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Interference between switched tasks

JEAN-MARIE CELLIER and HÉLÈNE EYROLLE

URA au CNRS No. 259, UFR de Psychologie, Université de Toulouse le Mirail, 5 allées Antonio Machado, 31058 Toulouse Cédex, France

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Interference between tasks in a task-switching situation was interpreted in terms of theoretical models of time-sharing. Controlled processing of two separate tasks in a time-sharing situation was hypothesized to require a strategy of management whose ease of execution depends on the complexity of the task involved. Switching from one task to the other requires activation of the resources required for performance of the new task and inhibition of the resources engaged in the first task. Failures in either of these two processes will interfere with the performance of the second task. This hypothesis was tested in a situation in which subjects had to switch from one detection task to another. Interruption of one task to carry out another task increased both processing time and error rate in the second task. The types of error (intrusions, confusions and omissions) were considered to be specific to time-sharing.

1. Introduction

The increasing complexity of many work situations often requires operators to carry out several tasks in a limited period of time. Numerous studies (Goldstein and Dorfman 1978, Navon and Gopher 1980, Wickens *et al.* 1981, Damos and Lyall 1985, Friedman *et al.* 1988) have been devoted to performance in time-sharing task situations. Most of these studies have employed a dual task paradigm, and, in outline, have shown that:

- perfect time-sharing, i.e. no degradation of performance of either task, only occurs when the tasks can be processed automatically (Shiffrin and Schneider 1977); an example is speaking while walking;
- there is generally some interference between the two tasks, and a variety of theoretical models, which will be discussed below, have been devised to account for these processes;
- serial rather than parallel processing is generally utilized (Damos *et al.* 1983).

Although parallel processing may appear to be taking place, fine analysis points to serial processing with varying switching rates.

The experiments reported here were designed to investigate performance in the particular time sharing paradigm (Leplat 1982) represented by task switching in which processing of one task is interrupted by the need to process a second task. A practical example is that of a secretary who has to interrupt typing to answer the telephone, retrieve files, etc. In this situation, the occurrence of the second task cannot be predicted by the operator, in contrast to the usual dual task situation in which the operator can program the alternation between the two tasks. In addition, the unpredictability of the occurrence of the second task is frequently complicated by the need to perform the two in a limited time span. This situation of task interruption is of interest from two points of view:

- the overall efficiency of human-machine systems. Task interruption is known to have a marked influence on human efficiency. For example, in process control situations, Bainbridge (1984) showed that malfunctions were often related to the occurrence of a second task which distracted the operator. In the nuclear power industry, Griffon-Fouco and Ghertman (1984) showed that operators had been distracted during execution of the primary task in more than 15% of the incidents leading to shut-down of operation. A study carried out in a telephone company sales office (Paquiot *et al.* 1984) showed that the occurrence of a second task interfered with the performance of the on-going task, reflected by an increased duration of execution.
- at a more theoretical level, understanding the mechanisms of interference requires fine analysis of the processes involved in the processing of both tasks, as well as those pertaining to the interaction between them.

We discuss the notion of interference, and propose a model for interference due to task interruption. We describe an experiment designed to test this model.

2. Theoretical overview

The three theoretical approaches which will be discussed briefly have differing relevance to the process of interference. Although these three approaches are not the only ones which pertain to this problem they are of particular interest to the time-sharing situation.

2.1. *Single channel theory*

The single channel theory (Broadbent 1958, Treisman 1964, Welford, 1967) stresses the limited capacity of the human information processing system. In a time-sharing task situation, the crucial stage is when the channel capacity becomes saturated, and parallel processing switches to serial processing. Saturation has been proposed to arise at two stages, an early stage after perception of the stimulus (Broadbent 1958, Briggs *et al.* 1972), or a late stage during response selection (Deutsch and Deutsch 1963, Keele 1973). Helm *et al.* (1978), however, have shown that the stage at which interference occurs depend on the demands of the secondary task (p. 666). McLeod (1977) compared four models which differed in their presumed stages of interference, and came to the conclusion that the multiprocessor model (Allport *et al.* 1972) accounted for the results better than the single channel model.

2.2. *Multiple resources model*

The multiple resources model proposed by Wickens (1980, 1984, 1989) stresses the limited processing capacity, not in terms of channel, but as a system of processing resources (Knowles 1963, Norman and Bobrow 1975). The concept of processing resources is a hypothetical variable designed to account for alterations in time sharing efficiency (Wickens 1984, p. 63). This model can account for some of the characteristics of time-sharing such as resource competition, the subject's control of resource allocation, and exchange of resources between the tasks. Limits in efficiency during time-sharing thus hinge on the level of difficulty of the tasks (mobilization of different amounts of resources) as well as structural limitations in the processing system. For example, interference in time-sharing may be due to overlap of the resources required for processing of the individual tasks.

2.3. *Information processing analysis*

Another approach is based on analysis of information processing. This is derived from selective attention theory and the distinction between automatic and controlled processing (Shiffrin and Schneider 1977). If at least one of the tasks can be carried out automatically (without conscious attention), time-shared processing can take place without degradation of performance. If both tasks require controlled processing, the overall strategy involved in processing two consecutive stimuli can be split into two mechanisms, facilitation and inhibition (Posner and Snyder 1975). Operation of this strategy requires attentional capacity which can lead to interference when the demands of the tasks exceed the available capacity.

A major factor affecting efficiency in time-sharing situations is thought to be task difficulty (Navon and Gopher 1979, 1980, Goldstein and Rollins 1986). Navon and Gopher (1979) suggest that the difficulty of a task can be defined in terms of the number of responses required and the time allocated for the given task (p. 220). Two variables are thus involved: temporal constraints (number of responses required in a given time span), and task complexity (amount of information that must be assimilated for execution of the task). This is a rather restrictive definition of complexity as it does not take any account of the nature of the processing required.

A third variable considered by most authors to be involved in time-sharing is task similarity, although it is still not clear whether it has a facilitatory or an inhibitory role. Like complexity, similarity can occur at various levels, from that of the stimuli through information processing to that of the responses required.

In a time-sharing situation, the processing of two tasks is thought to depend on a strategy of resource management, and the lower the demands of the task the easier will be the management decision. In a task-switching situation, resources required for the new task must be activated while those employed in the first task must be inhibited. Failures in either of these processes will give rise to interference.

In any non-automatic process, the management of task-switching will mobilize resources, and the resources available will also depend on the nature of the on-going task. If the first task is complex, and has to be executed rapidly, it will mobilize a large number of resources. The capacity of the system will thus be close to saturation, and few resources will be left over for resource management. This reduction in available resources due to the complexity of on-going information processing and the influence of time constraints can lead to failures in resource management giving rise to interference between the two tasks. Another source of failure stems from the similarity of the resources used in processing the tasks. Two types of resources can be distinguished. The first are those defined by Wickens (1984) as base resources. The second are those constructed by the subject, which are based on knowledge, learning, or inference. The relationship between the similarity of the base resources in an alternate task situation and failures in resource management is unclear. However, from an analysis of the nature of the errors (Norman 1981), similarities between the constructed resources could lead to an inappropriate allocation of resources for the second task. In this case, the similarity between the two types of constructed resources would disrupt the normal processes of inhibition and activation. Furthermore, disruption of inhibition and activation may be short-lived giving rise to an only transient loss of efficiency during execution of the second task.

3. Materials and methods

3.1. *Subjects*

Ninety-six female psychology students took part in these experiments. They were not paid to participate in the study.

3.2. *Apparatus*

The experiments were conducted using a microcomputer (Macintosh Plus).

3.3. *Tasks*

The subject was required to select particular items from a scrolling display of numerical and alphabetical information. The items to be selected appeared in a window on the screen (cf. figure 1). The information scrolled in a discontinuous fashion from right to left. The time constraint variable was represented by the rate of scrolling. Fourteen different information conditions were presented. Each subject performed two of the following six tasks:

- selected even numbers followed by an odd number (R1, T1);
- select even numbers followed by an even number (R2, T2,);
- select even numbers preceded by a letter and followed by a number over 50. (R3, T3);
- select odd numbers preceded by a consonant and followed by a number over 50 (R4, T4);
- select even numbers followed by a number over 50 (R5, T5);
- select even numbers preceded by a vowel and followed by a number over 50 (R6, T6).

The subject's response was made using the mouse, by moving the pointer to the row just below the selected information and clicking the button (cf. figure 1). If the information did not correspond to the rule, the subject had to make a response in the bottom row (cf. figure 1). Responses were signalled by the appearance of an asterisk in the corresponding box.

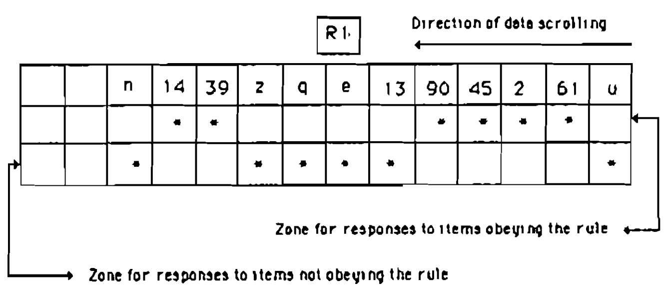

Figure 1. Diagram of a screen presentation.

The experiment took place in four stages, and each subject carried out each of the stages. Half of the subjects in each group carried out stage 3 before stage 2, the other half performed each stage in the normal sequence. This reversal did not affect the results for stage 3, and is thus not taken into account in the presentation of the results.

Stage 1: learning each task separately (10 min per task).

Stage 2: dual task (10 min). A second window like that shown in figure 1 was displayed on the screen. The subject had to carry out both tasks simultaneously in their separate windows.

Stage 3: task switching (20 min). This stage was carried out in six steps. The diagram shown in figure 2 illustrates the sequence of operations. Each subject carried out all six steps in the same order. Only one window was displayed on the screen. When the second task was about to be presented, the subject was warned by a tone and the appearance of the @ character on the screen above the data zone. The unpredictability in timing of the second task and the duration of presentation were varied in a pseudo-random manner within the following constraints:

- each task was presented 3 times to each group of subjects (six sequences for stage 3);
- for each task, the minimum duration was 1 min and the maximum 5 min.

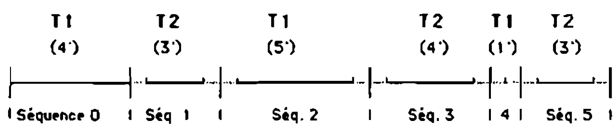

Figure 2. Attention of tasks in Stage 3. The duration (min) of each task is given in parentheses. Each task sequence included two measurement intervals indicated by dotted lines (...)
—beginning: first 30 s;
—end: last 30 s.

Stage 4: single task situation (5 min per task).
We only present here the results obtained during stage 3 as they were directly relevant to interference in a task switching situation.

3.4. *Variables*
There were three independent variables:

- Time constraint was varied by changing the rate of scrolling of the characters on the screen. Two rates were used: low = 18 characters per min (one new item every 3.33 s), high = 21 characters per min (one new item every 2.85 s).
- Complexity was defined as the amount of information to be processed. Two levels of complexity were used: low = 2 items, high = 3 items. Tasks R1, R2, and R5 were considered to be of low complexity, while tasks R3, R4, and R6 requiring application of rules were of high complexity.
- Similarity was defined by the amount of overlap between the nature of the items and the rules to be applied for execution of the task. The less the overlap the lower the similarity. Thus tasks R1 and R2 involving selection of even and odd numbers respectively were regarded as dissimilar. Likewise there was little similarity between tasks R4 and R6. On the other hand, R1 and R5 were more similar as the first element to be selected is an even number in both cases, and

the second element is also a number. For tasks R3 and R6, the only difference is in the second element (letter in R3 and vowel in R6).

To gain information on the mechanisms of inhibition and activation, performance was analysed during the first 30 s and last 30 s of each sequence (cf., figure 2).

A $2 \times 2 \times 2$ design was thus employed with a repeated measure for each sequence. Each group carried out two tasks of different complexity and similarity. Crossing over with the time constraint variable defined eight experimental groups, with a repeated measure for each sequence. Twelve subjects were assigned to each group at random.

Two dependent variables were analysed:

- Inter response interval (IRI in s). The response could be made either in the upper (match of item to criterion) or lower row (mismatch).
- The error rate expressed as the number of errors divided by the total number of items for each subject. The types of error are discussed below.

4. Results

4.1. *Interference due to task switching*

The 4 min sequence at the start of each stage (sequence 0, figure 2) was not analysed as we were only interested in the disruption resulting from task switching. Analysis of variance showed a strong time constraint effect ($F(1,88)=693{\cdot}7$, $p<0{\cdot}0001$) and a beginning/end of sequence difference ($F(1,88)=76{\cdot}38$, $p<0{\cdot}0001$).

There was a significant interaction between time constraint and beginning/end difference ($F1,88=6{\cdot}45$, $p=0{\cdot}013$). Newman-Keuls pairwise comparison indicated that the most significant differences were between the conditions with low and high time constraints ($W7=0{\cdot}375$, $p<0{\cdot}05$; $W6=0{\cdot}228$, $p<0{\cdot}05$) and between beginning and end of sequence ($W2=0{\cdot}147$, $p<0{\cdot}05$). It should be noted that the difference between the means was highest for the low time constraints. Under a low time constraint, the tasks may be data limited (Norman and Bobrow 1975), and so the subject does not have to employ a large number of resources to achieve a high performance except when a new task has to be carried out. On the other hand, under a high time constraint, the task remains relatively hard, requiring constant attention, and so the tasks are resource limited. This may account for the smaller difference when switching from one task to the other under the high time constraint. Another possible explanation hinges on the notion of activation (Kahneman 1973). This author suggests that the level of activation depends on the workload which mobilizes extra resources that are not utilized at lower workloads.

The increase in inter response intervals in the first 30 s after starting the new task can be interpreted in terms of a management strategy model. This gives a measure of the level of difficulty in swapping from one task to another. In order to find out whether this was temporary effect, we compared performance between the beginning and end for the sequences of identical duration (1 and 5). Sequence 1 is the first switching task while sequence 5 represents the last switching task. Analysis of repeated measures shows a significant sequence effect ($F(1,190)=3{\cdot}902$, $p=0{\cdot}050$) and a beginning/end effect ($F(1,190)=3{\cdot}964$, $p=0{\cdot}048$). There was also an interaction ($F(1,190)=3{\cdot}964$, $p=0{\cdot}048$). It can be seen from figure 3 that this disruption persisted over repeated sequences.

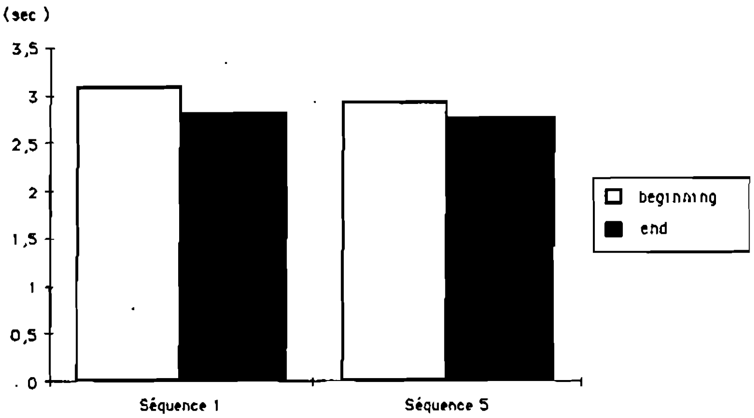

Figure 3. Mean inter-response intervals at the beginning and end for sequences 1 and 5.

In summary, switching between tasks led to an increase in inter response interval during the first 30 s of execution of the second task. This is interpreted to be due to the operation of a resource management strategy.

Although this effect was somewhat attenuated after repeated exposure it would appear that the management of resources during task switching represents a major source of difficulty in this situation. The greater increase in response time under low than under high time constraints could be accounted for by the constant higher state of activation under the high time constraint.

4.2. *Performance*

The overall quality of performance was expected to be affected by the need both to inhibit mechanisms involved in the first task, and to activate those required for the second task. Quality of performance was evaluated from error rates. We observed a significant beginning/end difference ($F(1,88)=42{\cdot}56$, $p<0{\cdot}0001$) as well as a time constraint effect ($F(1,88)=7{\cdot}82$, $p=0{\cdot}006$). There was an interaction between time constraint and complexity ($F(1,88)=3{\cdot}91$, $p=0{\cdot}05$). These results were comparable to those observed for the IRI. Newman-Keuls pairwise comparison indicated that the greatest difference was between low and high time constraints, especially for the tasks of low complexity ($W3=0{\cdot}0633$, $p<0{\cdot}05$). The error rate was greater under the high than under the low time constraints. The second main difference in error rate was between the tasks involving a high complexity under a high time constraint and those of low complexity under a low time constraint ($W2=0{\cdot}0548$, $p<0{\cdot}05$).

These results, along with those for IRI, show that switching from one task to the other leads to interference in the performance. This effect was most marked under a high time constraint. There is in apparent contradiction to that observed for IRI. IRI were found to be longer under a low than under a high time constraint. This was interpreted in terms of activation which does not however, account for the difference in error rates, which was assumed to be due to a trade-off between speed and accuracy. In this case, under a low time constraint the subject aims for accuracy, whereas under a high time constraint priority is given to speed.

Although there was no complexity effect, there was an interaction between complexity and time constraint. The fact that the error rate was higher when high complexity was associated with a high time constraint indicated that the lack of a complexity effect was due to an insufficient level of complexity.

As for IRI, we compared the beginning/end performances for the two equal duration sequences (1 and 5). Analysis of variance with repeated measures showed a significant beginning/end difference ($F(1,190)=28{\cdot}56$, $p<0{\cdot}0001$). It can be seen in figure 4 that this phenomenon persisted over repeated sequences.

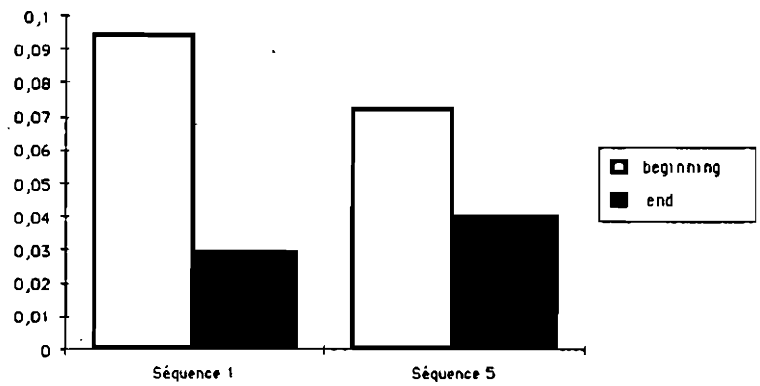

Figure 4. Mean error rate for beginning and end of sequences 1 and 5.

The effects observed (increase in IRI and error rate) on task switching could be simply ascribed to an adaptation effect. The subjects may not achieve optimal performance immediately on starting a new task. This possibility was assessed by examination of the nature of the errors recorded.

4.3. *Nature of errors*

Two types of error could be distinguished. The first included errors that we observed in both single task and task switching situations (Eyrolle and Paquiot 1989). These were errors of manipulation and anticipation which depended essentially on the nature of the experimental set up.

The second category consisted of errors observed essentially in the time sharing situation. They could be divided into three subgroups:

- *intrusions*: The subject made a correct response for task 1 while carrying out task 2.
- *confusions*: The subject selected an item obeying two rules. This type of error corresponds to the mixture errors described by Norman (1981), resulting from competition between two schemes.
- *omissions*: The subject missed an item obeying the relevant rule.

We refer to the first category as non-specific errors and the second as specific errors to time-sharing. We hypothesize that the specific errors stem from difficulty in activating resources required for the new task and inhibiting those engaged in the first task. These errors provide an indication of failures in the management of resources or a loss of activation during information processing (Norman 1981), and will tend to be observed when tasks are switched. For example, consider a subject carrying out R2 (select odd numbers followed by an even number) after R1 (select even numbers followed by an odd number) who selects 35/43. In this case, we assume that there is partial activation of the resources required for R2 and partial inhibition of the resources required for R1. There is thus a deficiency in resource management.

It should be noted that only 7·84% of the total errors were specific to the time sharing situation, and so the results should be interpreted with caution. The distribution over time of non-specific and specific errors (cf. figure 5) indicated a sensitivity to interruption, especially for the specific errors.

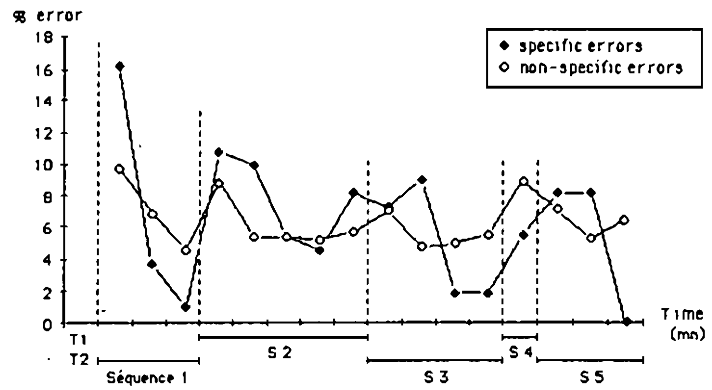

Figure 5. Distribution (%) of time-sharing-specific or non-specific errors over time.

5. Discussion

The results showed that interruption of one task in order to carry out another task led to:

- an increased processing time;
- an increased error rate;
- the appearance of certain types of error (intrusions, confusions and omissions) which tend to occur more frequently when tasks were switched.

The errors provided a measure of the degradation in performance that occurred when the tasks were switched. It has been suggested that the lower the demands of the individual tasks the lighter will be the management load for task-switching. The management strategy is assumed to involve activation of resources required for the second task along with inhibition of the resources employed in the first task. However, the increase in inter response time we observed under the low time constraints is in apparent contradiction with this model. This result was accounted for in terms of activation (Kahneman 1973), although this hypothesis could not account for the differences in error rates we observed, which were interpreted in terms of a conflict between speed and accuracy. The unexpected direction of the effect of time constraint on IRI, and the absence of a complexity effect does not, however, rule out an explanation based on the resource management model. The levels of difficulty of our tasks were determined in a dual task situation, and it may be that they become easier in the task switching paradigm. An experimental procedure combining a single task, dual tasks and task-switching designed to isolate errors specific to task switching may not have set the demand of the switched tasks high enough. We suggest that a moderate demand will facilitate the management process to a greater extent than a low or high demand.

Management is conceived as a process of resource allocation. The notion of resource is of interest in view of the nature of the different tasks in our study and the weak effect of similarity on performance. Wickens' (1984) definition of processing resources as a hypothetical variable invoked to account for alterations in efficiency in time sharing (p. 63) is quite wide. We propose a distinction between base resources and constructed resources. The former designate the processing structures described by Hirst and Kalmar (1987) in which structures refer to architectural components of an information processing system including central processing units, short term memory, processing channels or Fodor modules (1983) (p. 78).

The constructed resources are contextual elements or knowledge organized in the form of schemata (Norman and Rumelhart 1975, Bobrow and Norman 1975). In our study, only the constructed resources were manipulated, and it would be of interest to find out whether sensitivity to interference would be stronger for tasks with similar base resource requirements.

A further point is the distinction between the processes of activation and inhibition. We could not determine whether the process of activation of new resources inhibits previously employed resources. However, the observation of intrusion errors does indicate that the management process involves two components (activation and inhibition), although we could not assess their degree of interdependency.

In conclusion, our results throw more light on the phenomenon of interruption, and suggest ways of validating the resource management model and finding out more about the processes underlying human errors in work situations. It would be of interest, for example, to examine:

(1) the effect of a pause on both single and switched tasks in order to discriminate between the processes of activation and inhibition;
(2) performance in alternate tasks that differ considerably. This would help throw light on the role of base resources in interference;
(3) the effect of an alarm signal just before the second task.

Understanding the mechanisms involved in task-switching could improve comprehension of the processes leading to errors, and help devise methods for improving performances in such situations.

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References

Allport, D. A., Antonis, B. and Reynolds, P. 1972, One the division of attention: a disproof of the single channel hypothesis, *Quarterly Journal of Experimental Psychology*, **24**, 225–235.

Bainbridge, L. 1984, Diagnostic skills in process operation, in *Proceedings of 1984 International Conference on Occupational Ergonomics*, Toronto, Vo. 2, 1–10.

Bobrow, D. G. and Norman, D. A. 1975, Some principles of memory schemata, in D. G. Bobrow and A. Colins (eds) *Representation and Understanding* (Academic Press, London).

Briggs, G., Peters, G. and Fisher, P. 1972, On the locus of divided attention effects, *Perception and Psychophysics*, **11**, 315–320.

Broadbent, D. E. 1958, *Perception and Communication* (Pergamon Press, New York).

Damos, D. L., and Lyall, E. A. 1985, The effect of varying stimulus and response modes and asymmetric transfer on the dual-task performance of discrete tasks, *Ergonomics*, **29**, 4, 519–533.

Damos, D. L., Smist, T. E. and Bittner, A. C. 1983, Individual differences in multiple-task performance as a function of response strategy, *Human Factors*, **25**, 2, 215–226.

Deutsch, J. A. and Deutsch, D. 1963, Attention: some theoretical considerations, *Psychological Review*, **70**, 80–90.

Eyrolle, H. and Paquiot, J. 1989, Activité de gestion des tâches en situation de temps partagé. Approche expérimentale des interférences dans l'activité, de traitement, Thèse de Doctorat, Université Toulouse II.

Fodor, T. 1983, *The Modularity of Mind* (MIT Press, Cambridge, MA).

Friedman, A., Polson, M. and Dafoe, C. G. 1988, Dividing attention between the hands and the head: performance trade-offs between rapid finger tapping and verbal memory, *Journal of Experimental Psychology: Perception and Performance*, **14**, 60–68.

Goldstein, I. L and Dorfman, P. W. 1978, Speed and load stress as determinants of performance in a time-sharing task, *Human Factors*, **20**, 5, 603–609.

Goldstein, F. C. and Rollins, H. A. 1986, Multiple resources: the concepts of task difficulty and response requirements, *Bulletin of the Psychonomics Society*, **24**, 3, 189–192.

Griffon-Fouco, M. and Ghertman, F. 1984, Recueil de données sur les facteurs humains à Electricité de France, in *Operational Safety of Nuclear Power Plants*, Vienna, International Atomic Energy Agency, 157–172.

Helm, W. R., Fishburne, R. P. and Waag, W. L. 1978, Channel capacity and locus of interference under dual-task conditions, *Perceptual and Motor Skills*, **46**, 659–666.

Hirst, W. and Kalmar, D. 1987, Characterizing attentional resources, *Journal of Experimental Psychology: General*, **116**, 1, 40–49.

Kahneman, D. 1973, *Attention and Effort* (Prentice Hall, Englewood Cliffs).

Keele, S. W. 1973, *Attention and Human Performance* (Goodyear, Pacific Palisades, CA).

Knowles, W. B. 1963, Operator loading tasks, *Human Factors*, **5**, 2, 155–162.

Leplat, J. 1982, Les situations de travail, terrains d'avenir pour la Psychologie, in P. Fraisse (ed.), *Psychologie de demain* (PUF, Paris), 311–330.

McLeod, P. 1977, A dual-task response modality effect: support for multiprocessor models of attention, *Quarterly Journal of Experimental Psychology*, **29**, 651–677.

Navon, D. and Gopher, D. 1979, On the economy of the human processing system, *Psychological Review*, **86**, 3, 214–255.

Navon, D. and Gopher, D. 1980, Task difficulty, resources, and dual task performance, in J. Nickerson (ed.), *Attention and Performance* (Lawrence, Erlbaum, Hillsdale, NJ), 297–315.

Norman, D. A. 1981, Categorization of actions slips, *Psychological Review*, **88**, 1, 1–15.

Norman, D. A. and Bobrow, D. G. 1975, On data-limited and resource limited processes, *Cognitive Psychology*, **7**, 44–64.

Norman, D. A. and Rumelhart, D. E. 1975, *Explorations in Cognition* (Freeman, San Francisco, CA).

Paquiot, J., Eyrolle, H. and Cellier, J-M. 1986, Conséquences de l'interférence entre tâches de saisie sur la durée des traitements et l'occurrence des erreurs, in R. Patesson (ed.), *L'homme et l'écran* (Editions de l'université de Bruxelles), 199–209.

Posner, M. I. and Snyder, C. R. R. 1975, Facilitation and inhibition in the processing of signals, in P. M. A. Rabitt and S. Dornic (eds), *Attention and Performance* (Academic Press, New York), 669–682.

Shiffrin, R. M. and Schneider, W. 1977, Controlled and automatic human information processing: 2—Perceptual learning, automatic attending and a general theory, *Psychological Review*, **84**, 127–190.

Treisman, A. M. 1964, Selective attention in man, *British Medical Bulletin*, **20**, 12–16.

Welford, A. T. 1967, Single channel operation in the brain, *Acta Psychologica*, **27**, 5–22.

Wickens, C. D. 1980, The structure of attentional resource, in R. Nickerson (ed.), *Attention and Performance* (Lawrence Erlbaum, Hillsdale, NJ), 239–257.

WICKENS, C. D. 1984, Processing resources in attention, in R. Parasuraman and P. R. Davies (eds), *Varieties of attention* (Academic Press, Orlando), 63–102.

WICKENS, C. D. 1989, Attention and skill, in D. Holding (ed.), *Human Skills* (J. Wiley, Chichester), 72–105.

WICKENS, C. D., MOUNTFORD, S. J. and SCHREINER, W. 1981, Multiple resource, task-hemispheric integrity, and individual differences in time-sharing, *Human Factors*, **23**, 2, 211–229.

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