Switching attention between tasks: Exploration of the components of executive control and their development with training.

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Top down processes guided by attention and intention, have been recognized to be important determinants, and necessary complements in the formulation and guidance of skilled performance. The present paper summarizes the results of four experiments conducted to investigate the control operations and the cost involved in switching attention between task dimensions and attention strategies. Subjects were asked to switch between judging the value of digits, or the number of digit elements, in rows of digits presented on the screen. Alternatively they performed the task, switching between speed or accuracy emphasis. The experimental results provide strong evidence for the work of executive processes which operate as attention strategies and policy regulators. They are executed top down, in the service of intentions and basic attention policies, but depend on the existence of task representations, including the "so called" automatic performance units. Executive processes are shown to have sizable operation costs, over and beyond those imposed by the direct processing and response demands of the performed tasks.. These costs are reduced with specific training focusing on the improvement of control functions.

The interplay between bottom up and top down processes in proficient behavior is a main focus of interest in contemporary cognitive psychology. On the one hand, there have been vigorous behavioral and physiological research efforts in the study of the self organizing and adaptive capabilities of the human processing system, with direct experience with the outside world (e.g. Rumelhart & McClelland, 1986). On the other hand, there is an increasing realization that models of proficient behavior which are based solely on direct triggering of automated components and subroutines, are not sufficient to account for the complexity, richness and wide modularity of human skilled behavior. Top down coordination and supervisory control, guided by attention and intention, have been recognized to be important determinants and necessary complements in the conduct and guidance of skilled performance (e.g. Gopher, 1992, Shallice, 1988).

To be able to incorporate considerations of strategic control and executive operations in training and skill acquisition programs, it is necessary to first identify the contributing determinants, their rules of operation and the ways by which they are influenced by modes of training. These were the general objectives of a sequence of experiments conducted in our laboratory to study attention control in switching attention between tasks.

Changing intentions and switching attention among tasks are major functions associated with the performance of top down control operations. We switch attention at will among locations and objects in the visual field, memory bases, types of computational processes, use of procedures, classes of responses, etc. In the field of vision extensive efforts have been devoted to the study of the processes and mechanisms associated with moving attention at will among objects and locations in space (Ericksen and Murphy, 1987; Posner and Peterson 1990). Similar efforts have been conducted in memory research, (Jacoby, 1994). Nonetheless, as has been recently noted by Allport (1994) and Baddeley and Hitch (1994), the questions regarding the nature, rules of operations, and costs of the executive control processes, have remained to a larger extent unresolved.

The key issue in this debate is the necessity of postulating the existence of a separate class of executive and coordination activities and costs, over and beyond the direct processing and response demands of the involved tasks, or the spontaneous conflicts and interference effects arising from their activation. Are there different types of coordination and switching activities, that incur variable costs? Can subjects prepare in advance for an anticipated task switch? Can the cost of switching be reduced with practice? Experimental study of these questions has been very limited, (Allport, 1994; Rogers and Monsell, 1995). These have been the main questions addressed in a series of 4 experiments conducted in our laboratory and reported here.

METHOD

Subjects:

Subjects in all 4 experiments were male students at the Technion, 20-28 years old. There were 19 subjects in Experiment 1, nine in Experiment 2, twenty in Experiment 3 and twenty in Experiment 4.

Task and Procedure.

In all 4 experiments, subjects performed a simple classification task . In each trial, a single row of digits, all of the same value, was displayed on a computer screen (Figure 1). Subjects were asked to judge whether the value of digits, or the number of digit elements in this row, was higher or lower than 5 (five was not used in either dimension).

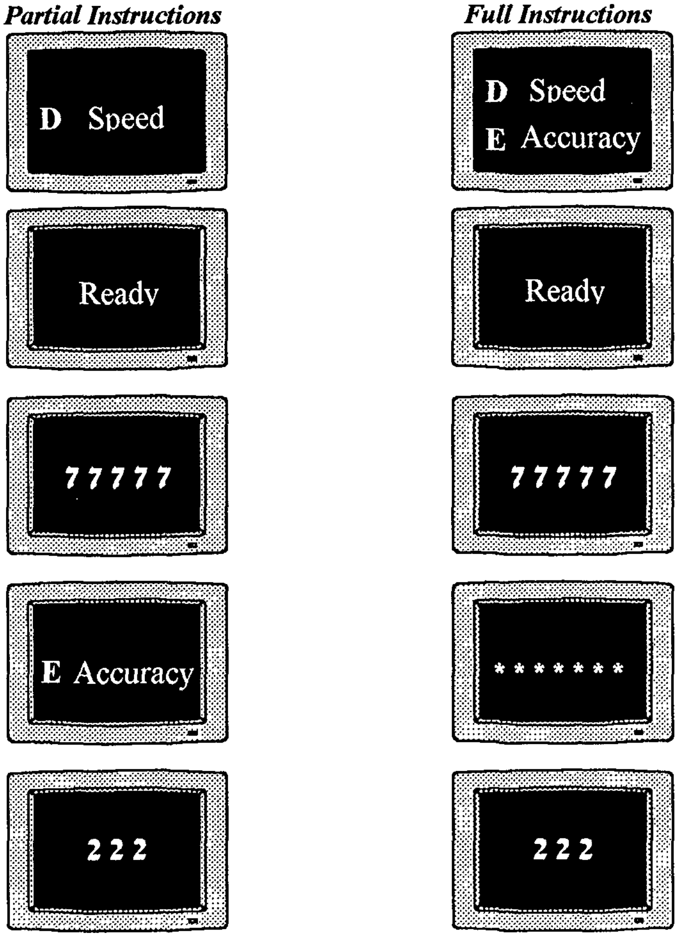
Partial Instructions **Full Instructions**

Figure 1: A schematic diagram of the experiment.

The task was performed in blocks of 15 trials. Performance was self paced and a new row of digits was generated immediately following the response to the previous one. Subjects started a block performing one task, i.e. judging Digit value or Element number (D or E). A new instruction, specifying the task for the second part of the block, was given between trials 5 to 12. Subjects could be instructed to switch between tasks (50%) or continue to perform the same task as in the first part of the block (50%). The experimental session lasted two hours and subjects performed a total of 192 blocks, each including 15 trials.

A second manipulation in these experiments was a change of attention control strategy. Subjects were asked to switch from Speed(S) to Accuracy(A) emphasis, or vice versa. While switching between D and E, implied a change in the relevant stimulus dimension, the significance of the Speed/Accuracy manipulation is that only the top down attention control strategy was changed, without changing the relevant stimulus dimension.

A third experimental manipulation was the method of giving instructions, comparing the influence partial (P) with full (F) instructions. In partial instruction conditions, subjects were given each time only the instructions relevant to the immediately following part of the block. Thus, at the beginning of each 15 trials block they received only the instructions for the first part, while the instructions for the second part were given at the point of reconsideration (randomly presented between trial 5-12). In full instruction conditions, the instructions for both parts were given at the beginning of the block and the point of transition between parts was identified by displaying a row of asterisks (Fig. 1). Comparison of performance under partial and full instructions enabled examination of the ability of subjects to prepare several seconds in advance, for a coming change in task or attention strategy.

In experiments 1 and 2, task dimensions (D/E) and attention strategy (S/A) were manipulated within experiment, while instructions (P/F) were varied between experiments. Thus instructions were always partial in experiment 1 and full in experiment 2, Task dimension and attention strategy varied between blocks of the same experiment. In experiment 3 only the task dimension was varied, while in experiment 4 only attention strategy was manipulated. In both experiments instruction type (F/P) was a within experiment variable. Each half of the experiment was performed under one instruction condition. Order of presentation was counterbalanced among subjects, such that half of the subjects practiced first with full instructions, while the other half were first given partial instructions.

Costs of switching and reconsideration and continue were computed by subtracting the response time and accuracy measures of the first trial after the switch, from the baseline performance levels of that task without switching. Baseline levels were obtained by averaging performance on the last 3 trials prior to the switch instruction. The extra costs of switching attention could hence be separated from the direct processing and response demands of tasks and the influence of training.

RESULTS

Switching between tasks

Baseline average performance levels for the two tasks when no reconsideration or switch was required were: 677 msec. and 643 msec. for the Digit value and the Element counting tasks, respectively. Errors measures were 5.8 and 5.7 percent, respectively. The requirement to stop, reconsider and initiate a new response sequence have added to these levels considerable costs in terms of response time. This is despite the fact that in the case of reconsideration there was no change in the task required between the first and the second parts of the block. When a switch of tasks was required, there was another step in costs, both in response time and accuracy. The average increase in response time for reconsideration and continuation and for task switching were in Experiment 1 (Partial Instruction) 306 msec. and 469 msec. respectively; in Experiment 2 (Full Instructions.), 274 msec. and 352 msec. ; in Experiment 3 (Task only change), 364 msec. and 640 msec. (These values reflect only the added RT cost at the time of change. Thus for example, the overall response times in Exp. 1 were 966 msec. and 1129 for reconsideration only and switching tasks, respectively).

In all experiments both the cost of reconsideration only and those of task switching were significantly different from zero. In addition, the added costs of switching as compared to reconsideration only were highly significant in experiments 1 and 3 (F=15.26, p<0.001; F=27.38, p<0.001, respectively). In Experiment 2 in which all instructions were given in advance (full instructions) these differences, though showing the same trend, failed to reach statistical significance (F=1.57, p=0.25). Error scores also showed an average increase when switch between tasks was required as compared to recoonsideration only. The increase was, 1.3, 0.7, and 2.5 percents, for experiments 1, 2 and 3 respectively. However, only the error increase in experiment 1 was statistically significant (F=5.88, p<0.026).

It hence appears that both a reconsideration and a switch requirement resulted in substantial costs to the processing system (40-90%), over and above the demands imposed by the performed tasks themselves. Moreover, the requirement to switch between task dimensions incurs additional costs in reaction time and error, over reconsideration with continued performance of the same task.

Change of attention control strategies

Similar patterns of differences were found when attention control strategies were manipulated (switching between speed and accuracy emphasis). Although the absolute and relative magnitude of these increases were smaller than those observed for changes in task dimensions. The average response time increase for reconsideration only and for switching requirements in Experiment 1 (partial instructions) were 374 msec. and 400 msec. respectively; in Experiment 2 (full instructions) 290 msec. and 336 msec, respectively; in Experiment 4 (only strategy change), 142 msec. and 224 msec. In all cases the added costs of both reconsideration and switching requirements were significantly higher than zero.

The expected difference between reconsideration and switching costs was present in all experiments, but was statistically significant only in experiment 4, in which the speed/accuracy switch was the sole manipulation (Exp. 1 F=1.5, ns; Exp. 2 F=0.98. ns; Exp. 4, F=6.00. p<0.02). In experiments 1 and 2 in which, both task and attention strategies were manipulated, the statistical analysis revealed that the influence of attention strategy changes, was modulated by the condition of task change. Thus, the interaction between the instructions on task dimension (switch/reconsider) and attention strategy (switch/reconsider), were statistically significant (F=12.59. p<0.008). When at the point of switch, only strategy but not task was changed, switching costs were significantly higher than strategy reconsideration only costs (367 msec. versus 213 msec. respectively). However, when a change of task was required, no further effects were observed for strategy manipulation (337 msec. for strategy switching and 335 msec. for reconsideration). Once a change of task has occurred, no further costs of strategy change could be detected.

It is interesting to note, that both the costs of task switching and those of strategies change were significantly reduced with training

Effects of partial versus full instructions

Could subjects prepare themselves to a change to come several trials and seconds later, if full information is given to them at the beginning of the block? The effects of full instructions were evaluated in two steps. We first examined differences in the initial preparation time, i.e. the time that subjects took for reading the instructions before pressing a key to start a block. In Experiment 2, preparation times were: 2000 msec., 2500 msec. and 3000 msec. for no change, one change (task or strategy), and both change blocks (F=39.58, p<0.001). In Experiment 3 (task change only), preparation time was 1950 msec. and 2500 msec. for no change and task switch, respectively (F=7.21, p<0.025). In Experiment 4 (strategy change only), preparation times were 3300 msec. and 4270 msec. for no change and switch of strategies, respectively (F=22.7, p<0.001). It hence seems that subjects took longer times to prepare for an anticipated more demanding change.

What were the effects of the advanced preparation on the costs of reconsideration only and switching. First we compared the effects of instructions on the cost of task change (D\E). In experiments 1 and 2, in which instructions were manipulated between experiments. As could already observed in the data reported above, the overall magnitude of reconsideration and switch costs pooled together, was lower with full instructions as compared with partial instructions. The pooled costs were 446 msec. in Experiment 1 (P. inst), but only 331 msec. in Experiment 2 (F inst.), F=3.61, p<.06). Moreover, under full instructions the differences between reconsideration only to task switch were much reduced and failed to reach statistical significance in Experiment 2 (F. inst.), while they were highly significant in Experiment 1 (F Inst.). In Experiment 3, partial and full instructions were varied within the experiment between the first and the second half of the experimental session, with the order of presentation counterbalanced across subjects. An interesting and highly significant interaction was found between type of instructions and order of presentation. When subjects were given partial instructions in the first part of the experiment and full instructions in the second half, they were able to take advantage of this knowledge and the costs of switching and reconsideration were reduced dramatically, from 650 msec. with partial instructions to 355 msec. with full instructions. However, when full instructions were presented in the first half of the experiment, subjects were unable to make use of this information ($F=5.05, p<.04$). These finding are depicted in Figure 2 . It hence appears that preparation and use of advanced information require the acquisition of some experience and proficiency in task performance, before they can be utilized.

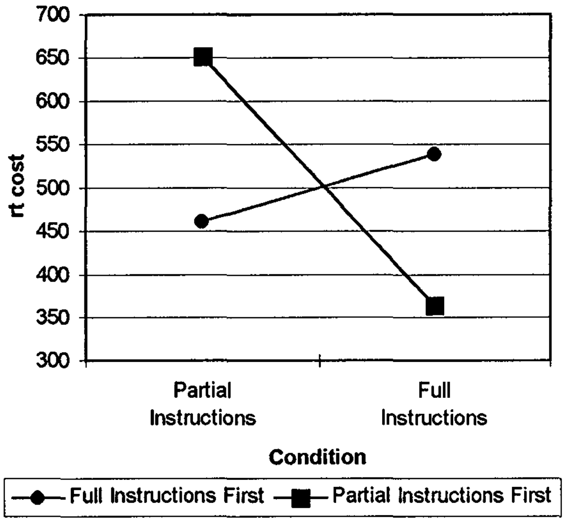

Figure 2: Interaction between Type of Instruction (F/P) and order of practice.

In contrast with the influence of advanced preparation on the costs of task dimension change, no significant effects were revealed for advanced information in Experiment 4, when attention control strategies were alternated, although the general trends of reduced costs were in the same direction as in task change. It seems that unlike that case of task change. Subjects were unable to use the advanced information despite the fact that they took longer times to read the initial instructions and prepare for a switch.

Effects of practice

Practice had significant effects on both initial preparation times and switching cost in Experiment 3 when task dimension was the only manipulation. Initial preparation time was reduced from 2643 msec. to 1832 msec. in the second half of the experiment as compared to the first part. ($F=20.2, p<0.0003$). The combined average cost of reconsideration and switching was reduced from 591.1 msec. to 413.0 msec. ($f=5.05, p<.03$). In Experiment 4, when only attention control strategies were changed, initial preparation time was reduced from 3855 msec. in the first half, to 2848 msec. in the second half of the experiment ($F=22.4, p<0.0002$). The combined average cost for reconsideration and switching was reduced from 216.2 msec. to 149.9 msec. ($F=227, p<.15$).

DISCUSSION

Taken together, the results of this set of experiments provide clear evidence in support of the claim that the acts associated with attention switching between tasks and control emphasis, or even a reconsideration of an existing commitment, incur additional costs and constitute an independent factor, separable from the direct processing and response demands of the performed tasks. The costs were not uniform and were shown to be related to the nature of the required control activity and the proficiency of performing it. Control costs were shown to be higher for switching attention from one task dimension, or attention control strategy to another, than the cost of a mere reconsideration of an existing set, and continued performance of the same condition. Changes that involved a switch in a task dimension were higher than those that require only a change in attention strategy, while maintaining the objective properties of the task intact.

An important finding was that an anticipated control operation could be prepared for ahead of time, several trials in advance, in case of task change, but not when only a change in attention strategy was involved. However, even in the case of task change prior practice and some proficiency in the performance of the involved tasks was required to realize the benefits of advance knowledge. It therefore appears, that this type of executive control processes is effective only after, and not before, some representations of the task and the situation have been established

The observed differences between task dimension change and attention strategy change in both magnitude of costs and the influence of advance information are interesting and revealing. There are at least two conceptual frameworks which are not mutually exclusive, that can be called upon for the interpretation of these findings. One framework is the class of models derived from Signal Detection theory (Sperling, 1984), in which the influence on performance of processing activity and sensitivity (d') are distinguished from those resulting from changes in response criteria (Beta). In our experiments, task change calls for a switch of stimulus dimension and the type of processing activities involved, while a change in attention strategy amounts only to a shift in response criteria . Based on the present results, it is possible to argue that a required change in processing activity is more costly to the system, than a shift in response criteria. At the same time, it is also possible that two processing activities, which operate on separate dimensions, can be primed, prepared for and held in working memory at the same time, even if executed in a sequence. In contrast, two different response criteria (biases) which need to be activated sequentially on the same ongoing processing activity, cannot be initiated and maintained in parallel, and hence cannot be prepared for.

A second framework for the interpretation of our findings may be the model of working memory proposed by Baddeley and Hitch (1994). According to this model, working memory comprises several slave systems each including and dealing with a specific type of information, and an executive controller that coordinates the work of the slave systems. In particular, Baddeley and Hitch bring empirical and theoretical arguments in support of two slave systems, the Visuspatial and the Phonological system. At the same time they do not exclude the possible existence of additional slave systems. In the context of our experiments, the tasks of judging the value of digits or estimating the number of elements clearly call upon different types of representations and computational processes. Value judgment is a semantic task, while evaluating the number of elements is visuspatial type task involving analog spatial type operations. A switch between task dimensions requires therefore a change of slave systems, while a shift in attention strategy is conducted within the same slave system. It can hence be argued that shifting slave systems is more costly than changing orientations within a slave system. Also, two different slave systems can be primed in parallel but not a change of orientation within the same system.

An important aspect of the results were the effects of practice and accumulated experience. Two types of practice were shown to influence the efficiency of control operations associated with switching attention between tasks. One type of practice involved developing competence and establishing representations for the different tasks involved. The results show that subjects could fully benefit from advanced information and prepare themselves for a future switch, only when some level of proficiency on the involved task has been reached prior to the request to apply differential control policies. A second and independent practice component was found to influence the costs of control operations themselves, as the costs of switching and reconsideration were reduced with practice. The emergence of two separate training factors underlines, on the one hand, the independent contribution of executive control functions to proficient performance. On the other hand, they demonstrate the dependence of these functions on the existence of task representations and knowledge bases developed with experience on the task. These findings have important implications for the development of training programs for complex skills. It is evident that both the content and the time schedule of training programs should be adjusted to reflect and accommodate the two classes of contributing factors, namely proficiency in task performance and development of executive control capabilities.

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