be surprising as it was additionally practiced on Day 2. All other comparisons were non-significant. Again, group did not seem to be a contributing factor to these retroactive effects.

### Transfer

To examine whether dominant and non-dominant hand learning resulted in differences in interference effects on performing S1 and S2 under transfer to the contralateral hand, a Group (D, ND)  $\times$  Hand (learned hand, contralateral hand)  $\times$  Sequence (S1, S2) ANOVA was performed on total movement times on Day 3 with repeated measures on the last two factors. The ANOVA yielded significant main effects of hand,  $F_{1, 18} = 87.81, p < .001, f = 2.21$ , and sequence,  $F_{1, 18} = 5.96, p < .05, f = 0.58$ , as well as a significant Group  $\times$  Hand interaction,  $F_{1, 18} = 8.75, p < .01, f = 0.69$ , without the presence of a significant Group  $\times$  Hand  $\times$  Sequence interaction. Follow up pairwise comparisons on the significant interaction between hand and group revealed that both groups performed significantly worse in the transfer condition. However, inspection of the means of the Group  $\times$  Hand interaction demonstrated that the ND group performed worse under transfer to the dominant hand than the D group transferring to the non-dominant hand. This asymmetric transfer is shown in Figure 5.8.

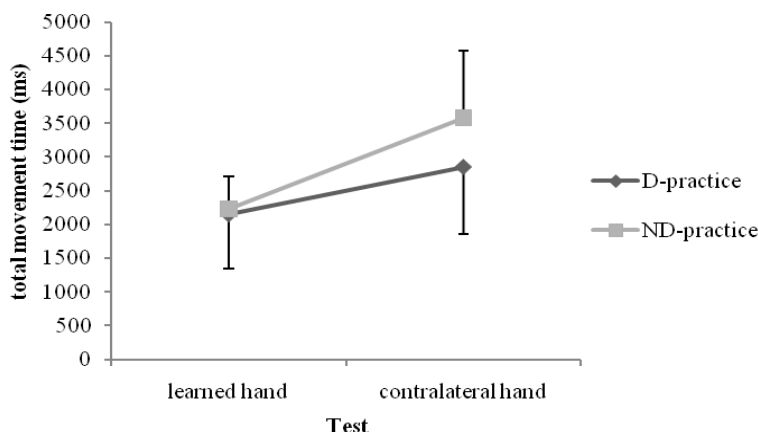


Figure 5.8. Average total movement times of S1 and S2 and standard deviations of both groups for the learned hand and the transfer to the contra lateral hand

Furthermore, the absence of a Group  $\times$  Hand  $\times$  Sequence interaction suggests that although there is an asymmetrical transfer in performance from the learned hand to the contralateral hand, this asymmetry has no influence on interference effects on performing S1 and S2 on Day 3.

### **Discussion**

Surprisingly, the dominant and non-dominant hands did not differ in performance during acquisition and retention. As such, they can be considered equally efficient effector systems in the current task. However, the transfer test data suggested that the transfer of the dominant hand to the non-dominant hand was facilitated more than the transfer from the non-dominant to the dominant hand. The non-dominant hand performed better under transfer, possibly because of the stronger representation of the movement structure acquired by learning with the dominant hand. This suggests that the strength of the representation of the movement structure plays a prominent role in transfer of sequential performance to the contralateral hand. This finding is in accordance with earlier work of Parlow and Kinsbourne (1989), who found that the non-dominant hand profited more from contralateral effector practice than did the dominant arm for an inverted writing task. Furthermore, the results are in line with predictions of both the proficiency model and the cross-activation model which state that in dominant hand learning a stronger memory representation of the movement is formed in the contralateral hemisphere than in non-dominant hand learning (Laszlo et al., 1970; Parlow & Kinsbourne, 1989). However, this difference did not lead to differences in proactive- and retroactive interference effects or to meaningful interference effects on the transfer test. It appears that the strength of the representation of the movement structure dictates the occurrence of interference effects already in a very early stage of learning. The additional difference caused by laterality is then marginal in the occurrence of interference effects. This fits with the idea and finding of Experiment 2 that movement structure is established very early in learning before optimizing, stabilizing, and standardizing the effector dynamics (Bernstein, 1996; Wilde Braden et al., 2007).

### **General discussion**

In a series of three experiments we studied interference effects in learning similar sequences of discrete movements. Overall, it appeared that changes in the movement structure rather than in movement dynamics are crucial in the occurrence of both proactive and retroactive interference effects. This conclusion is consistent with the model of hierarchical control of movement sequences. There are many studies showing that abstract motor plans are used in sequencing tasks, and that they

determine in fact the sequencing of movements (for an overview see Rosenbaum, Cohen, Jax, Weiss, & van der Wel, 2007). Rosenbaum et al. (2007) argued that the abstract spatio-temporal movement structure transfers from one movement to the next without transferring the accompanying muscle activation and joint angles. The current study suggests that the representation of the movement structure dictates not only sequential performance of a given movement sequence, but also interference effects in learning and performing multiple similar sequences. Just as with performing a single sequence, the effector dynamics plays a subordinate role, albeit not a negligible one.

Another property of single sequential performance is that the abstract movement structure can consist of different smaller, relatively independent movement units, which can be executed as a whole when they are chunked together (Miller, 1956). The current study demonstrated that chunking also plays a role in interference effects as it appeared that not only the changed movements between the two sequences interfered retroactively, as found for instance by Panzer et al. (2006), but also several of the surrounding movements. Jiménez (2008) showed that chunking is a self-organized, functional division of more complex sequences into smaller units. For instance, in the current study the distance between consecutive button presses varied within a sequence and, following the rationale of Jiménez, consecutive button presses with a small distance between them are more likely to be chunked together than consecutive button presses that are further apart. Indeed, this notion is consistent with our results. When interference effects transcended the imposed changes in the movement structure, the involved movements were of short distance and duration. This finding confirms that movement structures do not represent the sequences of individual movements in a one-to-one fashion (cf. Verwey, 1994). Moreover, it underscores once more that movement structure is an essential determining factor in the occurrence of interference effects between two similar sequences.

As for the causes of interference, it has been suggested that the movement structure of a first learned sequence is overwritten by that of the second sequence (Panzer et al., 2006), which would make it virtually impossible to retain and perform two similar movement sequences at the highest level. Another suggestion is that (part of) the movement structure of the first sequence is still available for movement execution, albeit with less salience and with higher retrieval and performance costs (Panzer & Shea, 2008). A prediction of the overwriting hypothesis would be that movement execution of the first sequence on Day 3 would not have a memory representation as this would have been overwritten. Effectively, this would mean that movement execution would have to be approximately as slow as at the start of learning, at least for the changed buttons. However, movement

times of the first sequence on Day 3 were much faster than at the beginning of learning, suggesting that the representation of the first sequence was still present. Although the representation of the first sequence was not readily accessible and took more time to retrieve than more salient representations, performance was still faster than at the beginning of learning.

One issue that needs to be addressed in comparing our results with those of Panzer and colleagues is the difference between our discrete experimental task and the more dynamic (continuous) task used in the studies of Panzer et al. (2006) and Panzer and Shea (2008). In light of this discussion, evidence is accumulating that in dynamical (pseudo) cyclical tasks movements are controlled using anchor points (Beek, 1989; Carson, Byblow, & Goodman, 1994; Roerdink, Ophoff, Peper, & Beek, 2008; Roerdink, Peper, & Beek, 2005). Anchoring is reflected by local reductions of movement variability at particular control points in the perceptual-motor work space where critical task-specific information is available for performance (i.e., the reversal points in the Panzer et al. set-up). Basically, anchoring implies that (quasi) rhythmical movements become discretized at certain fixed points in the movement cycle (for an overview, see Roerdink, 2008) providing common ground for the comparison between our discrete set-up and the more dynamical set-up of Panzer et al. (2006) and Panzer and Shea (2008). With this in mind, our findings seem to suggest that an old sequence is not overwritten by learning a new and similar movement sequence, but that the salience of retrieval changes over learning.

That movement structure plays a crucial role in interference effects should not be taken to imply that improvements in movement dynamics are unimportant or absent in learning similar movement sequences. For one, it seems that learning a first sequence results in overall improvement of performance on a second sequence, not only for the movements that were the same in the first and the second sequence, but even for some of the movements that were different (opposite) in the second compared to the first sequence. This suggests that learning the first sequence leads to general improvements in movement dynamics, eventually leading to faster movements to some (but not all) new buttons in the second sequence. That some new movements in the second sequence were facilitated by having learned a first sequence also suggests that the developing movement structures do not represent the sequences in strict one-to-one relations with the individual movements, an insight that already followed from the retroactive interference effects.

It appears that relatively early in skill acquisition the movement structure becomes established (automatization of sequential performance), thereby providing a first step towards expertise. Of course, the rate at which the structure becomes established is dependent on the length of the sequence and sequence complexity. In

this early stage of learning the movement structure is relatively flexible in transferring to other configurations (e.g., Dean et al., 2008; Wilde Braden et al., 2007; Wilde & Shea, 2006). The current study suggests that also in this stage the movement structure is already established to such a degree that changing the movement structure leads to interference effects between old and new movements. This is in line with Bernstein's (1996) idea that automatization occurs relatively early on the path to expertise and that only after extended practice stabilization and standardization of performance occur. This is supported by work indicating that extensive practice leads to the optimization of effector dynamics and to a stronger coupling between movement structure and effector dynamics (Wilde Braden et al., 2007; Wilde & Shea, 2006). What remains to be seen is whether and how similar movement sequences interfere during these final phases of learning, which apparently requires more repetitions than the maximum number of 250 used here or even the 640 repetitions used by Wilde Braden et al. (cf. Crossman, 1959; Ericsson, 1996; Koedijker, Oudejans, & Beek, 2008; Kottke, 1980). Other studies have suggested that prolonged learning of a sequence may lead to a lower rate of learning a second sequence (Ghilardi et al., 2009) or, more generally, to response production that is increasingly less flexible and more effector dependent (Wilde Braden et al., 2007).

To disentangle the relative contribution of movement structure and movement dynamics in the occurrence of interference effects, the reported experiments manipulated the number of practice trials (Experiment 2) and exploited hand laterality (Experiment 3). Another promising manipulation could be the use of mental practice to strengthen the movement structure without involving the effector dynamics (Wohldmann, Healy, & Bourne, 2008). Another possible direction for future research is to examine interference effects in learning similar sequences with different temporal rather than spatial structures. It could well be that the movement dynamics plays a more pronounced role in the occurrence of interference effects when changing the temporal pattern of a movement sequence. Another question worth looking into is whether the relative importance of movement structure and movement dynamics in the occurrence of interference effects is dependent on the amount of time between the learned sequences.

For now, it seems that the movement structure is the dominant factor in the occurrence of interference effects. Strengthening the representation of the movement sequence and increasing the effector dynamics, either by five times more repetitions or dominant vs. non-dominant learning and transfer, did not lead to differences in interference, suggesting that the movement structure is already strong enough in an early stage of learning to induce interference effects. Interestingly, the interference effects did not correspond one-to-one to changes within the sequence,

suggesting that chunks of subsequences within the movement structure are also implicated in the occurrence of (primarily) retroactive interference effects. From a practical perspective, this means that as the movement structure becomes established early in learning, practitioners must be careful when teaching new skills as even short stints of practice of a similar movement sequence might lead to unwanted interference effects in learning and performance. This would plead against, for example, the often used implementation of beginner's equipment or beginner's rules at the start of learning complex movements. Clearly, it is better to get it right the first time. Nevertheless, the results also show a general facilitative effect, indicating that practicing a similar sequence might also prove beneficial. Having typed for years on a qwerty-keyboard in general leads to faster typing when changing to a qwertz-keyboard, only with a window for error on the 'z' and the 'y' keys. Although it is better to get it right the first time, it might still be worthwhile in the end to do it 'almost right' for a while.

Furthermore, it appears that retroactive interference effects do not result from an old sequence being overwritten by a new sequence, but rather from a difference in salience of memory retrieval. This would imply that, although performance of an old sequence is affected by learning a new similar sequence, similar sequences can be retained and performed with little loss as long as the similar responses are very salient for their respective stimuli. This would mean that after extensive use of both qwerty- and qwertz-keyboards both should offer equal opportunities for optimal performance. Nevertheless, further studies are necessary to find out how two similar sequences interfere in the standardization and stabilizations phases of learning achieved after more extensive periods of practice. Also, a next step should be to look into the development of strategies aimed at limiting the occurrence and consequences of interference effects.

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