Transfer and interference in skill acquisition

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The Role of Difficulty in Interference: Re-pairing Rate and Task Demand

Two experiments investigate the impact of an increase in difficulty on the amount of interference occurring in two newly developed coding tasks. In experiment 4.1, the number of re-paired letters in the key was manipulated to examine its quantitative effects and whether the increased response latency was restricted to the re-paired responses only. Four groups were compared, one group with all letter-digit combinations re-paired, one group with a subset of letter-digit combinations re-paired and two control groups. The experiment demonstrated that after a period of similar performance interference occurred. Further analysis revealed that the increased latency was restricted to the re-paired responses, indicating that the subjects used no intentional inhibition strategy. Experiment 4.2 investigated by using a dual task paradigm whether an increase of the task demand led to a larger increase in response times and error rates in a transfer task with re-paired stimulus-response pairs (colour-key combinations) than in a control task. In colour coding a strong interference effect was found after re-pairing. Although introduction of the concurrent digit adding task caused an increase in response times and error rates, no differential effect was found. Both studies indicate that when difficulty is substantially increased, people perform the tasks in a controlled manner, resulting in the absence of interference immediate after the switch. After overcoming the initial difficulty, however, interference effects appeared, suggesting that for interference a firm representation of the key or a certain response fluency is required.

Transfer of training is a highly empirical domain (Adams, 1987). This chapter is in line with this tradition and has a strong empirical character. The research questions that are posed in this chapter originate from the previous experiments. Three of these questions will be addressed in two experiments. The skills in the previous experiments were relatively simple and as a consequence easy to learn. It was not clear whether the results of these simple skills could be generalised to more difficult variants of the coding task. Thus, the first question is whether the same pattern of results can be found in more difficult tasks. In the following experiments difficulty was manipulated in various ways. In Experiment 4.1 the difficulty of the coding task itself is increased, whereas in Experiment 4.2 the difficulty is increased by manipulation of the circumstances under which the coding task is performed.
Interference appeared mainly as an increase in response latency in our previous experiments. Therefore, the question rose whether the increase may have been the result of an intentional inhibition strategy by the subjects. If the subjects adopted such a strategy, the increased response latency should be global and therefore also affect the responding on non-re-paired letter-digit combinations. Because in the previous experiments all letter-digit combinations were re-paired this alternative explanation could not be ruled out. If the increase in response latency is restricted to re-paired letter-digit pairs, it excludes an intentional inhibition strategy and favours an interference effect that operates automatically.

The third question was inspired by the lack of a clear and consistent interference effect in error rates. Therefore, the question rose whether manipulating difficulty could increase the error rates in coding and more important, if it could increase the visibility of interference in error rates. The basis for this experiment was the anecdote of a colleague who switched recently from one motor to another. The way the gear was operated differed for the two motors. Operation of the gear under normal driving conditions was perfect. In more difficult situations, however, the colleague sometimes felt a tendency toward the old habit of gear operation. The suggestion that interference due to previously acquired traffic habits asserts itself in situations of emergency or stress can also be found in an article by Entwisle (1959).

Two completely new computerised versions of the coding task were developed to answer these questions. These new coding task versions differ from the previous in many aspects, such as stimulus presentation, stimulus material, and way of responding. One of the advantages of using new versions is that it may extend the evidence for the occurrence of interference in skill acquisition to a broader range of tasks. In Experiment 4.1, the number of re-pairings is varied to investigate the quantitative effects on interference. In addition, it is investigated whether the re-pairing of the letter-digit combinations only affects the re-paired responses or leads to a global negative effect. It is expected that in our experiment the performance deterioration is limited to the re-paired keys only because the interference effect seems more likely the result of a problem in an implicit response decision process than the result of an intentional inhibition strategy. In Experiment 4.2, a dual task paradigm was used to increase the difficulty. The main interest was whether the group with re-paired material was differentially affected by the increase in task demand. The most important manipulation to diminish the amount of attention devoted to the main task was the introduction of a concurrent task. It was expected that the increase of task demand lead to a larger increase of response time and error rate in the interference condition than in the control group.

**Experiment 4.1: Re-pairing Rate and Generalisation of Interference**

Smith, Zirkler, & Mynatt (1985) hypothesise that negative transfer might be limited to tasks that are relatively difficult to master. We hypothesise instead that negative transfer is constant across tasks and that net negative transfer is only visible in tasks that are relatively easy to master. This hypothesis assumes that the amount of negative transfer is dependent on the number of re-pairings, irrespective whether the task is simple or difficult. Because the absolute amount of negative transfer is constant from simple to complex tasks, negative transfer is only visible in aggregate scores when the effect of positive influences (e.g., learning
to learn) is smaller than that of the negative influences. In the previous experiments, it appeared that negative transfer occurred in relatively simple tasks and that net negative transfer only occurred in the simplest form of the coding task.

The current experiment investigates the influence of an increase in difficulty of the coding task, by extending the key from four letter-digit combinations to nine letter-digit combinations, on negative transfer as well as retroactive interference. A more specific interest is whether there is a clear difference between a partially re-paired key and a totally re-paired key. The partially re-paired key contains fewer re-pairings and is therefore more similar to the training key, whereas the totally re-paired key has more re-pairings, but also looks less like the training key. We expect that the number of re-pairings is related to the amount of interference that occurs and not, or at least to a lesser degree, to the similarity of the keys as manipulated in this experiment.

Another issue that became important during the previous experiment concerns the nature of the increased latency in the interference conditions. Is the increased latency limited to the re-paired responses or is it more global? Smith et al. (1985) found in a text-editing experiment a performance deterioration that also affected the non re-paired functions. Such a general effect might be explained by an intentional inhibition strategy. After switching to a transfer task with re-paired stimuli and responses, subject might adopt an inhibition strategy to remain the accuracy level of the training task. Our previous results may be explained by such an intentional inhibition strategy because the error rates did not always increase significantly after response re-pairing.

The initial memory load in the current experiment is larger than in the previous experiments because the key was extended to nine letter-digit pairs. To gain insight into the memory for the keys, a recall test was administered at the end of the experiment. Some caution in interpreting the recall data is needed because the recall data may be influenced by primacy and recency effects (leading to better recall of the training key) and the interference itself (leading to worse recall of the transfer key).

Method

Participants

Eighty students of the University of Amsterdam participated in this experiment in exchange for course credit. Each participant was assigned randomly to one of four conditions and was tested individually.

Materials and Design

In the current experiment a key (button) had to be pressed in response to a stimulus letter according to a given set of letter-digit combinations, the key (code). The key consisted of nine letters linked to the numbers 1 to 9 depicting the nine buttons on the numeric keypad. The keys were constructed in a way that they could be used in all four groups (see the Appendix for the letter sets and their combinations). The letter sets in the different conditions
were identical, only the combinations of the letter sets (training and transfer set) were
different. The keys were counterbalanced across phases. Stimuli were arranged in 40 blocks of
36 trials each, with each letter appearing 4 times in a pseudo-random order, with the
restriction that the same letter never appeared twice or more in a row. After 20 blocks
participants switched to the transfer task and switched back to the training task after 30 blocks.
The presentation order of the letters was predetermined and differed for every block. This
order was the same for every participant.

Four groups were compared in this study. After training, the total re-pair (TR) group
switched to a key in which all previously encountered letters were re-paired with the digits.
The partial re-pair (PR) group switched to a key in which four letters were re-paired and five
letters held the same combination with the digits. The other two groups serve as a control
group for respectively the TR group and PR group. The total new (TN) group switched to a
key in which all new letters were used. The partial new (PN) group switched to a key in which
four new letters were used and five letters remained the same. An example of the different
switches for every group is given in Table 4.1.

<table>
<thead>
<tr>
<th></th>
<th>Training Phase</th>
<th>Transfer Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PR</strong></td>
<td>L D W G J T B N R</td>
<td>W D N G J L B T R</td>
</tr>
<tr>
<td><strong>TR</strong></td>
<td>L D W G J T B N R</td>
<td>W G N R B L J T D</td>
</tr>
<tr>
<td><strong>PN</strong></td>
<td>L D W G J T B N R</td>
<td>Z D P G J M B V R</td>
</tr>
<tr>
<td><strong>TN</strong></td>
<td>L D W G J T B N R</td>
<td>Z H P S C M K V F</td>
</tr>
</tbody>
</table>

**Table 4.1.** Example of the re-pairing of the letter sequence LDWGJTBNR in the
different groups. Letters that were in the same position in the training and transfer
key are underscored. PR = partial re-paired group, TR = total re-paired group, PN =
partial new group, TN = total new group.

**Apparatus**

The experiment was conducted on an Apple Power Macintosh 4400 and a 14-inch
monitor. The numeric keypad was used as an input device.

**Procedure**

The experiment started with onscreen instructions of the test. After the instructions, the
experimenter verified whether the task was understood. Then subjects continued with the
colour-coding test. This colour-coding test was performed to practice the use of the numeric
keypad and to clarify the nature of the task. In the colour-coding task, participants saw a key
of four coloured spots (yellow, red, blue and green) paired with the digits 4, 5, 6, and 7,
corresponding with the keys on the numeric keypad. Participants were instructed to press the
key that corresponded with the colour as fast as possible. The index finger operated keys 4 and 7, the middle and ring finger operated respectively keys 5 and 6. After two colour-coding blocks of 36 trials each, letter coding was explained and started.

In letter coding, the participant had to press the correct button in response to a presented letter. The letter-digit combinations were shown in the upper middle part of the screen and were constantly available during the task, except for during the pauses between blocks. Participants were instructed to make their keypress responses as rapidly and accurately as possible. After the response was made, the next stimulus appeared directly. Thus, the trials in every block were presented as a continuous series of stimuli. Feedback about the mean time and the number of correct responses was given after each block.

The colour-coding task was repeated after the letter-coding task. Finally, the subjects had to recall the two keys used in the letter coding experiment. Subjects filled the letters in on a form with two keys from which the letters were omitted. Only letters that were placed in the correct position were counted as correct. Dependent variables were response times (RTs) and error rates.

Results

RTs shorter than 100 ms and larger than 4 s were dropped. In addition, RTs smaller or larger that 2 standard deviations from the mean in that block for that subject were excluded from analysis. Only the correct responses were used in the analyses. The results of the letter coding are presented first.

Training phase (RTs)

We first address the data from the training phase (Blocks 1-20). Mean RTs and error rates were obtained for each subject, as a function of Block. A significant main effect for Block, $F(19, 1444) = 273.6, p < .0001, MSE = 14,646$, confirmed the reduction in RTs with practice that can be seen in Figure 4.1. In addition, a significant Group x Block interaction was found, $F(57, 1444) = 1.38, p < .05, MSE = 14,646$. This interaction is mostly due to the slower, although not significant, performance of the partial new group.

The mean RT data (Blocks 1-20) are well fitted ($r^2 = .994$) by a two parameter power function. These data are well described by a power function, which indicates that learning occurs and suggests that letter coding shares some fundamental qualities with many skills (Woltz, Bell, Kyllonen, & Gardner, 1996). The flatness of the curve in the last trials indicates that the performance of the task is relatively automated.

Transfer phase (RTs)

RT data for the transfer phase, Blocks 21-30, show main effects for group, $F(3, 76) = 3.42, p < .05, MSE = 416,581$, and block, $F(9, 684) = 101.75, p < .0001, MSE = 13,852$. In addition, a significant Group x Block interaction, $F(27, 684) = 2.33, p < .001, MSE = 13,852$, was found. Bonferroni-Dunn post hoc comparisons revealed that the RTs between the total repair group and the (partial and total) new groups differed at $p < .01$. The difference between
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The total re-pair group and the partial re-pair group was only marginally significant, $p = .058$. As can be seen in Figure 4.1, the difference between the total re-pair group and the other groups starts at Block 23. T-tests showed there were no significant differences between these groups on the first two blocks.

![Figure 4.1](image_url)

Figure 4.1. Mean correct RTs with standard error of the mean as a function of block and group. TR = total re-pair group, PR = partial re-pair group, TN = total new group, PN = partial new group.

**Retest phase (RTs)**

The RT data for the retest phase, Forms 31-40, showed no main effect for group, $F(3, 76) = .66, p = .58, MSE = 377,117$, indicating that the re-pair letter groups were as fast as the new letter groups in the retest phase. A main effect for block, $F(9, 684) = 43.24, p < .0001, MSE = 8,241$, and a significant Group x Block interaction, $F(27, 684) = 1.90, p < .01, MSE = 8241$, were found. The significant interaction is probably the result of the slower performance of the total re-pair group. T-tests on the first form of the retest phase revealed a significant difference between the TR group and the PN group, $t(38) = 2.47, p < .05$, and a marginal significant difference between the TR group and the TN group, $t(38) = 1.84, p = .07$. These differences suggest a short interference effect in the TR group after switching back to the original task.
Error Rates

The overall percentage of errors in letter coding was 4%. Repeated measures ANOVAs were performed on the error rates. The factors for the ANOVAs were group and block. In none of the three phases a significant main effect of group or a Group x Block interaction was found. Only in the training phase there was a significant decrease in number of errors across blocks, $F(19, 1444) = 1.61, p < .05, MSE = 1.111$.

Comparison of re-paired and non-re-paired letters in the PR group

To control for an intentional inhibition strategy in the transfer phase, the RTs on the re-paired letters were compared with the RTs on the non-re-paired letters in the partial re-pair group. A repeated measures ANOVA revealed a significant difference, $F(1, 19) = 42.31, p < .0001, MSE = .008$, between the mean RTs on the re-paired letters and non re-paired letters. To exclude the possibility that this result was based on a possible confounding, such as key positions, the mean RT of the non re-paired letters in the partial re-pair group was compared with the mean RT on the new and same letters in the partial new group (for a better understanding see the PR and PN group in Table 4.1). T-tests showed no reliable differences between these means (Table 4.2). Thus, the RTs on the changed letters are slower and the slowing is restricted to re-pairing of responses. In addition, the interference effect, which was not so clear in the partial re-pair group in the overall analysis, can be found in a more fine-grained analysis.

<table>
<thead>
<tr>
<th></th>
<th>Re-paired</th>
<th>Non re-paired</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR group</td>
<td>1.38 (.24)</td>
<td>1.20 (.20)</td>
</tr>
<tr>
<td>PN group</td>
<td>1.24 (.25)*</td>
<td>1.24 (.23)*</td>
</tr>
</tbody>
</table>

*In the PN group the new letters were introduced instead of re-pairings of old letters.

Free recall of the keys

An oneway ANOVA was performed on the number of correctly recalled letters of the first learned key (key A, used in the training and retest phase) with group as independent variable. No significant difference was found between the four groups, $F(3, 76) = .88, p = .228, MSE = 4.60$. Another oneway ANOVA was performed on correct recall of the transfer key (key B). A significant difference was found, $F(3, 75) = 3.69, p < .05, MSE = 10.30$. A Bonferroni-Dunn post hoc analysis revealed that only the recall scores of the total re-pair group and the partial re-pair group differed at $p < .01$. A paired t-test showed that the recall on
the training key was better (2.4 letters more) than the transfer key, \( t(78) = 7.65, p < .0001 \). The results show that there is a large advantage of the first letter-digit system, irrespective of the group one was in (see Table 4.3).

**Table 4.3.** Mean number of correct recalled letters with the standard error of the mean in parentheses for key A and B for each group

<table>
<thead>
<tr>
<th></th>
<th>Mean key A</th>
<th>Mean key B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Re-pair</td>
<td>7.7 (2.5)</td>
<td>4.4 (3.4)</td>
</tr>
<tr>
<td>Partial Re-pair</td>
<td>8.6 (.9)</td>
<td>7.4 (2.8)</td>
</tr>
<tr>
<td>Total New</td>
<td>8.0 (2.0)</td>
<td>4.7 (3.0)</td>
</tr>
<tr>
<td>Partial New</td>
<td>7.6 (2.7)</td>
<td>6.0 (3.6)</td>
</tr>
</tbody>
</table>

**Colour Coding**

Two blocks of colour coding were performed before and after the letter-coding task. A repeated measures ANOVA on the RTs with block as a factor showed a significant main effect, \( F(3, 231) = 335.826, p < .0001, MSE = 6396 \). Paired t-tests revealed that the colour coding RTs of all blocks differed from each other (all \( p's < .0001 \)). The coding data show that there is a decrease in RT across blocks. After the interpolated letter coding, the performance on the colour coding still becomes better. The transfer from letter coding to colour coding is positive, although the increase in performance may also be explained by a training effect in the colour coding itself.

A repeated measures ANOVA on the error rate with block as a factor showed a significant main effect for block, \( F(3, 231) = 4.735, p < .01, MSE = 1623 \). T-tests on the mean error rates of all blocks showed that only the differences between the first block and the other three blocks were significant (all \( p's < .05 \)). Thus, the number of errors diminished quickly and became stable after the first block of colour coding. The overall error rate in the colour-coding task was 4.0%.

The comparison of the first blocks of colour coding with the final blocks can be seen as a control for fatigue and loss of motivation. Although fatigue and motivation loss may have had an effect, the faster performance on the second colour-coding task indicates that these factors did not have a large detrimental effect or were masked by a training effect.

**Discussion**

Re-pairing of all nine letter-key combinations led to a clear increase in RTs. However, also the switch to nine new letter-key combinations led initially to the same performance decrease. After the second block in the transfer task the interference effect became apparent. After the switch the task is so difficult in the total re-paired and total new groups (learning nine letter-digit combinations), that the subjects in these groups perform in a very slow and controlled way leaving no room for intrusions of the first task in the total re-paired group. A
possible explanation is that immediately after the switch there is no firm representation of the second skill yet. Although the precise mechanism behind the delayed interference effect is unknown, it suggests that fluent responding is a prerequisite for interference.

The slowing was, as expected, restricted to the re-paired responses as was demonstrated in the partial re-pairing group. This result excludes the intentional inhibition strategy as a possible explanation for the interference effects found in coding. This also illustrates the importance of the level of analysis in interference research. In this more fine-grained analysis an interference effect was found in the partial interference group, whereas no difference was found between the partial interference group and the new control group in the group comparisons.

No effects were found in error rates, apart from decreasing error rates in the training phase of the experiment. The absence of the effect in error rates indicates that there were no problematic trade-offs between RTs and error rates.

The recall test showed that recall on the first learned key was considerably better than on the interpolated key. Interpretation of the results is difficult because of a possible recency effect. The colour coding appeared to be a easy-to-learn type of coding task and the performance on the colour coding sessions at the end of the experiment suggested that there was no large motivation loss or tiredness.

**Experiment 4.2: Interference in Single and Dual Task Situations**

Our previous studies with the letter-digit coding skill show that previous learning may interfere with subsequent learning or performance of a similar skill. The interference effects were seldom found in error rate (see for example Experiment 4.1). Another noticeable finding was that error rates in the simple coding tasks were very low (less than 1%). The coding tasks in chapters 2 and 3 were relatively simple and the subjects could completely focus on the main task. These factors, together with the willingness of the subjects to avoid errors, may have led to the low error rates. One of the conclusions that can be drawn from our previous experiment is that interference often has a more subtle influence than can be measured with error rates alone. Therefore, it is recommended not to use error rates as the only dependent measure for fundamental research on interference in skill learning.

The present study is an attempt to create a situation in which interference is not only found in RTs, but also in error rates. Instead of manipulating the difficulty of the task itself, as was done in Experiment 4.1, in the current experiment the difficulty of the circumstances under which the task was performed is manipulated. The present study is based on the idea that in situations where less attention is focused on the main task, the old habits may intrude more easily. By increasing the task demand (e.g., lessening the amount of attention that could be devoted to the coding task) and a removal of ways of response verification (e.g., removal of colour-key combinations, no feedback on errors), it was attempted to increase the number of errors. The main goal was to investigate whether the group with the similar responses suffered more from these manipulations than the group with the new responses. The task demand was altered in various ways.
The first way to increase the task demand was by removing the key after several blocks. Although this is an extra demand at the beginning of the task, it could make the task easier after some blocks. Because the combinations are well learned and the combinations are no longer available, the tendency to look at the combinations, maybe only for control, is suppressed.

A second and more rigorous way to increase the task demand is to divide the attention between the coding task and another task. For this purpose a concurrent task was introduced: digit adding. In addition to coding, the subjects added digits that were shown in an irregular duration above the coloured spot. After each block, the subject had to give the sum of the digits shown in that block. Digit adding was chosen because the task is easy in isolation and should therefore have an impact on the main task without totally absorbing the attention. Digit adding has a sustained component, holding the sum in memory, and an incidental component, calculation of the new sum after a new digit is shown.

A third way was to state a limit of two seconds for giving an answer. The period of two seconds that was in most cases long enough to give an answer could give some extra pressure to hurry and reminded the subjects the goal was to respond as fast as possible. This manipulation led to a third dependent variable in addition to RTs and error rates, namely non-responses. In addition, no error feedback was presented. The effect of the dual task manipulation could be experimentally verified in this study, the effect of the other alterations was not experimentally verified because it was not our primary interest.

The first question is whether interference occurs in colour coding. Because this task was never used before as an experimental task it was necessary to verify whether colour coding could lead to interference as found in letter coding and whether it can be obtained in RTs, error rates, and non-responses. The second question is whether the dual task manipulation does lead to an increase in RTs and error rates and whether it leads to a larger increase in the A-B, A-Br situation. In other words, does lesser attention make way for the previous habit? The design of the current experiment made it possible to investigate whether there is a difference in the occurrence and amount of interference in Phase 2 and 3. In other words, is there a "neutralising" effect of the learning of unrelated stimuli or, another explanation with the same effect, a forgetting of the first combinations that leads to a diminishing of the interference effect?

In the current study, yet another coding variant was used, to broaden our scope beyond the use of letters alone and to control whether our previous results were no artefact of the letter coding. In experiment 4.1, a colour-coding task was administered for instructional purposes and it proved to be a very easy task to learn. In the present version of the colour-coding task, the subject responded by pressing a key in response to a presented colour. The subject could determine the correct key because during the first five blocks the correct combinations were presented onscreen. The task was performed with four fingers on four keys and trials followed immediately after another. In ideal conditions, the block of twenty trials was coded in a quick burst of touch-typed correct responses.
Method

Subjects

Subjects were fifty-one students of the University of Amsterdam who received course credit in exchange for their participation. Ten subjects were dropped from the study because they did not meet one or more of the following three criteria. The first criterion was a smaller than 25% error rate on Part 2 of T1. In this part, the coding was performed without the colour-key combinations. A large error rate indicated that the subject did not remember the colour-key combinations, which was a prerequisite for the following phases. The second criterion was an overall error rate smaller than 25%. The third criterion was a minimum of one correct answer on each of the digit-adding tasks in the dual task situation. Zero scores on the concurrent task indicated that the subject did not understand the task, or was not capable of handling the two tasks at the same time, or did not pay attention to the concurrent digit-adding task at all.

Design & Materials

The experiment consisted of three phases (T1, T2, T3). All phases consisted of three parts (Part 1, Part 2, Part 3). In Part 1, the coding task was trained with the colour-key combinations present. In Part 2, the coding task was done without the colour-key combinations present. In the Part 3, digit adding was added to the coding task without the colour-key combinations. After the training (T1), two groups were compared in the transfer phase (T2). The re-paired first group coded with the same colours and keys as in T1, but in different combinations than in T1. The new first group coded with new colours and the same keys as in T1. In the third phase (T3) the conditions reversed. Thus in T3, the re-paired first group coded with new colours and the new first group coded the re-paired colours. By using this design (See Table 4.4), in which all subjects passed through both conditions, the interference effect was not only studied between subjects, but also within subjects.

<table>
<thead>
<tr>
<th>Phase</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
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<tbody>
<tr>
<td>Same Colours First</td>
<td>A</td>
<td>A'</td>
<td>B</td>
</tr>
<tr>
<td>New Colours First</td>
<td>A</td>
<td>B</td>
<td>A'</td>
</tr>
</tbody>
</table>

Every phase consisted of three parts. Part 1 (5 blocks) consisted of colour coding with the colour-key combinations present. Part 2 (10 blocks) consisted of colour coding without the presence of the colour-key combinations. Part 3 (10 blocks) was identical to Part 2, apart from the additional digit-adding task. The dependent variables were RTs per keystroke (RT), error rate, and non-responses.
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Apparatus

The experiment was conducted on an Apple Power Macintosh 4400 with a 14-inch colour monitor. Responses were given with the 4, 5, 6 and Enter key on the numeric keyboard. These keys were chosen because these were the easiest to operate with the four fingers of the right hand. The unique position and form of the Enter key on the numeric keypad made it possible to use the little finger without causing cramp.

Procedure

The instruction was presented on screen and the experimenter verified whether the instruction was well understood. Subjects were instructed to make their keypress responses as rapidly and accurately as possible with the four fingers of their right hand. Each finger had to operate one designated key. The index, middle, ring and little finger had to operate respectively the 4, 5, 6 and Enter key. The experiment consisted of three phases of 25 blocks each. Between the phases was a short instruction about the change of the colour-key combinations. Between each block was a short break during which the total time for the last block was shown. During these breaks no key was present. A block consisted of 20 trials. In each block, the four colours appeared five times in pseudo-random order with the restriction that the same colours never appeared in a row. The next coloured spot appeared immediately after the response. If no response was detected within two seconds, the next trial appeared automatically.

Before Part 3 of T1 the instruction for the dual task situation was presented. In the dual task situation subjects had to code as before and to add digits that appeared in irregular intervals above the coloured spot. After each block, the subjects typed the sum and received immediate feedback.

Materials and Counterbalancing

Four different sets of colour-key combinations were used (Set 1, 2, 3, 4). Set 1 contained the colours purple, cyan, red, and yellow, respectively paired with the keys 4, 5, 6, and Enter. Set 2 consisted of the same colours and keys, but in other combinations. This new set was re-paired according to a 3421 schedule. For example, the third colour in Set 1 (red) was the first colour in Set 2. Thus, the resulting sequence of the colours in Set 2 was: red, yellow, cyan and purple. Set 3 contained completely different colours: orange, blue, green and brown. Set 3 was also re-paired according to the 3421 schedule, resulting in Set 4: green, brown, blue and orange.

For digit adding nine digits were used. The number of digits shown in a block ranged from 4 to 6 digits. The sums for the different blocks ranged from 15 to 34.

The four colour sets were counterbalanced across phases. The presentation orders of the colours and the sums were not counterbalanced and were the same for both conditions. To maximise the comparability between the phases, the presentation order of the colours was the same for the three phases. The required sums in digit adding differed across the phases, to prevent that subjects used recollection instead of calculation to obtain the correct sum.
Results

Phase 1: training

An alpha level of .05 was used for all statistical tests. T-tests showed no significant differences between the groups for RTs, error rate and non-responses in Phase 1 (in all cases \( p > .50 \)), thereby indicating that the groups were similar in terms of speed and accuracy. The difference between the Parts 2 and 3 in T1 was significant for RTs, \( t(40) = .26, p < .0001 \), errors, \( t(40) = 19.61, p < .0001 \), and non-responses, \( t(40) = 12.14, p < .0001 \). Thus, digit adding increased the workload considerably, and impeded performance. In Part 3 of T1 the correlation between error rate and the mean RT per block was .18, which was not significant. Error rate and non-response rate for coding correlated with error rate on digit adding respectively .54 (\( p < .001 \)) and .57 (\( p < .0001 \)). These relatively high correlations indicate that some subjects are overall more accurate than others are. The lack of a significant negative correlation between error rate and mean time per block shows that the more accurate subjects were not slower than the more error prone subjects were.

Phase 2 and 3: Condition Reversal

Repeated measures ANOVAs were performed on all three dependent measures. The factors for the ANOVAs were group (re-paired first group, new first group) and phase (only T2 and T3). The interaction of phase with condition was significant for RTs, \( F(1, 39) = 35.36, p < .0001 \), error rates, \( F(1, 39) = 21.39, p < .0001 \), and non-responses, \( F(1, 39) = 13.73, p < .001 \). This interaction clearly shows the hindering effect of re-pairing of the colours and responses as compared with pairing new colours to the same keys. As expected, the re-paired first group performed in T2 worse and in T3 better than the new first group. This pattern of effects applied for RT, in which, in addition to the significant interaction, also the differences between the groups in T2 and T3 were significant according to t-tests, respectively \( t(39) = 2.25, p < .05 \) and \( t(39) = 2.21, p < .05 \). For the errors, the difference between the groups was only significant in T3, \( t(39) = 2.16, p < .05 \). In the non-responses no significant group differences were found. Although not all group differences were significant, the pattern of the interaction between the phases and group was the same for all dependent measures, indicating there was no problematic trade-off between them. The overall percentage of errors in this experiment was 13.1\%, which is considerably higher than in the previous experiments.

Digit Adding

A repeated measures ANOVA was performed on the scores for digit adding. The factors for the digit adding ANOVA were group (re-paired first group, new first group) and phase (T1, T2, T3). There were no significant main effects for group or phase and there was no Group x Phase interaction (all \( p > .15 \)), indicating that the groups were comparable in terms of accuracy on the digit adding and that the digit adding scores were very constant.
Figure 4.2. Mean correct Response Times, Error Rates, Non responses with standard error of the mean as a function of phase (left pane) and group (right panel).
Further analysis within the phases demonstrated that digit adding led to a significant decrease in performance. A repeated measures ANOVA was performed on Part 2 and Part 3 of each phase for all three dependent measures. In each phase, the introduction of the digit adding in Part 3 caused a significant increase in RTs, error rate and non-responses in comparison with Part 2, $F(1, 39)$ ranging from 41.98 to 392.7, all $p < .0001$. However, digit adding did not have an extra effect on the performance in the re-paired colour conditions. According to t-tests, there were no significant differences between the groups in RTs, error rates, and non-responses in the third parts of each phase.

Discussion

Also in colour coding a strong negative transfer effect was found. The switch to the same colours in different combinations with the same keys led to the same, or even worse performance level, than at the start of the training phase. Coding with re-paired colours led to an increase in RT in comparison with coding with completely new colours. This increase of RT was also found after interpolated learning of new colours. This suggests that there is no “neutralising” effect of another related task. This also suggests that unlearning is not very likely. The same pattern of effects was found for error rate and non-responses, although these effects were smaller, as is illustrated by the insignificance of the isolated between group comparisons.

The goal to increase the error rate in comparison with our earlier experiments was reached. Especially, the introduction of digit adding led to an increase in error rate. Digit adding had, however, no differential influence on the transfer condition where the competitive colour-key bindings were used. A possible explanation for the lack of a differential effect may be that the combination of the two tasks is so difficult that subjects from both groups work in the same controlled manner. As Experiment 4.1 already suggested, a minimal amount of fluency in the operation might be a prerequisite for the occurrence of interference.

General Conclusion

Do the results from the reported experiments provide the answers to the questions posed in the introduction? The answer is: partially. Negative transfer and to a lesser degree retroactive interference is found in these more difficult tasks. Overall transfer is positive but by the use of control groups the interference effects could be isolated. Interestingly, when the tasks became very difficult, in experiment 4.1 immediately after the switch to the transfer phase and in experiment 4.2 during the dual task situation, there was (initially) no interference effect. The implication of this result is that a certain degree of fluent operation is required to obtain interference. It may not be the fluent operation itself, but it may be necessary to establish a firm representation before interference may occur. This suggests that the negative transfer found is not so much a problem in learning, as well as a problem in retrieval.

The question whether subjects adopt an intentional inhibition strategy after switching to possibly interfering tasks can be answered negatively. Subjects did not adopt an intentional inhibition strategy, only the RTs on the re-paired letter-digit combinations increased. This result is in favour of an interference effect that operates automatically.
Finally, the last question was whether subjects in possibly interfering situations could be forced to make more errors than subjects learning a new skill when brought in difficult task situations. All subjects made substantially more errors as a consequence of the manipulations. The number of errors was very large for all conditions, indicating that in very difficult task situations there is no additional effect of interference. This may have been the result of the relatively slow operation under difficult circumstances. That the dual task situation is very difficult can be derived from the fact that there was almost no improvement in the performance across the adding tasks.

This chapter nicely illustrates that negative transfer and retroactive interference do occur under a wide range of task variations (e.g. more letter-digit combinations, serial responding, and colour stimuli). These experiments add further evidence for the existence of negative transfer and interference in skill learning. In addition, these experiments also demonstrate that the occurrence and the pattern of interference in skill acquisition, as in verbal learning, is not easy to predict and is dependent on several factors.
### Appendix

Key combinations used in Experiment 4.1. The first set of nine letters represents the training key and the second set of nine letters the transfer key.

<table>
<thead>
<tr>
<th>Partial Re-paired Keys</th>
<th>Partial New Keys</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDWGJTBNR• WDNJLBBTR</td>
<td>LDWGJTBNR• ZDPGJMBVR</td>
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<tr>
<td>LFWHKTCNS• WFNHKLCSTS</td>
<td>LFWHKTCNS• ZFPHKMCVS</td>
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<tr>
<td>LGWRTJNDF• WGNRBLJJTD</td>
<td>LGWRTJNDF• ZGPRBMJVD</td>
</tr>
<tr>
<td>LHWSCTKNF• WHNSCLKTF</td>
<td>LHWSCTKNF• ZHPSCMKVF</td>
</tr>
<tr>
<td>MDZGJVBPR• ZDPGJMBVR</td>
<td>MDZGJVBPR• LDWGJTBNR</td>
</tr>
<tr>
<td>MFZHKVCPS• ZFPHKMCVS</td>
<td>MFZHKVCPS• LFWHKTCNS</td>
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<td>MGZRBVJPDP• ZGPRBMJVD</td>
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<td>WGNRBLJJTD• ZGPRBMJVD</td>
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