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Abstract

Routines may help groups to effectively reduce coordination requirements when solving interdependent tasks. However, routine problem solving always involves the risk of a negative transfer, which appears if a routine is applied to novel problems even though it is inappropriate. In this experiment, negative transfer was produced by first teaching individuals a procedure for solving the Tower of Hanoi problem. Next, participants were asked to solve several transfer tasks either individually or in pairs. However, the routine could not be applied directly to the transfer tasks but led to a long detour. As expected, the individuals surpassed the dyads, who insisted more strongly on their routine. This result fits with studies that corroborate the claim that groups are prone to a "principle of inertia" when solving problems or making decisions.

Introduction

A *routine* may be defined as a well practiced problem solving procedure, which has been applied repeatedly and, therefore, does not need much planning but may be executed rather automatically (for an overview on various definitions, see Betsch, Haberstroh, & Hoehle, in press). Typically, in the problem-solving domain, routines consist of several single action steps that have to be executed in a particular order. Even though the single steps may require some planning, the sequence of the steps itself is usually highly internalized. From this automation follows that procedures or schemata that have become a routine may easily be transferred to novel tasks. However, routines are not only transferred to structurally equivalent tasks (positive transfer), but are sometimes also applied to tasks that share only surface features with the learning task. Accordingly, there is ample evidence showing that the successful use of a scheme enhances the likelihood of a *negative transfer effect*, i.e., worse performance compared to a condition in which the scheme has not been repeatedly applied before (cf. VanLehn, 1996).

In the present study, we sought to extend the literature on learning transfer to group problem solving. In particular, the study aimed at testing whether negative transfer effects are more pronounced in dyads than in individuals. On the one hand, it may be more likely that a dyad recognizes a change in task demands. On the other hand, adapting a routine in a group usually requires coordination processes, which may cause process losses (cf. Gersick & Hackman, 1990). Moreover, there are several studies showing that groups often tend to accentuate preferences or decisions that are held by a majority (cf. Hinsz, Tindale, & Vollrath, 1997). In general, if individuals are predisposed to process information in a biased way, then, groups usually tend to enhance this bias. However, if groups use strategies more reliably and consistently than individuals, then, transfer effects should also be enhanced in groups, irrespective of whether this transfer is positive or negative.

In this study, the hypothesis that negative transfer is more pronounced in groups than in individuals was tested by asking participants to solve Tower of Hanoi problems either individually or in pairs. There are several procedures that guarantee an optimal solution of the Tower of Hanoi problem (cf. Simon, 1975). In order to produce transfer effects, participants were first taught either the goal-recursion (R) or the move-pattern procedure (M). These two procedures differ in two aspects, which make them suitable for studying transfer effects within the Tower of Hanoi problem:

(1) Only the R-procedure but not the M-procedure may be directly applied to a transfer task in which the start peg is the middle peg. (2) The two procedures lead to different patterns of move latencies. Hence, differences in move latencies may be used as an indicator of the respective procedure applied and to what extent a problem solver insisted on his/her routine.

Whereas the first study tested for process losses in pairs, the second study compared homogeneous with heterogeneous pairs and additionally considered individual learning.

The Tower of Hanoi Problem

The Tower of Hanoi problem consists of three pegs and a fixed number of disks of different sizes (Simon, 1975). The original task is to move all the disks from the left to the right peg under the following constraints (cf. Figure 1): (a) only one disk may be moved at a time, (b) only the disk that is on the top of the pyramid may be moved, and (c) a larger disk may never be placed on top of a smaller disk. A problem with *n* disks requires a minimum of 2^n–1 moves.

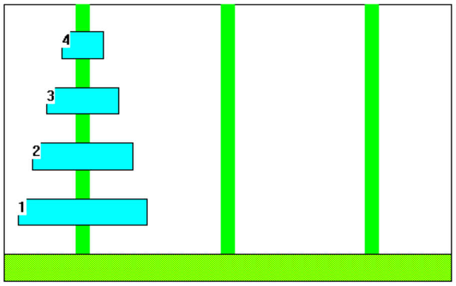

Figure 1: The Tower of Hanoi problem.

The goal-recursion procedure The *goal-recursion procedure* (R) consists in forming sub-goals. Each problem with $n > 1$ disks can be decomposed into three sub-problems: Into (1) a problem consisting of $n–1$ disks, (2) the move of the largest disk from the start peg onto the goal peg, and (3) into a second problem consisting of $n–1$ disks.

For example, the four-disk problem in Figure 1 can be decomposed into two three-disk problems and the move of a single disk: (1) First of all, the three-disk pyramid (consisting of the disks 2 to 4) has to be moved from the start peg onto the middle peg; (2) in the next step, the largest disk (number 1) can be moved onto the goal peg; and (3) finally, the three-disk pyramid has to be moved again, this time from the middle peg onto the goal peg. The three-disk problem is itself a Tower of Hanoi problem with one disk less than the original problem. Hence, the three-disk problem can be decomposed into two two-disk problems and the move of a single disk. Thus, the recursion procedure is based on a chunking strategy by dividing a problem into sub-problems until only one disk remains and there is no longer any problem.

The move-pattern procedure The *move-pattern procedure* (M), on the other hand, is based on a stimulus-driven instead of a goal-driven heuristic, without formulating any sub-goals. According to this procedure, one has to learn a particular pattern of moves, whereby attention has to be paid to the *position* of a disk and to its *parity*: *Odd*-numbered disks should always be moved from the left to the right, from the middle to the left, and from the right to the middle. *Even*-numbered disks are moved the other way round, from the left to the middle, from the middle to the right, and from the right to the left. Additionally, the same disk should never be moved twice in one go. The latter constraint guarantees that it is always clear which disk is to be moved next. For example, according to these rules, disk 4 in Figure 1 should be moved onto the middle peg because it is an even-numbered disk. Next, disk number 3 should be moved onto the right peg, because the same disk should never be moved twice in one go and *3* is an odd number.

Original vs. transfer tasks It is worth noticing that both procedures lead to the same pattern of moves and to an optimal solution, provided all rules are strictly adhered to. This functional equivalence holds for any number of disks. However, if the start peg is the *middle* peg instead of the left peg, only the recursion-procedure is optimal. The move-pattern procedure may be applied to such a *transfer task* as well, but it requires twice as many moves as the optimal goal-recursion procedure: If a transfer task is solved by applying the move-pattern procedure, the entire tower moves first onto the left peg and then onto the right peg.[1]

Differences in move-latencies Even though both procedures lead to the same pattern of moves with original tasks, they differ in the amount of planning and, therefore, result in different patterns of *move latencies* (cf. Reimer, 2001a). If the M-procedure is applied, the cognitive effort is almost the same for all moves (despite the fact that the decision as to which disk should be moved next may vary among different game situations). Thus, a player who applies the M-procedure is expected to move disks relatively regularly. According to the R-procedure though, at the very beginning as well as in situations, in which a new sub-tower has to be solved, extensive planning is required. Whereas these "first moves" should last long, subsequent moves (i.e., all other moves) should be carried out fast in order to execute the planned recursion smoothly without extensive interruptions. Hence, ideally, an application of the R-procedure results in high latencies in the first moves and short latencies when subsequent moves are performed.

In general, the extent to which a player spends more time on first moves than on subsequent moves may be quantified by the following strategy index (S):

$$S = FM / SM,$$

with FM = mean time for first moves and SM = mean time for subsequent moves. Because the M- and R-procedure differ in the extent of chunking and planning, participants who were taught the R-procedure were expected to score higher on the strategy index than participants who had been taught the M-procedure (S_R

[1] In order to meet this criterion, the original move-pattern procedure, which was described by Simon (1975), was slightly changed by linking the move patterns to the left, middle, and right peg instead of the start and the goal peg.

> S_M). Additionally, the strategy index may also serve as a measure of the extent to which participants in the M-condition change their strategy towards a chunking-strategy when solving transfer tasks.

Study 1

The first study aimed at (1) testing for differences in performance between pairs and individuals, and, in particular, to test whether the M-pairs suffer from any process losses when solving transfer tasks (*process-loss hypothesis*); (2) testing the claim that the M-pairs insist more strongly on their procedure than the M-individuals, which should result in a lower strategy index for the M-pairs than the M-individuals (*persistency hypothesis*); and (3) testing to what extent the potential process losses are mediated by the strategy index (*mediation hypothesis*).

Method

Sample and design The design consisted of three factors: Firstly, participants were individually taught either the R- or the M-procedure (factor *procedure*). Secondly, participants solved problems either individually (I) or in pairs (P) (factor *group*). Finally, type of task was varied as a within-subjects factor. Each individual and each pair had to solve two original and two transfer tasks, one four- and one five-disk problem each.[2] The 90 students who participated in the study were randomly distributed among experimental conditions (15 pairs in the conditions R-P and M-P and 15 individuals in the conditions R-I and M-I).

Procedure Each participant was first individually explained the R- or the M-procedure. Additionally, each person completed a computerized training run with 30 tasks that always required only a single move. In the *R-condition*, their task was to solve sub-problems. For this purpose, one or more disks were already marked on the computer screen. The respondent's task consisted in moving the respective sub-problem in the correct direction. In the *M-condition*, respondents were also confronted with different game situations. Here, the task consisted in executing the next move according to the M-procedure. In both conditions, immediate feedback was provided by the computer on whether the single move was correct or wrong.

In the testing phase, participants were asked to solve two original and two transfer tasks in as few moves as possible. In the pair condition, they moved in turns without communicating with each other. The opportunity to correct or to undo moves by moving a disk twice in one go was explicitly mentioned in the instructions. If a person tried to place a larger disk on top of a smaller one, an error message appeared on the screen.

Results

Number of moves Table 1 shows the mean number of moves that were required by the individuals and pairs. An ANOVA with the factors, *procedure* (R vs. M), *group* (I vs. P), and *task* (original vs. transfer tasks), revealed an interaction of *task x procedure*, which was due to negative transfer in the M-condition ($F(1,56)_{\text{task x procedure}}$= 115.51; p<.01; $F(1,56)_{\text{procedure}}$= 94.32; p<.01; $F(1,56)_{\text{group}}$= 0.13; ns; $F(1,56)_{\text{task}}$= 121.43; p<.01). In the R-condition, the original as well as the transfer tasks were solved almost perfectly ($M_{\text{original task}}$= 24.15; $M_{\text{transfer task}}$ = 24.38; $t(29)$= –.50; ns).

Table 1: Mean Number of Moves.

	R		M	
	I	P	I	P
Original tasks	24.83	23.47	25.87	23.50
Transfer tasks	25.20	23.57	39.97	46.77

However, participants who had been taught the move-pattern procedure required many more moves to solve the transfer tasks than the original tasks ($M_{\text{original task}}$= 24.68; $M_{\text{transfer task}}$= 43.37; $t(29)$= –10.2; p<.01). Moreover, as can be seen in Table 1, this negative transfer was enhanced in the group of the M-pairs. Accordingly, the two-way interaction was further qualified by a significant three-way interaction of *task* x *procedure* x *pair*, F (1,56)= 7.55; p<.05. Obviously, the M-pairs suffered much more from their routine than the M-individuals when solving transfer tasks ($t(28)$= 2.17; p<.05).

Move latencies Are these process losses caused by a higher persistency of the M-pairs? First, as expected, participants in the R-condition had much higher strategy indices than participants in the M-condition throughout (cf. Table 2).[3] This holds true for original tasks ($t(58)$= 8.3; p<.01) as well as for transfer tasks ($t(58)$= 4.28; p<.01).

Additional ANOVAs, which were conducted separately for the M- and the R-condition, confirmed the persistency hypothesis:

[2] For the following analyses, measures were aggregated across the four- and five-disk problems throughout. Problems with four disks are solvable in 15 moves and problems with five disks require 31 moves. Thus, the minimum number of moves is 23, irrespective of the task conditions, i.e., regardless of whether original or transfer tasks are solved.

[3] The distribution of latencies was positively skewed. For this reason, each latency per move was transformed first by taking the logarithm. All reported analyses are based on these transformed latencies.

Table 2: Mean Strategy Index.

	R		M	
	I	P	I	P
Original tasks	1.16	1.08	1.04	1.02
Transfer tasks	1.18	1.09	1.10	1.02

In both analyses, the main effect of *group* ($F_R(1,28) = 55.61$; $F_M(1,28) = 12.88$; $ps<.01$) was significant, indicating higher strategy indices for the individuals than for the pairs. These main effects may be explained by the time that is required by the pairs when taking turns. Secondly, there was also a significant main effect of *type of task* in both conditions: Overall, participants in the R- ($F_R(1,28) = 6.27$; $p<.05$) as well as in the M-condition ($F_M(1,28) = 6.94$; $p<.05$) showed higher strategy indices when solving transfer tasks compared with original tasks. However, only in the M-condition the two main effects were qualified by a significant interaction ($F_M(1,28) = 5.16$; $p<.05$; $F_R(1,28) = 0.70$; ns). As can be seen in Table 2, the M-individuals had a much higher strategy index in the transfer tasks than in the original tasks ($t(14)= 2.70$; $p<.05$), whereas the M-pairs did not change the way in which they structured the problem solving process ($t(14)= 0.44$; ns).

Predicting performance by the strategy index The observed persistency may also serve as an explanation for the differences in performance. In order to show that the observed process losses are due to the extent to which the M-individuals and M-pairs changed towards a chunking strategy, an ANCOVA on the number of moves was run using the strategy index as a covariate. As can be seen in Figure 2, which refers exclusively to the M-condition and to the transfer tasks, the observed process losses disappear if differences in the strategy index are controlled.

Discussion

Participants who had been taught the goal-recursion procedure did not have any serious problems solving the transfer tasks (positive transfer). Within the move-pattern condition, however, a negative transfer effect appeared. Further, the M-pairs performed worse on the transfer tasks than the M-individuals, which confirms the process-loss hypothesis. However, these process losses do not seem to be due to mere mutual distraction in the pairs, that is, it is unlikely that participants distracted each other in general when joining a dyad. If this were the case similar process losses should have been observed in the other pair conditions, too. Rather, the results confirm the persistency hypothesis: Obviously, the M-pairs did not only need many more moves to solve the transfer tasks but also insisted more strongly on using their strategy than the M-individuals, who reacted much more flexibly and tried to adopt a chunking strategy.[4]

In general, participants in the R-condition spent more time on the first than on subsequent moves, whereas participants in the move-pattern condition made their moves much more regularly. Thus, in the original tasks, the participants in the R- and M-condition did not differ in their performance, but could easily be identified on the basis of their strategy index. Moreover, differences in performance disappeared when differences in the strategy index were controlled (mediation hypothesis).

Thus, the first study confirms the assumption that negative transfer effects will be enhanced by dyads who were taught the same inappropriate routine and, therefore, share a common knowledge. However, it is reasonable to assume that it is this unanimity in particular that puts the pairs at a disadvantage. According to this interpretation, persistency was fostered by the fact that both members had learned the same inappropriate procedure. However, if this is true, then, *heterogeneous pairs* should perform much better, in particular if one member has access to an appropriate procedure. On the other hand, if participants persist in their procedure irrespective of what the other person does, such a mixed pair should not perform better than a uniform M-pair.

Study 2

This issue was addressed in the second study, in which each person belonged to a pair condition. In order to test for the heterogeneity hypothesis, a mixed pair-condition was introduced, which consisted of one M- and one R-participant (condition MR). Additionally, immediately after the learning phase and at the very end of the experiment, participants were also asked to solve several tasks individually in order to test for differences in individual learning.

Method

Sample, design, and procedure The sample consisted of 112 senior high school students who were randomly assigned to one of the three pair-conditions, MM, MR, or, RR, under the restriction of approximately equal numbers within the mixed (26) and uniform pairs (15 pairs each). First, as in experiment 1, each participant was individually taught either the M- or the R-procedure. During the testing phase, each pair had again to solve four tasks, two original and two transfer tasks, of which one problem consisted of four and one of five disks.

[4] As further evidence for the persistency hypothesis, a classification of single moves revealed that the M-pairs carried out relatively more moves that are in accordance with the move-pattern procedure than the M-individuals when solving transfer tasks (cf. Reimer, 2001a).

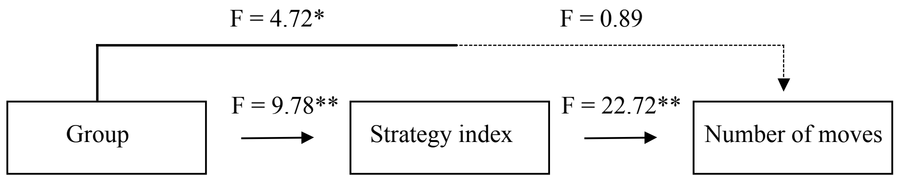

Figure 2: Path diagram: Study 1.

Additionally, participants had to individually solve two original problems with four and five disks prior to the group condition and two respective transfer problems immediately after the group condition.

Results

Single person condition I Table 3 shows the mean number of moves that were required by the individuals solving original problems immediately after the learning phase. This table is not based on the dyads but rather on the single persons as unit of analysis. For example, the condition *R / Uniform* refers to those participants who had been taught the goal-recursion procedure and who joined a person in the group condition who had access to the same procedure.

Table 3: Mean Number of Moves in the Individuals.

	R		M	
	Uniform	Mixed	Uniform	Mixed
Original tasks	29.33	26.68	28.08	26.72
Transfer tasks	28.35	28.22	52.32	49.54

An ANOVA with the factors *procedure* (R vs. M) and *group* (uniform vs. mixed) confirmed that there were no significant differences between the three experimental pair conditions on the individual level prior to the group condition (all Fs < 2; ns). Even though it is again impossible to identify the procedures on the basis of the number of moves, the two conditions M and R may be identified on the basis of their strategy index.

As is shown in Table 4, participants who were taught the R-procedure had higher scores on the strategy index than participants in the M-condition. Accordingly, a 2x2 ANOVA revealed a strong main effect of *procedure* (F (1,108) = 121.9; p<.01; Fs for the main effect of *group* and the interaction were less than 1).

Group condition A 2x3 ANOVA on the number of moves showed two main effects (cf. Table 5):

(1) Overall, more moves were made to solve the transfer tasks than to solve the original tasks (main effect of *type of task*: F (1,53) = 100.26; p<.01).

Table 4: Mean Strategy Index in the Individuals.

	R		M	
	Uniform	Mixed	Uniform	Mixed
Original tasks	1.17	1.17	1.05	1.04
Transfer tasks	1.16	1.17	1.08	1.05

(2) The highest number of moves was required in the uniform move-pattern condition (MM). The mixed pairs (MR) took the middle position and the RR-pairs performed best (main effect of *group*: F (2,53) = 38.08; p <.01).

(3) However, as expected, there was again a significant interaction of *type of task x group*, F (2,53) = 37.08; p <.01. As can be seen in Table 5, the differences between the pairs were almost exclusively due to the transfer tasks.

Table 5: Mean Number of Moves in the Pairs.

	RR	MR	MM
Original tasks	23.47	23.77	23.50
Transfer tasks	23.57	31.71	46.77

Overall, the observed pattern in performance may be described as follows: Whereas the original problems were solved almost optimally in each condition, there were huge differences in performance between the pairs on the transfer tasks. These difficulties were most pronounced in the MM-condition and to a much lesser extent in the MR-condition. In the RR-condition, participants had no problems with the transfer tasks at all. Interestingly, the mixed pairs, who differed significantly from the MM- as well as from the RR-pairs, performed better than the pooled uniform pairs (M_{MR} = 31.71; $M_{MM / RR}$ = 35.17; p<.05).

As expected, the pairs also differed consistently in the extent to which they applied a recursion strategy (cf. Table 6). A 2x3 ANOVA on the strategy index revealed a main effect of *group*, F (2,53) = 29.35; p <.01 (the Fs for the main effect of *type of task* and the interaction were <1.3; ns). Within the original as well as the transfer tasks, the three pair conditions may be rank ordered on the basis of their strategy index ($S_{RR} > S_{MR} > S_{MM}$).

Table 6: Mean Strategy Index in the Pairs.

	RR	MR	MM
Original tasks	1.09	1.05	1.02
Transfer tasks	1.10	1.05	1.03

Moreover, in analogy to experiment 1, the differences in performance were, at least partially, mediated by the strategy index. If the strategy index was included as a covariate, differences in performance were reduced (F (2,53) = 38.08 vs. F (2,52) = 20.0; effect of the strategy index as a covariate: F (1,52) = 57.5; all ps<.01).

Single person condition II Table 3 and 4 (see above) also show the mean number of moves and the strategy indices in the final test of the individuals. In this test (1) the R-individuals achieved better results than the M-individuals (main effect of *procedure*: F (1,108) = 54.03; p<.01). (2) There were no significant differences in performance between the M-individuals who had joined an M- or an R-partner in the group condition (the Fs for the effects of *group* and of *procedure x group* were < 1; ns). (3) Analogous results were also observed for the strategy index (main effect of *procedure*: F (1,108) = 92.33; p<.01; neither the main effect of *group* nor the interaction were significant).

Discussion

As in the first study, the original tasks were solved almost perfectly by all pairs, even by the mixed MR-pairs. Here, the two distinct procedures *converged* to a common problem solution (cf. Reimer, 2001b). The result, i.e., that these pairs performed much better on the transfer tasks than the uniform M-pairs, suggests that group heterogeneity improved performance. Further analyses of the contributions of the M- and R-*individuals* within the mixed groups revealed that the M-participants performed significantly better when solving problems in mixed pairs than in uniform pairs. The M-participants who belonged to a mixed pair made a much higher relative number of correct moves than the M-participants who belonged to a uniform pair. This pattern was reversed for the R-participants who performed worse in the mixed pairs than in the uniform pairs. Even though this seems to support the heterogeneity hypothesis, an interesting question for further research would be whether the advantage of the M-participants who joined a mixed group had also appeared if both players had been taught *distinct inappropriate* procedures. Astonishingly, the advantage of the M-participants who belonged to the MR-pairs disappeared in the final test. However, when interpreting the results on individual learning, one should keep in mind that the pairs were not allowed to talk to each other and, therefore, had no opportunity to explain and even exchange their ideas.

Whether communication enhances or reduces the observed process losses may be another interesting issue for future research likewise the question whether the findings can be generalized to groups that consist of more than two members. In general, we can expect that the larger the groups the stronger the transfer effects supposing a group consists of homogeneous group members that share the same routine. As far as the communication issue is concerned, there is at least some evidence that communication enhances performance in pairs who have not been taught a routine but who have to develop a common strategy (cf. Reimer, 2001a).

Overall, these studies confirm the claim that groups who have routinized a problem solving procedure persist more strongly in their routine than individuals. Groups tend to behave like "ocean steamers": They often need much time and effort to work out an efficient problem solving procedure. However, once having reached a solution they are likely to persist in their routine and stick to their course irrespective of changes in the environment. The most obvious *advantage* for a group in following "the principle of inertia" consists in saving time and energy, because routines need not be actively managed and, subsequently, reduce coordination requirements (cf. Gersick & Hackman, 1990). Moreover, in situations in which the "ocean steamer" is on the right course and a routine is appropriate, groups may be expected to *surpass* individuals (cf. Hinsz et al., 1997) by better compensating for individual errors and by fostering positive transfer.

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