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PRACTICE UNDER CHANGING PRIORITIES: AN APPROACH TO THE TRAINING OF COMPLEX SKILLS *

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The present paper discusses the theoretical foundations and methodological rationale of a novel approach to the training of complex skills. This approach is based on the introduction of multiple emphasis changes on subcomponents of a complex task. The approach links together arguments from models of skills and theories of attention. It is construed that the core of expert performance is an organized set of response strategies that can be employed flexibly to meet task demands. Strategies can be constructed through emphasis change. This approach was applied to the training of 4 groups of players in a highly demanding computer game. Subjects trained under emphasis manipulations performed significantly better than control players who played the game for the same duration without instruction. Moreover, the advantage of the trained groups continued to increase after formal training had been terminated. Low-ability subjects benefitted more than high ability subjects from multiple emphasis changes. The proposed approach appears capable of resolving several of the difficulties that were hitherto encountered by traditional part–whole training methods.

Introduction

'Practice makes perfect'. This statement is one of the more reputed and widely cited rules of folk psychology. It has its roots in two powerful observations. One is the immense quantitative and qualitative differences between the performance of novices and experts on any given task. The other is the fact that these differences are built up in the course of experience and practice. The more complex and demand-

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ing a task, the larger the gap between expert and novice, and the more powerful the effects of learning. Scientific theory and research on skill acquisition, while accepting the general truthfulness of these observations, have also demonstrated time and again that practice is not enough. Not all forms of practice make perfect, or even lead to a positive gradient of progress. Some schedules of training are much more efficient than others and the difference cannot be simply compensated for by additional time on task (see Adams (1987), Wightman and Lintern (1985), Schneider (1985) for recent reviews). In addition, there is also an ongoing debate on the interpretation of the concept of 'perfect', or the ultimate product of practice. Namely, theoretical models differ in their views on the nature of skilled performance, its basic faculties, memory mechanisms and organizing rules (Gopher and Kimchi 1989).

Embedded in the claim that the mere prolongation of practice time may not lead to perfect performance, is an argument that the human is not necessarily a 'natural optimizer'. Hence, additional time on task may not lead to convergence on an optimal, 'perfect' solution. A better understanding of the dimensions of skills and the way they develop with training are, therefore, essential for the efficient development of a training program.

In the present paper, we examine the response properties of individuals attempting to acquire expertise on a complex and demanding task. We also propose and test a new approach to the training of complex skills. This approach ties together arguments and concepts that have been developed in the fields of attention, skills acquisition and knowledge representation. Key constructs in this approach are the voluntary control of attention, strategies of performance and action schemas. We shall use these concepts to restate and examine some of the main issues that have been associated with the process of acquiring expertise, as well as to present new perspectives for future research.

From strategies to schemas

Central to our approach is the idea that the heart of a complex skill is an organized set of response schemas, which can also be viewed as strategies of performance. Performance on any task of intermediate or higher level of complexity requires the execution and coordination of many complex action sequences, several of which are likely to be active at any given moment. When performing such tasks, the performer is often required to operate in parallel or interweave several action sequences that overlap in time, or impose concurrent demands on the same processing mechanisms. Each action sequence is by itself a complex ensemble of responses, frequently requiring pattern identification, mental computations and decision making. It also draws upon a considerable amount of information from knowledge bases and memory storages.

Hence, the more complex a task, the more likely it is to exceed the concurrent processing and response capabilties of the performer, especially in early stages of training. In addition, the larger the number of components in a task, the greater is the number of combinations that can be used to achieve the same final outcome. Strategies can be thus conceived to determine which of the combinations will be selected, what emphasis will be put on different aspects of performance and which components will be integrated together.

A strategy is defined as a distinct approach, a set of differential weights or attention biases, that influence the performer's mode of response to the requirements of a task. A strategy reflects the solution developed by the performer to better cope with the set of subgoals of a task, the demands imposed by its different elements and the situations within which it is practiced. While beginning as a controlled and voluntary act of choice or instruction, strategies once developed and practiced may become high-level schemas that can be triggered automatically.

The 'schema' concept is the building block of most contemporary models of human skills, across a wide range spanning from perceptual, memory and problem-solving skills (Anderson 1981, 1985), to motor responses and psychomotor tasks (Adams 1987; Norman and Shallice 1980; Schmidt 1975, 1982). While there is no consensus among researchers about the actual parameters and elements of schemas, there is an agreement on the general nature of schemas. They are viewed as well organized sequences of responses that can be triggered as a unit. The operation of a schema is assumed to require little attentional resources (Schneider 1985). Lower-level schemas or a family of schemas can be triggered by higher-level schemas (Norman and Shallice 1980). The more complex and diversified a task the more elaborated is its hierarchy of schemas. (See e.g. Chase and Ericsson (1981) for an experimental example of the development of a hierarchy of schemas in a memory task. See Rumelhart and Norman (1982) for such an example in the acquisition of a typing skill.)

The key process in the development of schemas, and hence in the acquisition of skills, is the linking together of elementary units and their organization into larger coherent units. Many of the more advanced skills and especially those that are acquired at an adult age (e.g. typing or driving), capitalize primarily on the restructuring and reorganization of existing and already well practiced elementray units. The control of fingers and the aiming movements of the arms are examples of elementary units. In the new skills they are recombined and incorporated in schema units that may now serve the operation requirements of a typewriter keyboard or the control of the wheel of a car.

The idea that strategies may develop into schemas and alter the final response of the system by effecting the connections between elements, without a necessary change in the composition of elementary units, fits well with contemorary neural network theory and the Parallel Distributed Processing (PDP) models. Proponents of the PDP approach (McClelland and Rumelhart 1985, 1986), propose that the brain's processing system consists of a collection of simple processing units, each interconnected with many other units. The units take on activation values and communicate with other units by sending signals modulated by weightings associated with the connections between units. Units are organized into modules that receive inputes from other modules. The units within a module are richly interconnected. According to the PDP approach a mental state is a pattern of activation over the units in some subset of modules. Alternative mental states are simply alternative patterns of activation over modules.

There is a clear similarity between the concepts of strategies and mental states. Moreover, the emergence of modules and consistent patterns of activation with reinforced repeated experience, may provide the theoretical base for describing the processes underlying the change of strategies into high level schemas.

A concrete example may better clarify the notions of strategies and schemas. In the game of tennis, the champion player has to master the various elements of the game and memorize its rules and procedures. Isolated game elements, such as forehand and backhand strokes or serves are important, but in themselves are of relatively low weight until they can be incorporated into higher-level game strategies, as the player plans his opening tactics, defensive game from the back line, or offensive play at the net. Planning and application of game strategies is difficult and demanding in the process of their development. However, once established they can be operated almost automatically, as strategies become well organized schemas. Note, that as each individual game develops, or different opponents are encountered, strategies may have to recombine or change priorities dynamically. Hence, one feature of expertise is the availability of different strategies and the ability of the performer to be flexible in adjusting them to meet the changing requirements of the situation.

Note also that there is more than one way that may lead the player to the same final outcome: winning the game. To qualify for the national team, a tennis player cannot neglect any aspect of the game. Yet, he may excel in some elements and be weaker in others. For instance, he may have such a good serving stroke that he may score 40% aces. This may compensate for weaknesses in his defensive or offensive game. In other words, optimal strategies in complex tasks represent a match between the abilities and capabilities of an individual and the requirements of the task.

We view the Space Fortress game, which is the experimental task employed in this study, as representative of this general class of complex, high-load tasks. Consequently, our main research efforts have been directed to the development of training methods that will teach subjects strategies to cope with the complexity of the game and enable them to select those strategies that best match their capabilities.

Emphasis change and attention control

It is apparent from the examination of the tennis example and from our definition of strategies, that voluntary control of attentional resources plays an important role in the development of strategies, as well as in the ability to carry out the performance policies which are dictated by them. The decision of a tennis player to switch from a defensive to an offensive game reflects a change of strategy, which implies a major change in the focus of attention and increases the saliency of some schemas and task elements, while others move into the periphery. The act of shifting strategies is hence also an act of changing the focus of attention.

Furthermore, as a task becomes more complex and demanding and the load on the central processor is increased, the performer is less able to attend to everything and has to decide wisely how to divide his attention efficiently and how to mobilize available resources to meet task demands. There is a vast literature discussing the contribution of attention limitations to performance decrements under divided attention conditions (see Kahneman (1973) and Gopher and Donchin (1986) for a review). Two important questions in this context are, how able are human subjects in controlling their attention? and, can the control of attention be improved with training?

Several lines of experimental work proved the importance of studying these questions. They showed that, in general, subjects have only limited knowledge of the efficiency of their resources and make little spontaneous effort to explore different allocation policies. However, when given proper instructions and feedback information, subjects are quite capable of mobilizing attention voluntarily and greatly improve their performance under high load conditions (Gopher and North 1977; Gopher and Navon 1980; Gopher et al. 1982). Moreover, additional experiments showed that performance under high-load conditions benefits most when subjects are trained under several, or varying, levels of subelement priorities (Gopher 1980, 1981; Brickner and Gopher 1981; Spitz 1988). In these experiments, the levels of emphasis on members of a dual-task paradigm were changed in different experimental trials. Subjects were able to follow those changes and explore the effects on performance of different attention levels. They also appeared to have developed a better match between the requirements of the tasks and the efficiency of their efforts.

Referring back to the analogy drawn between changes in the focus of attention and altering strategies of performance, the term ‘ emphasis change’ in the above description, can now be substituted with the term strategy change. The argument can now be restated to say, that when performing a demanding task subjects have little knowledge about, and do not spontaneously explore, alternative strategies. When led to do so, performance improves. This claim echos our final statements in the discussion of schemas and performance strategies. Thus, from two quite independent lines of thinking, schema models and attention theory, we converge to propose the same approach to training. An approach based upon the the introduction of systematic changes in the emphasis on subcomponents.

Emphasis change as a new variant of part training

Part–whole training has been the most common solution to the training of a task which is difficult and demanding and cannot be initially coped with (see Adams (1987), Wightman and Lintern (1985), Schneider (1985) for recent discussions). Under this approach, the whole task is decomposed into segments. Subjects are trained on each of the segments separately before moving to practice the total task as a whole. Wightman and Lintern (1985) distinguish between three major approaches to decomposition, which they label segmentation, fractionation and simplification. Segmentation entails the isolation of distinct temporal or spatial segments. Fractionation breaks down the task into elements (an example may be the separate training of aeroplane control on the pitch and roll axes). Simplification implies the reduction of difficulty on one or more elements of the task.

In application, the part–whole approach has encountered several problems. In many situations, it is difficult to determine what are the most appropriate parts to train separately. Another concern is that by isolating segments their nature may change, because they are removed from the broader context in which they were performed. A related possibility is that response strategies that were acquired while parts were practiced in isolation will not transfer, or will even have negative transfer, to the performance of the whole task. The severity of these problems is magnified if we accept McClelleland and Rumelhart's (1985) claims that the main properties of schemas reside in the connections between elements. These connections are lost when tasks are decomposed. This may be one theoretical reason that explains the fact that the empirical support for the efficiency of part training has been inconsistent and mostly negative (Wightman and Lintern 1985).

In our training approach, we propose to manipulate only the relative emphasis (priority) of selected subcomponents and leave the whole task intact. This approach avoids most of the above problems and provides several additional advantages. When emphasis is changed, rather than separating a designated task segment and isolating it from the whole, we only change its attention status. We create a new figure–ground relationship between this segment and all other elements of the task. But, we do not break physically the task into parts. This has the additional advantage that, when emphasis on elements is changed, subjects not only receive more information on their performance on the emphasized element, but may also learn the costs to performance on other aspects of the task that have been de-emphasized. On different training trials, different elements are selected for emphasis. Thus, the essence of the procedure is training under varying conditions of subcomponent priorities.

It is important to note that under the emphasis manipulation approach, the task in general is not simplified. If anything, it is complicated, because in addition to the original requirements, subjects must also monitor priorities, allocate and change the allocation of attention to comply with the change of emphasis. However, it is a much more organized and structured complexity. There are goals and subgoals and an order of priorities in which elements have to be attended to while developing proficiency.

Method

Experimental task: The Space Fortress game

The Space Fortress (SF) game was developed at the Cognitive Psychophysiology Laboratory of the University of Illinois, to simulate a complex and dynamic operational environment (see Mané et al. (1983), Mané and Donchin (1989, this vol.) for detailed description). The main elements of this game are plotted in fig. 1. They were presented on an HP, CRT display governed by a PDP-11/23 microprocessor. Sound effects were produced by a Votrax voice system. Subjects interacted with the game through a right-hand stick and and a left-hand 3 pushbutton panel. The task was to control the movement of a space ship in a frictionless environment, with the aim of firing missiles to destroy the space fortress located in the middle of the screen. The ultimate objective of the game was to achieve the highest score.

The fortress itself which rotated around its center point, aimed and fired at the ship. Other elements were mines, which appeared every 4 seconds. They chased the ship in order to destroy it and were active until destroyed, or 10 sec. had elapsed. When a mine appeared, firing at the fortress was ineffective. Mines were identified as friend or foe, by a letter displayed above the fortress. A friendly mine could be destroyed by the ship with the regular missles. To kill a foe mine, the weapon system had to be changed by pressing twice, with an interpress interval of 250–400 msec, on the IFF button located on the left. The player had a total of 100 missiles, but could obtain more, or alternatively receive extra points, by monitoring the random symbol display below the fortress, for the appearance of two successive $ signs. A general display sector at the right bottom of the screen, informed subjects of the interval between IFF presses, the remaining number of missiles and the general score. The control dynamic of the ship was very difficult and there was also a strict limitation on the rate of firing. When violated, the fortress vulnerability index returned to zero. Subjects received 4 points for

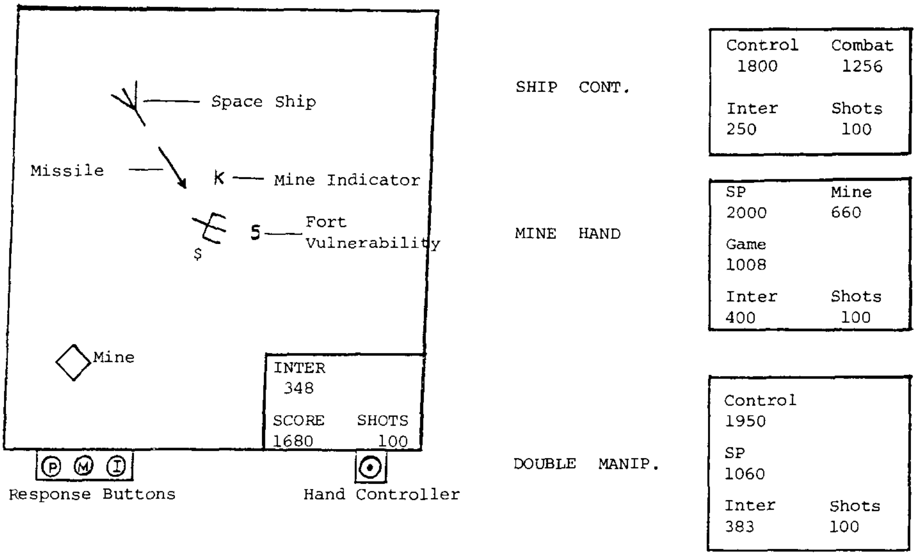

Fig. 1. Subject's display in the Space Fortress game. The three boxes on the right-hand side of the main display depict the information that was presented for each of the emphasis manipulation groups (see description below). These boxes replaced the information box on the right bottom of the standard game display.

each hit of the fortress, 100 for destroying it, 30 for hitting a mine, 100 if they selected a point bonus. They lost 50 points when hit by the fortress or by a mine 3 if fired when there were no missiles.

The game was built to include the main components of a complex, dynamic psychomotor and cognitive control task. It has a difficult manual control element, several discrete and precise motor responses, complex visual scanning and monitoring, memory requirements for letter sets and for procedures, decision making and resource management considerations, high workload and dynamic allocation of attention. Experienced readers may recognize the resemblance to the requirements of piloting an aeroplane or operating in an industrial control room.

Development of emphasis manipulations

Experiments were conducted with two types of emphasis manipulations: one which focused on the control of the ship, and one which concentrated on the handling of mines. The decision to concentrate on these two elements was influenced by several lines of information. One was our own analysis of goals and subgoals in the game. It became immediatly apparent that good control of the ship is the key element determining playing ability. Without such control, efficient aiming and shooting at the fortress and mines, or avoiding being hit, is almost impossible. It also became evident that the control of the ship is very difficult. The handling of mines was identified as a second element of importance. Mines incapacitate the ship's ability to score hits against the fortress and can destroy the ship. Fast destruction of mines is a good way to accumulate points and secure larger number of time intervals during which the fortress can be fired at.

Another line of evidence supporting the selection of these task segments came from the results of an additive factors analysis conducted by Mané et al. (1983). Finally, we also ran a pilot study, during which 6 subjects played the full game for 10 or 20 hours. The subjects' behavior was continually observed and scored. They also completed a long structured questionnaire at the end of each session, and a short one after each game segment. They were also interviewed informally. Of the 6 subjects only 1 reported good control of the ship at the end of 10 hours. Regarding mine handling, there were continuing reports of problems changing the weapon system and responding quickly.

Manipulation 1 – Ship control

As indicated above, the control dynamics of the ship was complex and players had difficulties in maneuvering it. They often crossed the limits of the screen and had to restart controlling the ship from the other end of the screen, at increased velocities. Without good control, the difficulty of performing all other subtasks such as aiming and firing, killing or avoiding a mine and monitoring the bonus display was greatly increased. When control was achieved, the best pattern of behavior was to circle the fortress at low to moderate speed. This style of control was found to minimize control efforts and enable comfortable aiming and firing.

Our first manipulation addressed the ship control component. An additional score counter was added to the total game score and was labeled 'Control' (fig. 1). The values in this counter increased positively as a function of the amount of time during each game trial (3 or 5 min), that the ship stayed on the screen, did not cross its boundaries, and did not bounce into the fortress. Another monitor rewarded ship movement at a speed equal or lower than prescribed velocity. In addition, a number indicating current ship velocity appeared above the ship symbol each time its movement velocity exceeded the instructed value. Hence, subjects had to master two main elements: (a) they had to learn to change trajectories and keep away from the edges of the screen, (b) they had to move at slow to moderate velocities. The best way to achieve these goals was to circle slowly around the fortress. All subjects trained with this manipulation indeed converged to this mode of response. The old game score counter was renamed 'Combat' (fig. 1). Note that subjects could continuously compare their relative achievements in ship control to those of the other elements of the game, by comparing the values of these two counters.

Manipulation 2 – Mine handling

A similar logic has been applied to emphasize the development of all skill elements related to the handling of mines. Under this manipulation two additional counters were added: one was labeled 'Mines (MN)', the other was labeled 'Speed (SP)' (fig. 1). The old game score was labeled 'Game'. The mine score combined points given for destroying friend and foe mines and penalties due to the ship being damaged by mines. The speed score awarded a decreasing number of positive points for identifying and destroying mines. Subjects were thus most rewarded when they identified and destroyed mines quickly. To recapitulate, in terms of the ultimate objectives of the game, to obtain the highest score, immediate destruction of mines was important in two respects: (1) it awarded subjects positive points, and (2) it gave them more time to deal with other components.

Note that neither of the two manipulations changed the physical elements of the game and their relationship. The only changes were in the tradeoff matrix for patterns of behavior and the addition of displays to reflect those changes (fig. 1).

Procedure

In the training experiment the two manipulations were given to three groups of subjects. one group practiced only with the ship control emphasis change. A second group received the mine handling manipulation. The third groups was trained under both manipulations together. Finally, a fourth groups served as a control. Subjects in this group played the game for the same duration, without exposure to any of the emphasis change versions.

Subjects in all groups played the game for 10, one hour, sessions. Each session was composed of several, few minute, game trials interspersed with rest periods. Most sessions were administered on consecutive days, unless interrupted by a weekend. In no case was the interval between two sessions longer than two days. The criteria for testing the efficiency of the different training schedules was the score achieved by subjects at the 10th hour, in playing the standard complete game.

The following is a concise description of the schedule of training given to each of the 4 experimental groups. A detailed description can be found in Gopher et al. (1986):

(1) Control group. Standard instructions, followed by 5, five minute games at the first meeting. Seven, 5 minute games at the second meeting, 8 at meetings 3–10. The net duration of game playing for this group during the 10 sessions was 380 minutes.

Emphasis manipulation groups

(2) Ship control. Time structure was as in the control group. However, subjects played the ship control version with the auxiliary displays for 6 meetings (45 trials × 5 min, total 220 minutes). They were transferred to the regular standard game on meetings 7–10 (32 trials × 5 min, total 160 minutes). When the ship control version was practiced, subjects were instructed, in addition to the standard instructions, to focus attention on the control of the ship and attend to other elements as much as feasible, while not allowing ship control to suffer. The significance of the special counters was explained, and subjects were told how to increase their score on these counters. On the 7th meeting the special counters were removed and subjects were instructed to give equal attention to all elements of the game.

(3) Mine handling. The schedule of trials was as in the ship control group. However, the instructions emphasized the mine handling priority manipulation and explained the additional counters associated with it.

(4) Double manipulation. To increase the possible number of emphasis changes, subjects in this group were given shorter game trials of 2 and 3 minutes. However, the

last game in each meeting was of 5 minutes. This was done to enable the comparison between performance levels of this group with the other 3 experimental groups on equal duration trials. During the first 3 meetings subjects were given only the ship control instructions, although their display included the auxiliary counters of both manipulations (28 trials, total 100 minutes.). At meetings 4–6, instructions were given regarding the mine handling manipulation. Subjects were now instructed to move their emphasis to mines, but try to maintain high ship control scores (30 trials, total 120 minutes). At meeting 7–9 all auxiliary indications were withdrawn, subjects returned to the standard game, still maintaining the 2 and 3 min. game trials, except for the last block (30 trials, total 120 minutes). At the 10th meeting they played only 5 min games (8 trials, 40 minutes).

Although the total play time that subjects had in the double manipulation group was not different from the time given to subjects in the other groups, they had many more trials and many brief rests. The rationale was to enable a larger number of emphasis changes between trials, that may give subjects the opportunity to explore changes in allocation policy. To control for the possibility that this change of schedule may have caused a difference between the groups, we added 4 subjects to each of the other three groups and trained them on the time schedule of the double manipulation group. Since the performance levels of these subjects were not significantly different from their respective manipulation group, it was concluded that trial length did not influence progress rates. Their results were, therefore, pooled together with those of the other subjects in their conditions.

Subjects

There was a total of 66 subjects in the 4 experimental groups: 24 in the control group, 16 in each of the single manipulation groups and 10 in the double manipulation group. The unequal number stemmed from the need to add 4 subjects to the first 3 groups, due to changes in the time of game trials for the double manipulation group (see above). In addition, there were 6 subjects in an early pilot study that was conducted to select the dimensions of emphasis change. These subjects were not included in the formal data analysis.

Subjects were male students at the Technion, aged 18–24. All subjects were given an initial selection test which was based upon the aiming subcomponent of the game. The test was previously validated at the University of Illinois and was found to correlate at the 0.6–0.7 level with subjects' final game scores (Mané et al. 1989, this vol.). Only subjects who obtained a score of 780 points or more in the aiming test were admitted to the experiment. They were further divided into high (1000 +) and low (780–1000) ability groups based upon these scores.

Experimental groups were matched according to subject screening scores and each group included about equal proportions of high and low ability subjects. The average and variability scores for the aiming task at the 4 groups were as follows: *Control*, avg. 990 points, *sd* 94. *Ship control*, avg. 999, *sd* 116. *Mine handl.*, avg. 1010, *sd* 129. *Double manip.*, avg. 994, *sd* 115. The differences between groups were not significant ($F(3, 65) < 1$).

Results

Although the main focus in the description of results is on quantitative measures of performance and the outcomes of statistical analysis, we would like to begin with some less formal observations on the behavior of subjects in the control group. In the context of the present experiment, these subjects can be regarded as the closest approximation to naive players, who attempt to acquire expertise spontaneously. When first introduced to the game, many subjects expressed panic. They reported feelings of being completely out of control and incompetent. They all complained bitterly on the excessive difficulty of the game: things happened too fast, they did not have enough time to monitor all the displays, were unable to track the relevant information and make all the necessary responses.

Having recovered from the initial shock, most subjects were able to develop a strategy of performance that allowed them to survive in the context of the game and progress with the continuation of practice. However, as will be detailed later, from the analysis of the game requirements and our knowledge on the basic ability of subjects it can be concluded that most of these strategies were suboptimal with respect to the capabilities of the individual and the conditions of the game. The following are two examples of spontaneously developed strategies.

A popular strategy that was displayed by 6 of the 24 subjects in the control group (25%), was labeled 'wrapping' (see also Mané et al. 1989, this vol.). This strategy attempted to solve the psychomotor difficulty of controlling the ship. In wrapping, subjects set the ship on a fixed, constant velocity, vertical trajectory, which was parallel to the fortress and at a close distance. Because the basic control dynamics of the ship was that of an object moving in a frictionless environment, once established on a trajectory, the ship would maintain it with no further intervention. The ship moved from the lower to the upper edge of the screen, disappeared and reappeared at the lower edge on the same trajectory. Thus, subjects were freed from the main load of controlling the ship and from the requirement of developing this skill. They could then concentrate on aiming and firing at the fortress, or on other elements of the game. However, wrapping had its toll. Subjects could only aim while moving at relatively high velocities and from a limited sector of the screen. They had many 'dead time' intervals and were forced into very unusual aiming angles. Firing at mines was also performed from larger distances and unusual angles. Finally, because they did not acquire good control of the ship, they had difficulty in re-establishing a trajectory when accidental or intentional deviations occurred. In summary, the wrapping strategy was clearly suboptimal.

Another example is a strategy developed by 2 subjects. They discovered that one of the features of the game program was, that if the ship could be brought to a complete standstill, at points within 10 degrees on either side of the fortress front, the fortress could not hit it. Using this strategy, one is completely redeemed from all hardships of ship control. One subject who adopted this strategy, scored in one game trial 1,200 hits at the fortress without destroying it with a double shot (4 points were gained for each hit and 100 for fortress destruction). When questioned he explained that since a new game cycle was started each time the fortress was destroyed, there was little chance that he could get the ship again to a standstill in a safe zone. Standing still is, therefore, another clear example of a suboptimal compromise. Only about 1/3 of the subjects attempted a strategy similar to the slow circling mode that was encouraged by our ship control manipulation, and they had only partial success in its application.

Not only were spontaneously developed strategies most often suboptimal, but subjects were also unlikely to change them. None of the subjects in the control group changed strategy during the 10 hours of playing the game. As practice progressed they became more and more persistent and consistent in its application. They did not explore other options.

General effects of emphasis change

Fig. 2 depicts the average learning curves of the four groups in terms of the overall standard game scores. The plots are based on the last trial of each of the first 9

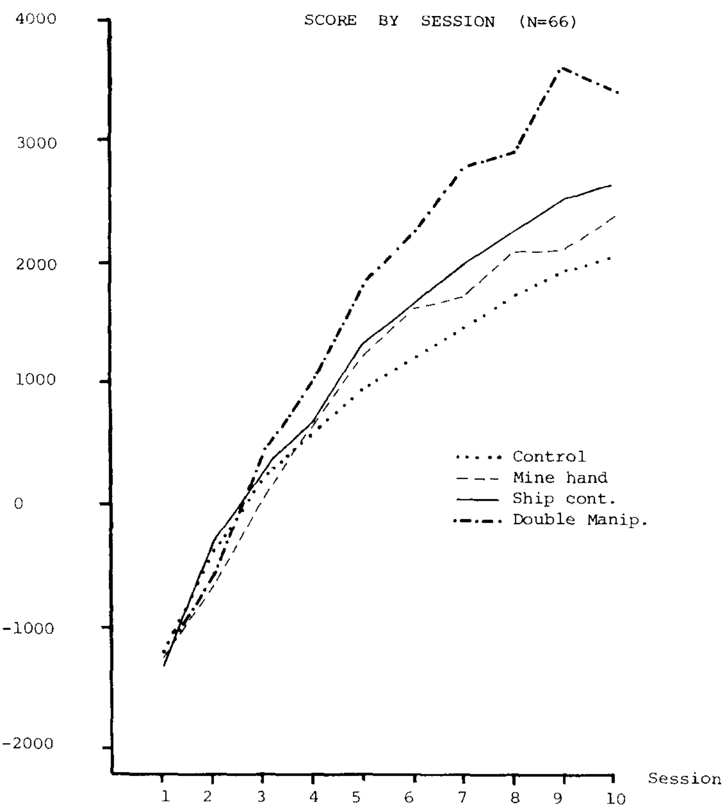

Fig. 2. Learning curves of the 4 experimental groups. Performance is described in terms of total game scores.

Table 1
Average game scores at the 10th meeting. Averages are computed for each experimental group and for high- and low-ability subjects.

Ability	Condition				Average
	Control	Mine handling	Ship control	Double manipulation	
Low ablity	1,695	1,669	2,095	3,215	2,168.5
High ablity	2,494	2,934	3,185	3,506	3,029.8
All subjects	2,061	2,380	2,640	3,419	2,625.0

meetings and the average of the 10th and last meeting. It is evident from these curves that the single manipulation groups had an advantage over the control group and that the double manipulation group was the best of all. Note also, that all groups obtained high negative scores at the end of the first meeting. This is another, and more formal, indication of the difficulty of the game.

Table 1 presents the average numerical values of the total game score, obtained by the groups during the 10th hour of training. Also presented is a breakdown between high- and low-ability subjects. Subjects in the low-ability groups had initial aiming scores of 780–1000 points. High-ability subjects obtained scores of 1000–1200 + .

In fig. 3, the learning curves of the high- and low-ability groups are plotted separately. Again, the emerging differences between the 4 training conditions are clear for both ability groups.

We also constructed a second, net, progress score for the effects of training, by computing the difference between the game score obtained by each subject on the last game trial of the first meeting and his average score at the 10th meeting. The average differences between experimental conditions and ability groups are summarized in table 2.

Separate statistical analyses were conducted for the effects of training on the two dependent measures. We first ran a two way analysis of variance (Manipulation(4) $\times$ Ability(2)), on the average game scores of the 10th session (table 1). This analysis yielded highly significant F ratios for the effects of emphasis manipulation and ability. The outcome for the influence of training conditions was $F(3, 58) = 5.34$, $p < 0.0027$. Duncan post analysis comparisons categorized the effects into three groups, the double manipulation group on top, the control group at the bottom, and the two single manipulation groups in the middle. This classification can be readily observed in figs. 2 and 3. For the ability factor, $F(1, 58) = 15.96$, $p < 0.001$, high-ability subjects, in all groups, achieved much better game scores than low-ability subjects. The interaction between the two factors was not significant.

Analysis of variance of the net progress measure (game points), yielded a similar pattern of results. The training method and the ability factor had significant main effects, with no significant interaction between them. The respected F ratio for training conditions was $F(3, 59) = 5.7$, $p < 0.0018$. For the ability factor $F(1, 58) = 11.16$, $p < 0.015$. Duncan post analysis comparisons showed again the double manipulation

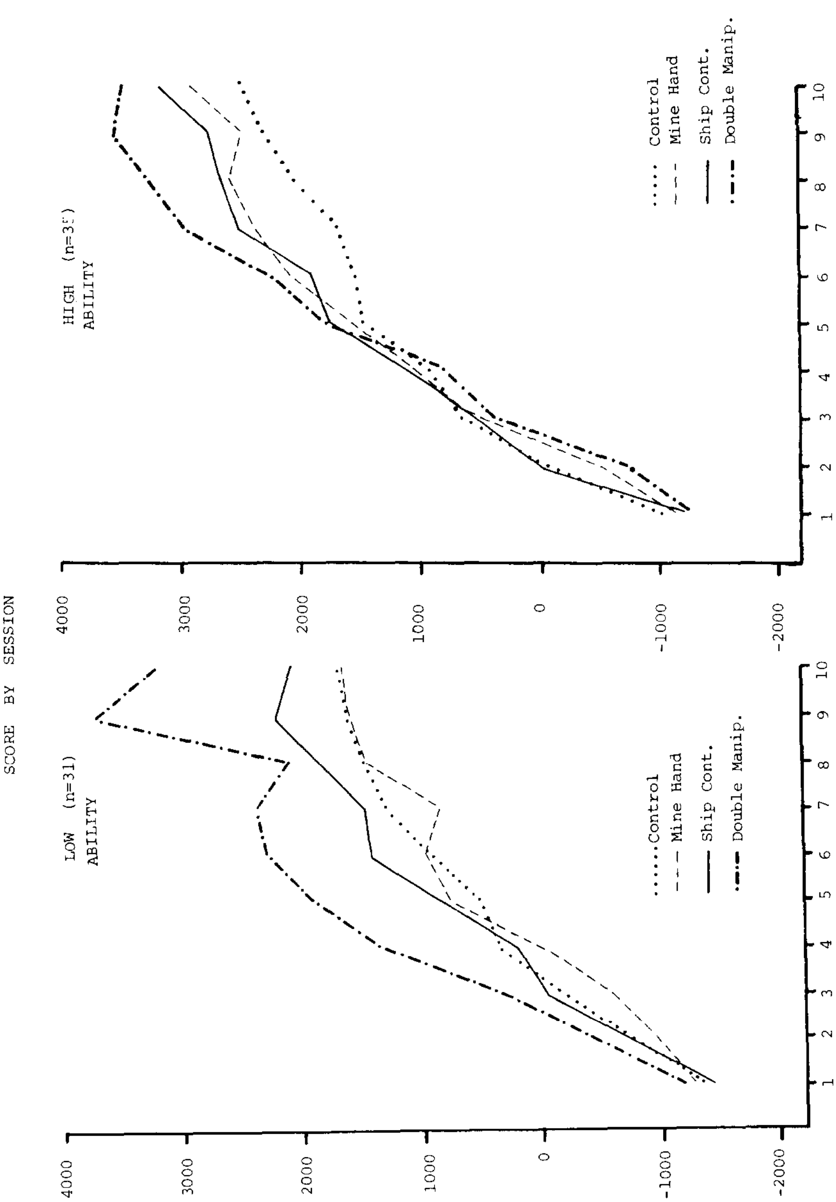

Fig. 3. Learning curves for low- and high-ability subjects in the 4 experimental groups.

Table 2
Averages of the net progress in game scores during the 10 training sessions. Averages are presented by experimental conditions and ability groups.

Ability	Condition				Average
	Control	Mine handling	Ship control	Double manipulation	
Low ability	3,051	2,944	4,513	4,400	3,477
High ability	3,511	4,113	4,412	4,776	4,203
All subjects	3,261.9	3,601.6	3,962.7	4,574.5	3,840

and control groups at the upper and lower extremes, with the two single manipulations in the middle. The net progress of high-ability subjects was larger than the progress of low-ability subjects.

The effect of basic ability

It is clear from the data presented in tables 1, 2 and fig. 3, as well as from the results of the ANOVA's, that individual differences in the basic ability of subjects were an important determinant of their progress and final score. On the average, low-ability subjects in all groups obtained lower scores than high-ability subjects. However, in both analyses, the interaction term between the ability and emphasis factors was not significant. Nevertheless, a closer examination of table 1 and fig. 3 hints at an interesting difference in the magnitude of the effect, between high- and low-ability subjects. For high-ability subjects, the difference at the last meeting between the control condition and double manipulation group was much reduced (1,012 points). Also, the single manipulation of ship control by itself, brought subjects very close to the double manipulation performance levels. In contrast, among low-ability subjects, the single manipulation conditions were not much better than the control condition. However, applying both manipulations had a dramatic impact; it brought the low-ability subjects of this group close to the group of high-ability subjects, demonstrating a gain of 1,520 points over the score of the control group.

It is possible that due to the small number of subjects and the statistical complications arising from the existence of unequal number of subjects in cells, the two way ANOVA was not sensitive enough to reflect this type of interaction. We, therefore, conducted two additional tests of the statistical significance of these observations. In the first, we ran a one way analysis of variance on the scores of the 10th meeting, for the 8 groups that can be created by crossing the 4 training conditions with the 2 ability levels (table 1). We then employed Duncan post analysis comparisons, to test how these 8 groups would compare in terms of their game scores. The logic of this analysis was that if low-ability subjects of the double manipulation group, indeed distinguished themselves, they would be grouped together with the high-ability subjects and separated from all other low-ability groups. In our second analysis, we computed the

Pearson product moment correlation coefficients within each training group, between the initial ability scores of subjects on the aiming selection task and their final game score. If low-ability and high-ability subjects in the double manipulation groups did not differ much in their final game scores, the correlation in this group between initial ability and the final game score, should be lowest.

Both expectations were substantiated. The analysis of variance for the 8 groups had an $F(7, 58) = 4.82$, $p < 0.0003$. In the following Duncan comparison, the low ability subjects of the double manipulation group were grouped together with the high-ability subjects of all emphasis manipulation conditions. They were ranked second from the top. All other low-ability subjects and the high-ability group of the control condition were pooled together in the low-score category. The correlation analysis yielded the following results: In the *control group*, $r(20) = 0.652$ $p < 0.0018$; *mine handling*, $r(16) = 0.654$ $p < 0.021$; *ship control*, $r(16) = 0.826$ $p < 0.0009$; *double manipulation*, $r(10) = 0.478$ $p < 0.162$. The correlation in the double manipulation groups was indeed the lowest and the only one that was not significant.

Differential effects of emphasis change

A key question is how effective the two emphasis manipulations were in guiding subjects to attend to different aspects of the task. There are two parts to this question. One is the effect of the emphasis manipulations during the training sessions within which they were applied (1–6). The second point of interest is their impact on performance during the 10th, final meeting, when subjects were no longer instructed to apply differential emphasis. Fig. 4 compares the learning curves of the Ship Control, Mine Handeling and Double Manipulation groups during the first 6 meetings within which the emphasis manipulations were administered. Excluded from this comparison are the results of the control group, because subjects in this group did not receive any systematic manipulation of emphasis. Panels a, b, and c in fig. 4 depict the average scores of the special counters reflecting ship control, mine handling and the speed of responding to mines. These special scores were computed for all groups, but remained latent to the group that did not practice an emphasis manipulation in which they were used.

The plots in fig. 4 show the large but differential influence of the emphasis change. On the ship control score (a), both groups that practiced it were about equal and much better than the Mine Handling group. Analysis of variance for the averages of the three groups on this score at the 6th meeting was highly significant, $F(2, 39) = 7.67$, $p < 0.01$. Duncan post analysis comparisons grouped the Ship Control and Double Manipulation conditions together, separated from the lower Mine Handling condition.

On the scores of mine handling and speed of handling mines (b and c), it is the Ship Control group that was much inferior. The analyses of variance for the differences between the three groups on these scores at the 6th meeting, supported the significance of the observations. For the mine handling score $F(2, 39) = 15.62$, $p < 0.001$. For speed of mine handling $F(2, 39) = 17.13$, $p < 0.001$. On both scores, the Double Manipulation and Mine Handling conditions were grouped together, and subjects in the Ship Control condition obtained significantly lower scores.

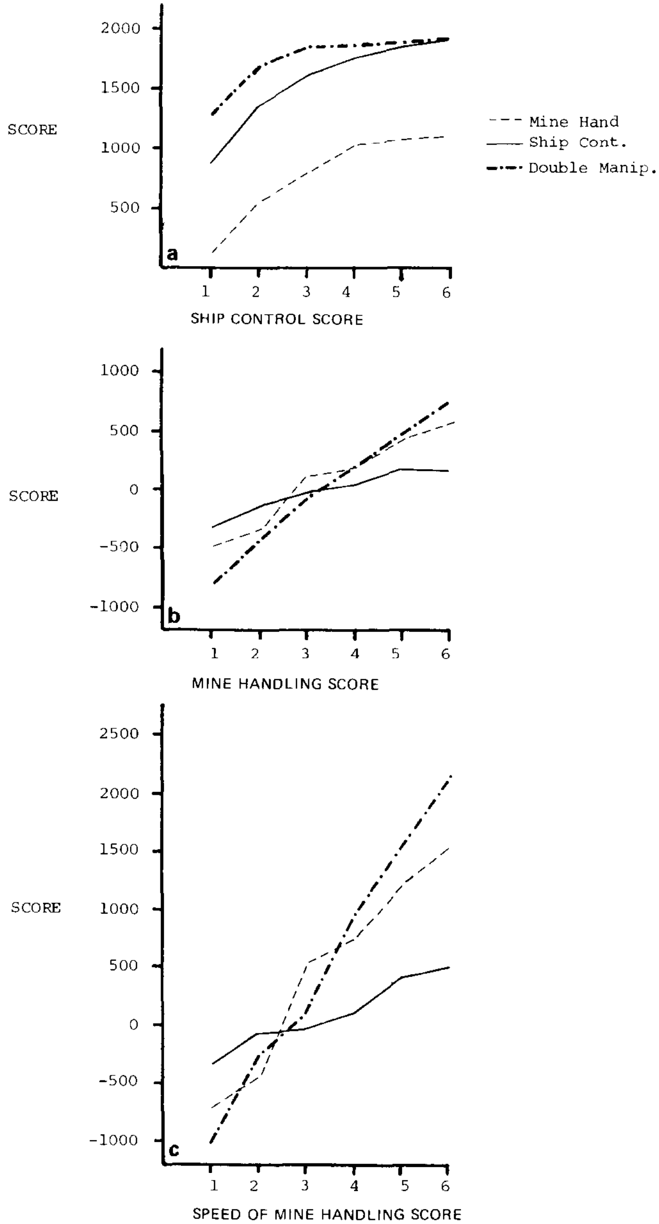

Fig. 4. Comparative learning curves of the three emphasis manipulation groups during the first 6 training meetings. The three panels depict progress in terms of the special, augmented, feedback displays, developed for the ship control and mine handling emphasis manipulations.

Table 3
Average scores on secondary performance measures, for game trials of the 10th meeting.

Type of measure	Manipulation			F df (2,35)	$p <$
	Ship control	Mine handling	Double manipulation		
No. ships hit by a mine	5.2	4.3	3.3	1.21	ns
No. kills of foe mines	16.0	17.7	18.3	2.62	0.09
No. kills of friend mines	17.5	18.9	18.2	2.45	0.10
Av. time to kill friend mines (sec)	2.1	1.9	1.8	5.65	0.007
Av. time to kill foe mines (sec)	2.9	2.8	2.3	1.84	ns
No. hits of fortress	154.3	134.4	211.6	5.15	0.011
No. fortresses destroyed	12.6	10.7	16.7	4.04	0.026
Av. time to destroy fort. (sec)	17.4	20.6	14.8	4.70	0.015
Efficiency (shots/fort destruction)	16.7	20.0	15.2	3.38	0.04
No. times the ship left the screen	2.7	21.6	1.9	4.87	0.013
No. of shots when there were no missiles	47.0	70.0	31.6	1.54	ns
Percent bonuses used	81.6	66.2	88.8	4.72	0.015

Table 3 summarizes the average performance levels for the three manipulation groups on 12 secondary performance indices, computed for the data of the 10th meeting. Due to technical problems, the latent computation of the special scores plotted in fig. 4, was discontinued after the 6th meeting, when subjects returned to play the standard game.

Several outcomes should be noted in this table. The first 5 measures are all related to aspects of responding to mines. On all of them the Mine Handling group obtained better scores than the Ship Control group, although only one measure (average time to kill a friend mine) reached the conventional level of significance. One possible explanation for the lack of statistical significance is the small number of subjects. Another possibility is that subjects in the Mine Handling group were generally somewhat less stable in their performance, which may have lessened the power of the statistical test (standard deviations for the total score in the three groups were: 1037.4; 1018.3; 1123.4; for the Double Manipulation, Ship Control and Mine Handling, respectively). Nevertheless, the general trend was very consistent.

The next group of 5 measures in table 3, are all related to aspects of hitting the fortress and efficient control of the ship. On all of them, the Ship Control group significantly outperformed the Mine Handling group. What is also significant is that on both the first and second type of measures, the scores obtained by subjects in the double manipulation group, were as good or better than those obtained by the respective single manipulation group.

The final two scores in table 3. 'No. of shots' when there were no missiles and 'percent of bonuses used', can be considered to reflect aspects of resource management. On both measures subjects in the Ship Control group were better than Mine Handling and Double Manipulation subjects were the best, although the differences were significant only for the 'percent of bonuses used' measure.

Performance of the control groups in Israel and in the US

One serendipity which results from the fact that the present work was part of an international effort is the ability to compare the performance levels of naive subjects in the control groups of the Technion – Israel and of the University of Illinois – USA. To recapitulate, in both countries, the sample was restricted to male subjects, 18–24 years of age, and excluded candidates who played videogames more than 2–3 hrs a week, on a regular basis. The learning curves of the US and the Israeli control groups are plotted in fig. 5. There were 20 subjects in the Israeli group and 40 in the American. Data points represent the game score of the last trial in each session.

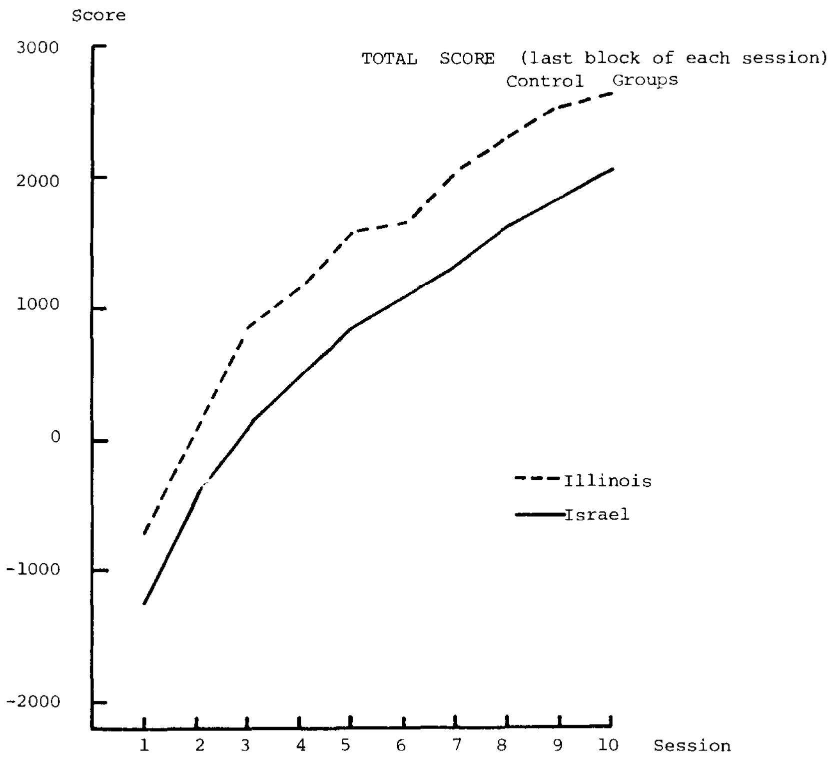

Fig. 5. Learning curves for the control groups in the Technion (n = 20) and in Illinois (n = 40).

It is clear that subjects in the control group of Illinois were better than those of the Technion. The advantage is already revealed in the scores of the first meeting and does not decrease or converge in the 10 hours of training. The average score on the last block of the 10th meeting was 2,045 in the Technion group, and 2,680 in Illinois, a difference of 31 percent. This is so despite the fact that subjects in both countries went through the same selection test, and the proportion of high- and low-ability subjects was the same in both groups.

As significant were the rejection rates in the two countries, namely, the proportion of caniditates who volunteered for the experiment, but were rejected because of low scores in the aiming selection test. Of the 101 tested in Illinois, only 7 (7%) were below the cutoff score of 780 (Mané, unpublished report, March, 1985). In Israel, of the 98 tested candidates, 32 (33%) were below this score.

Discussion

Many aspects of the results, but mainly the behavior of the naive players in the control group, the requirement to administer a preliminary selection test, and the high negative scores that were obtained by subjects of all groups during the first meeting, attest to the difficulty and demanding nature of the present SF game. The focus of our discussion is hence on the process of developing expertise on a complex and highly loading task. Recall that the key claims in our approach were that spontaneous, unistructed practice may be unsatisfactory, and that part training through emphasis change may be an efficient method of training. This is because it will teach subjects strategies and lead them to incorporate those strategies in long-term schemas. We turn now to consider these claims in the light of the obtained results.

The experimental results lend strong support to the proposed view of skill acquisition and the process of training. They also demonstrate the adequacy of the method, which was developed for the application of this approach. Instructed shifts of attention, guided by knowledge of results of their effects (feedback indicators), had strong influence on performance. They changed the immediate and long-term style of subjects' behavior and improved their general ability to cope with the demands of the game. Single changes of emphasis were better than no change, and the double manipulation of emphasis had the strongest effect.

Moreover, the effects of training under emphasis change persisted after the manipulation was discontinued. Although at the end of the 6th meeting subjects began to play the standard game without augmented displays, the effect of strategies persisted and continued to increase over the following 4 meetings (figs. 2 and 3). Hence, the emphasis manipulation can be interpreted to have had an effect on subjects' general approach to learning (strategies), and on the more enduring structures (ultimate high-level schemas) of the acquired skill. This is in contrast to an interpretation favoring only transient and local effects of augmented feedback information on performance. Under this latter interpretation, performance should have deteriorated once the additional information displays were removed, and subjects in the emphasis manipulation groups should have lost their advantage over the control group. Thus, the continually growing gap between the experimental groups during the last 4 meetings is an important demonstration of the deep and powerful influence of the training procedure.

The employment of the augmented information counters during the first 6 meetings to display the effects of emphasis change, played the well-known role of 'knowledge of results' in the acquisition of skills. Knowledge of results (KR), has been shown in a large body of studies to be a major force helping a trainee to tune his behavior to the objectives of the task. It serves to highlight aspects of performance that the trainee may have not been conscious of, and give feedback on progress with respect to the aims of the task. (See Newell (1977), Salamoni et al. (1984), Adams (1987) for theoretical analysis and empirical review.) There are two main criteria for a successful incorporation of KR into a training program. The first is the capability of the trainee to use the information. The second is his ability to internalize the information, or to build up alternative representations that may take over and preserve the required pattern of performance once KR has been terminated. On both criteria the present manipulation of emphasis faired well.

The first criterion was dependent on the ability of subjects to control their attention. Namely, subjects needed to follow the change of emphasis instructions, shift attention selectively, and manifest the resultant differential styles of response.The data plotted in fig. 4 proves the fulfillment of this requirement. The second criterion i.e., development of alternative structures, has also been clearly met, as evident both from the smooth transition from the 6th (KR) to the 7th (No KR) meeting (figs. 2 and 3), and the continued progress of learning without the augmented displays. The smooth transition from training to play of the standard game also provides important evidence to support the methodological power of the emphasis change manipulation, in the context of the part–whole method. As has been argued in the introductory section, because the whole task is not decomposed physically and emphasis changes allow all other elements to be present and vary in the background, there are fewer costs for transitions. There is no need for reintegration and subjects are less likely to suffer from negative transfer when they begin to play the standard game. These have been the main causes of problems in traditional applications of part training (Adams 1987; Wightman and Lintern 1985).

Many aspects of the data contribute information and present vivid illustrations of the concepts of performance strategies and their nature, role and influence on the development of complex skills. The first clear indications of the development of sponteneous strategies came from observing the behavior of subjects in the control group. Wrapping and navigating the ship to a standstill were two examples of such strategies. They both reflected an attempt of the performer to gain some control over the events of a complex and dynamically changing environment. Spontaneous strategies developed in the Space Fortress game can hence be conjectured to reflect an attempt to cope with complexity which is made under conditions of high stress and task load.

It is hardly surprising that under such conditions the performer was not at his best and that the developed strategies were prone to be suboptimal, as was the case with 'Wrapping' and 'Standstill' modes of ship control. Furthermore, we also have evidence, in the behavior of the control group, for the stubborn clinging of subjects to a strategy once it is developed.

Another vantage point on strategies was provided by the instructed manipulations of emphasis. They showed not only that subjects can be guided to attend selectively, but also demonstrated the fact that in a complex task like Space Fortress, performers can obtain similar levels of overall performance though emphasizing different components. Subjects of the Ship Control and Mine Handling groups, reached a similar level on the total game score, although as evident from the results presented in fig. 4 and table 3, they developed different styles of response.

These observations serve as a good anchor for an attempt to interprete the power of emphasis change as a training method. For the novice trainee, the Space Fortress game in its standard form represented a situation that was beyond his capabilities, presenting demands with which he was unable to cope. There was, therefore, a need to set priorities, and to decide upon goals, subgoals, and ways to accomplish them. The emphasis change manipulation fulfilled these needs. It provided the framework and the tools for a systematic development of solutions to deal with load and complexity. When such a framework did not exist (as in the case of the control group), it was developed spontaneously with inferior results. The absence of a guiding framework may also lead to a state of despair and reduced motivation, which may end in a total collapse of performance (see Gopher and North (1977) for an experimental example). Indirectly, the present results clarify the role of voluntary control of attention in the early stages of skill acquisition, and show how initial attention biases can be formulated with the progress of training into high-level schemas. This is the dynamics of moving from strategies to schemas. It may also explain why, once developed, strategies are hard to change, and why the initial stages of training are so significant.

An important outcome that should be carefully evaluated is the large additional benefit of practicing two emphasis versions rather than one. Not only were subjects in the double manipulation group much better on their total game scores, but they were also as good or better on all secondary measures relative to the group that practiced only the respective emphasis manipulation (fig. 4 and table 3). A closer examination of the results summarized in table 1, reveals that the actual difference between the control and the double manipulation group was 51% larger than the additive value of the separate contributions of the two single emphasis manipulations (1,358 game points as compared with 898, for the additive contribution of Ship Control and Mine Handling manipulations on the 10th meeting). Similar effects appear on the net progress measure (table 2). What can be the sources of such a magnified effect?

Several possible sources can be offered, which may not be mutually exclusive. One is the simple fact that subjects in the double manipulation group received special training, with augmented KR, on two rather than one important element of the game. It is true that the period that they practiced each version was shorter than the period given to the groups practicing only a single change. Nonetheless, it appears that the allotted time was sufficient, because the rate of progress on emphasized elements, made by subjects in the double manipulation group (fig. 4), was not different from that of subjects in the respective single manipulation conditions. If, however, this was the only contributing source, and even if the effects of the two manipulations had been completely independent (which we believe they were not), the impact of introducing both, should have been additive. The observed overadditivity requires consideration of other possible influences of the multiple emphasis procedure.

Two additional factors may be related to the effects of high load and to training under time-sharing conditions. Several recent papers discuss the possible adverse effects of excessive load on the process of learning and acquisition of skills (Gopher 1980; Gopher and North 1977; Schneider 1985). In general, high load and pressure may interfere with the learner's ability to extract information and exhaust the KR information (Newell 1977). It is possible that the early training in control of the ship which was given to subjects in the double manipulation group, resulted in a general reduction of their load and enabled them to invest more resources in learning to handle mines when this latter condition was introduced. From our initial analysis of the game, we have argued that control of the ship was mandatory to competent game performance. Subjects who were immediately exposed to the mine handling manipulation could not maximize the utility of their training because of their poor control. The double manipulation group was in a better position in this respect.

This interpretation gains support from several aspects of the results. To begin, subjects in the Ship Control group were generally better than the Mine Handling group in terms of their total game score. The differences were consistent, although they did not reach the conventional levels of significance. High-ability subjects in the Ship Control group were almost as good as the high-ability subjects of the double manipulation group (fig. 3). This hints at the senior status of this game element. Scheduling the order of emphasis changes the way we did may have helped subjects to gain more from the learning situation on emphasized aspects as well as on others. To better substantiate this argument, we should have run another double manipulation group in which the mine handling manipulation preceded the introduction of ship control. Due to technical problems, time and budget constraints, this group was not run. Its absence hampers the strength of our interpretation, while delineating directions for future research.

Another possible influence of training under multiple strategy changes is that it may have given subjects a broader perspective of the task, improved their knowledge on the efficiency of their resources, and given them greater flexibilty in adopting modes of response. The role of such knowledge and flexibility in expert behavior was elaborated upon in the introduction to this paper. Expertise was typified by the existence of a set of well organized strategies and the flexibility in their usage. The play characteristics of a champion tennis player were discussed to illustrate these notions. Given the evidence from the present experiment, which showed that subjects did not change strategies spontaneously, the possible contribution of the enforced change under the double emphasis manipulation is underlined. It is also strengthened by the results of earlier work, showing that subjects trained under variable priorities in dual-task conditions performed much better than subjects who performed under fixed or no priority instructions (Gopher 1981; Brickner and Gopher 1981; Spitz 1988).

Note that the effects of double maipulation were largest on low-ability subjects. These subjects were brought very close to the achievements of high-ability subjects in this condition during the 10 hours of training. A complementary finding was that the performance levels of low-ability subjects who were given only a single emphasis change were not much better than those of the control group. These are important findings, because the basic ability of subjects was shown to be an important determinant of their final score. One possible interpretation of these findings is that training under multiple emphasis change enabled subjects to explore response modes that better matched their individual capabilties. Development of such a match was more crucial for low-ability subjects, because high-ability subjects were less susceptible to the occurrence of mismatch. This interpretation is related to the possibility discussed above of increased flexibility and improved knowledge of the resource efficiency in the double manipulation group.

Another alternative is that high-ability subjects could gain enough information from partial training to continue developing expertise by themselves, while low-ability subjects had to be given the full program of training. A variant of this interpretation can be developed with reference to the possible hierarchy between the ship control and mine handling manipulations. It can be argued that low-ability subjects were those who had more difficulty in advancing without an early systematic introduction to the ship control version. If first given the opportunity to practice ship control, they could then progress and benefit when introduced with the mine handling manipulation. High ability subjects could manage for themselves, and were capable of learning under the single Mine Handling manipulation, even though they did not have a previous instruction with ship control.

At this stage we do not have enough data to decide between these alternative interpretations, a fact that does not reduce the practical importance of the findings. Needless to say, low-ability trainees are the major concern of most training programs. This is where the manipulation of emphasis and enforced strategy changes appears to have worked best.

An interesting finding in this context of discussing the influence of initial ablities is the striking differences found between the performance of the control groups at the Technion and at University of Illinois (fig. 5). These differences become even more dramatic if we consider the fact that all the Israeli subjects were students of the Technion, which is the top engineering school in the country, while participants at Illinois came mostly from the liberal arts and social sciences domains.

The source of the difference is not difficult to guess. American youngsters are much more experienced in videogames. Considering the age of our subjects, the American subjects, most certainly, were exposed to videogames at an earlier age and have had more opportunities to play them – even considering that arcade champions were excluded from the experiment. Game arcades are relatively rare in Israel and were even more scarce during the relevant years of the present Technion sample. Home computers are also not as prevalent. Consequently, the majority of our subjects had very little videogame experience at any period of their lives. The observed difference may hence be argued to reflect a difference in experience and not a difference in basic potential and ability. But even if this argument is correct (and we believe it is), the differences are still striking and should not be overlooked. Remember, these differences emerged in strong force even though the lowest 33 percent of the Israeli candidates were excluded from the experiment. In addition, they did not disappear in 10 hours of playing the game, although both groups progressed well with practice.

Whatever the sources of the differences and the factors that have influenced performance, their effects were not short term nor easily compensated for. It is also clear that the additional experience that the American subjects can be claimed to have had was of a very general nature. The Space Fortress game was as new to them as it was to the

Technion subjects. They had no experience before on the specific elements of the situation, nor the demands imposed by its task components. They transferred their past experience with this general class of situations, in much the same way an experienced musician uses an already established general knowledge base in music, when he is required to master a new instrument. The demonstrated existence of such a 'general skill base' in the case of computer games increases their appeal and the claim for their use as general training devices. Contemplating the implications of the above presented cross-cultural comparison, one realizes that computer games may be more than 'just a game'.

Summary remarks and directions for future research

With due caution, because of the preliminary stage of the work on emphasis change as a training approach, we can conclude that the experimental results support the proposed view of complex skills and the approach to their training. They support the general logic, the selection of elements, and the techniques that were employed to incorporate changes in the routines of the task. At this stage it appears important to reiterate the fact that the present manipulation had an impact despite the increased complexity that it introduced into an already complex situation. This is counter to the underlying simplification logic that guides all traditional part–whole approaches. Human subjects appear to be able to deal with complexity. It is, however, a well organized and informative form of complexity, which includes clearer recommendations on the order of importance of elements and knowledge of results to evaluate alternatives.

Our final concern is with topics for future research. It is clear that many questions arise, or are left unanswered by the present work. Some salient ones are: How many emphasis changes it is productive to introduce on a given task? What are the rules of ordering changes? How long should each change be practiced before a trainee is transferred to a new condition? How should basic abilities be taken into consideration? Underlying all these questions is the requirement for a better understanding of the relationships between the concepts of schemas, strategies and attention control that were linked together in the present work.

Most important of all is the basic question of how to select the best candidates for emphasis manipulation. A tentative answer to this question is that we want to choose those manipulations that, when applied, will lead to marked changes in the style of performance, and will be sufficiently different from one another. The logic for this claim is that these are the most likely manipulations to lead to the development of a broad arsenal of response strategies, and thus they are most likely to lead practice to make perfect. Analysis by assessing the effect of emphasis changes, is proposed as a possible basis for a new method to conduct task analysis. This appears to us to constitute an important direction for future research.

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