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The Domain of Supervisory Processes and Temporal Organization of Behaviour [and Discussion]

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The domain of supervisory processes and temporal organization of behaviour

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SUMMARY

The possibility that the supervisory system of Norman & Shallice (1986) can be fractionated into different subprocesses is discussed. It is argued that confronting a novel situation effectively requires a variety of different types of process. It is then argued that evidence of separability of different processes may be obtained by the observation of very low correlations across patients on more than one measure on each of which frontal patients show a performance deficit. Examples of this are provided by examining the Hayling sentence completion and the Brixton spatial anticipation tasks. Finally, differential localization of the subprocesses and hence the conclusion that they are separable is discussed with respect to the localization of monitoring and verification processes in memory.

1. INTRODUCTION

In recent accounts of the cognitive processes carried out by the prefrontal cortex it has been common to characterize them in terms of some key single type of process. The most common characterization has been in terms of working memory (e.g. Kimberg & Farah 1993). However, rival unitary accounts exist. Thus Duncan (1993) argued that 'goal-weighting' – the weighting of candidate goals to control behaviour in the next period of time – underlies general intelligence *g* and is the key process carried out by prefrontal cortex. We have argued for what may seem to be a related position, namely that prefrontal cortex is the seat of one overriding system – the supervisory system (Norman & Shallice 1986; Shallice & Burgess 1991). However on this approach a 'system' is viewed as such because of how it interacts with other systems outside itself and not because it carries out only a single process.

In this paper we will present three lines of argument that even if it is appropriate to view the supervisory system as a single system, it is not correct to view it as carrying out only a single type of process. Indeed the evidence points to the existence of a variety of processes carried out by different subsystems but operating together to have a globally integrated function.

The processes carried out in human prefrontal cortex are, in causal terms, relatively far from both stimulus input and response output. Therefore they do not map transparently into the stimulus or response parameters of simple tasks. Characterizing these processes therefore is best achieved by a form of converging operations. In addition, one of these operations needs to be a theoretical framework of the types of processes likely to be present.

In the approach we have adopted, like in most of the competing characterizations, the prefrontal cortex is the seat of high-level processes that modulate lower-level ones. On such an approach it is essential that the lower-level modulated processes are adequately characterized. In an earlier version of the present theory (Norman & Shallice 1986; Shallice 1988) the more detailed aspects of the theorizing concerned the modulated system – so-called 'contention scheduling'. Contention scheduling has recently been simulated (Cooper *et al.* 1995). When noise is added in the implementation to produce an analogue of a lesion it gives rise to behaviour analogous to utilization behaviour (Lhermitte 1983; Shallice *et al.* 1989) and the core characteristics of the action disorganization syndrome (Schwartz *et al.* 1993). As these are both existing neurological syndromes this increases the plausibility of the approach.

In this paper we continue to adopt the contention scheduling/supervisory system framework and address the question of how one should proceed in the fractionation of the supervisory system into its basic subcomponents. We begin by broad theoretical considerations and then discuss two types of empirical evidence: neuropsychological dissociations and localization by functional imaging.

2. THEORETICAL CONSIDERATIONS

We use the term situation to refer to a particular combination of environmental and internal states, particularly goals. Under the theory, a routine situation is one where thought and action schemas, essentially subroutines which are capable of realizing the relevant goals effectively, are selected through the automatic triggering on-line of well-learned perceptual

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or cognitive cues. Various types of evidence exist that the prefrontal cortex is, however, critically involved in coping with novel situations in contrast to routine ones – neuropsychological (e.g. Luria & Tsetkova 1964; Shallice & Evans 1978; Walsh 1978; Shallice 1982), electrophysiological (Knight 1984) and from functional imaging (Raichle *et al.* 1994).

While computational theories such as *Soar* (Newell 1990) show that the distinction between 'novel' and 'routine' can be effectively implemented, no existing computational theory of confronting novel situations is psychologically plausible (see Cooper & Shallice 1995 for discussion). The following position is therefore essentially speculative. The first basic premise of this paper is that coping with a novel situation involves a variety of different types of process operating over at least three stages. The second basic premise is that a key element in coping with a novel situation is the construction and implementation of a temporary new schema, which can take the place of the source schema triggered by the situation for routine control of behaviour, and which will in turn be capable of controlling lower-level schemas so as to provide a plausible procedure for achieving the situation goals. This temporary new schema can be an existing one, which is not directly triggered by the situation but more usually is an adaptation of an existing schema or schemas. Its phenomenological equivalent is the strategy the subject is carrying out (see also Robbins, this volume).

The processes assumed to be involved are:

Stage 1

As will be discussed shortly, a variety of processes can be involved in constructing the temporary new schema.

Stage 2

A process (process 1) is required for implementing the operation of the temporally active schema constructed in stage 1. This will require a working memory. However this will be far from a general-purpose working memory, but one for the specific purpose of holding the temporally active schema since the schema is not triggered automatically in the situation.

Stage 3

A process (process 2) is needed for monitoring how well the type 2 processes are effected as with both the schemas and the situation being novel, temporary schemas cannot be known to be effective. This process can lead on to the rejection or alteration of the existing temporary schema (process 3).

The processes involved in stage 1 (strategy generation) are more complex. Strategy generation can occur spontaneously or through a process of problem solving. 'Spontaneous' strategy generation refers to the way that a procedure for tackling the situation can come to mind without any explicit attempt to solve a problem, but merely following a sense of dissatisfaction with the preceding method of tackling the situation. To implement it would necessarily be far more complex than say the running of a program (process 1) but in this paper we merely assume it to be a distinct process (process 4).

The second alternative is to use problem solving which frequently occurs in situations which do not explicitly require it (see Burgess & Shallice 1996*a*). Problem solving involves processing passing through a series of phases which, at the grossest level, are the phase of problem formation or orientation, the phase of the deepening of a solving attempt, then the phase of the assessment of a solution attempt followed by a return to the first phase or of a phase of recapitulation and checking (see De Groot 1966, p.148). The control of the sequence of phases must require a process for the determination of what we call the processing mode in operation for that particular phase, by analogy with Tulving's (1983) conception of 'retrieval mode' (process 5). The one of these phases which would seem to require a process different to those previously discussed is that of the initial problem formation or orientation and in particular what De Groot (1966) calls the 'evaluative moment', the process which leads to 'goal-setting' and 'quantitative expectancy' about what is to be achieved (process 6). This process is critical in that it provides the criteria for the later assessment of the solution attempt.

A final category of process consists of special purpose processes to assist in appropriate strategy generation. One is the formation and realization of intentions (process 7), so that one can prepare a strategy and plan action for a later time. A second is episodic memory retrieval (process 8) which according to Schank (1982) has the function of providing the raw material of related experiences for confronting novel situations (Burgess & Shallice 1996*d*). These processes all clearly relate to Fuster's (1980) conception of the prefrontal cortex as responsible for the structuring of behaviour over time (see figure 1).

It seems likely that all of these eight processes involve prefrontal structures. However in the discussion of empirical evidence that follows we will not attempt to separate processes 1 and 4 (to be called process 1/4) or processes 2 and 3 (to be called process 2/3) and we will not be concerned with process 6 (but see Duncan 1986 and Damasio this volume) or process 8 (but see Burgess & Shallice 1996*a*). This leaves four processes to be considered later.

A key element in this approach is the temporary schema with its phenomenological correspondence, the subject's strategy. Since the 1960s it has been known in cognitive psychology that to understand the performance of subjects in many tasks it is necessary to know which strategy has been used, which they can typically report. Prefrontal patients often have a striking deficit in this domain, in that they do not use the strategy normal subjects typically generate. For instance, Shallice & McGill (unpublished) carried out an experiment which was an analogue of Corsi's experiments (see Milner 1971) on recency judgments except that Corsi's time dimension was replaced by an importance dimension. Stimuli (words or faces) were

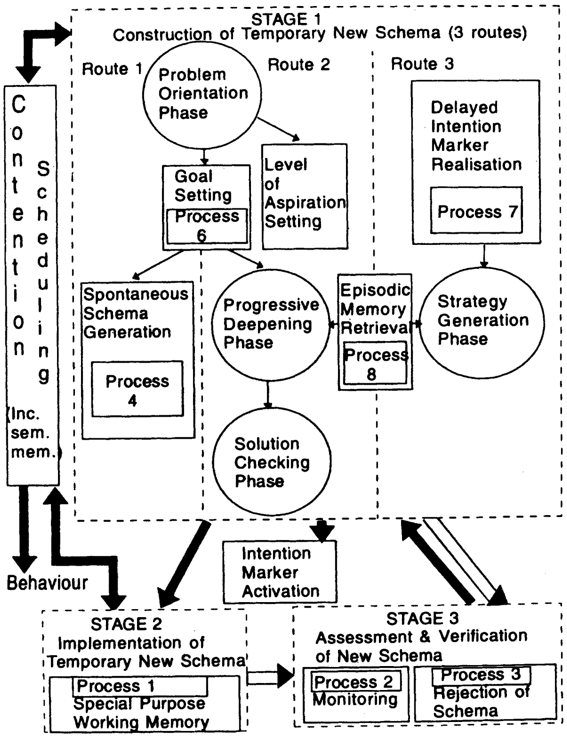

Figure 1. Diagram of the relation between the theoretical constructs discussed. Within the dotted rectangles representing the different stages, temporally distinct phase of supervisory system processing is depicted by a circle. An operation, which corresponds to a change-of-state of one or more control variables, is depicted by a solid rectangle. Solid lines between the stage represent flow of control between the operation of different stages or between the supervisory system and contention scheduling. Unfilled lines represent information transfer used in monitoring operations.

presented and at the same time the subject was told 'important' for some of the stimuli. On interspersed test trials subjects were presented with two types of forced choice in a mixed sequence, namely ones based on relative importance and ones based on simple forced-choice recognition. Most normal subjects develop the strategy of paying less attention to stimuli not labelled important at input, to facilitate the first and more difficult of the discriminations. Of the 46 posterior patients, 78% indicated that they developed the strategy compared to only 50% of the 46 patients whose lesions involved the frontal lobes.

In a quite different situation Owen *et al* (1990) found that frontal patients have a deficit on a spatial working memory task. However, they also showed a significant deficit on a measure which reflected the consistency in the search strategy they employed. The basic deficit in the group appeared to concern their strategies (see Robbins this volume). Finally we have recently studied the ability of patients to inhibit a prepotent verbal response (Burgess & Shallice 1996*b*). Subjects were given a sentence with its final highly constrained word removed. They were instructed to give a word which had no relation to the sentence frame. Again, normal subjects were typically found to adopt a strategy, in order to avoid the need to inhibit the prepotent response. They used one of two procedures to generate a candidate word prior to the response and then checked it for suitability or rather unsuitability after the sentence frame was presented. Frontal patients used such a strategy significantly less than patients with posterior lesions, although this time the original deficit was still present when the strategy score was used as a covariate. Process 1/4 therefore seems to be impaired by frontal lesions.

In none of these studies does one know to what extent the problem of the prefrontal patients was in strategy generation or in a strategy realization. However, strategy realization would involve the holding of a small programme of internal commands based on previously learned operations (schemas) and if/then operations using perceptual or cognitive signals (triggers). It would take the form of a temporarily active schema, but being not well learned it would need to be retained in a specific working memory store; this is a plausible candidate function for the working memory stores described in dorsolateral prefrontal cortex (e.g. Goldman-Rakic 1987).

The process of monitoring for errors (process 2) is discussed in §4, and determination of processing mode (process 5) in the next section. The final process to be considered (process 7) intention generation and realization – we held to be the critical component giving rise to the impaired performance of three patients with frontal head injuries in carrying out so-called strategy application disorder tasks (Shallice & Burgess 1991). These are tasks in which it is necessary for the subject to carry out a set of unrelated subtasks without any specific triggering of individual subtasks by relevant instructions as to when they should have been carried out, and to do this while obeying certain simple rules of task execution. When starting the experiment, the subject needs to set up intentions both to carry out the individual tasks and to obey the rules, which requires process 7. These frontal patients spent much longer on individual subtasks seemingly forgetful of the other tasks that needed to be carried out (see also Goldstein *et al.* 1993; Cockburn 1995). Later research has shown that performance on one such task – the six elements task – is the most highly correlated (0.46) of a set of executive tasks with relatives' assessments of the difficulty patients had in realizing plans (Burgess *et al.* 1996). It has also been shown in a group study that frontal patients are strongly impaired on this task by comparison with normal controls, even though the two groups did not differ on Raven's matrices (Burgess *et al.* unpublished).

We have so far shown that of the four processes to be considered two are impaired by frontal lobe lesions. However, before considering the other two, the issue of the empirical separability of subprocesses will be discussed.

3. LOW CORRELATIONS BETWEEN TASKS WHICH LOAD ON SUPERVISORY FUNCTIONS

Classically within neuropsychology the way to determine whether two processes involve separable systems is to begin by establishing cross-over double dissociations between certain tasks which load heavily on one of the processes and tasks which load heavily on the other. The use of individual case studies is, however, primarily of value when three conditions hold. The range of performance of normal subjects must leave an ample region in which to observe clearly impaired performance. Normal performance must be approximately stationary, and theoretically interesting variations on the basic task must be effectively usable on the individual subject. These three conditions are frequently not all satisfied with tasks that load heavily on 'frontal functions'. For exceptions with respect to single dissociations see the example of the selective inability to modulate strategies in working memory tasks (Robbins *et al.* 1995) and the selective inability to carry out multiple unscheduled tasks (Shallice & Burgess 1991; Goldstein *et al.* 1993).

Group study methodology, however, offers an apparently analogous approach, namely to show low correlations between frontally loaded tasks in a group of patients with frontal lobe lesions. At least three recent studies have reported relatively low correlations in tasks known to be frontally loaded – word fluency and Wisconsin card sorting – in patients who perform poorly on them (0.35, 0.25 and 0.37 for fluency-Wisconsin categories and −0.40, −0.13, −0.41 for fluency-Wisconsin perserverative errors (Crockett *et al.* 1986; Shoqeirat *et al.* 1990; Kopelman 1991).

There are a number of problems in drawing inferences to fractionation within the frontal lobes from such evidence. First, word fluency and Wisconsin card sorting use different sorts of material and require different sorts of non-frontal processes in their performance. Thus they load on different non-frontal processes and indeed the patients in these studies would all be expected to have lesions which extend outside the frontal lobes. Moreover on a working memory hypothesis, working memory for different types of material would be expected to involve different regions of the frontal lobe, given that different locations are relevant in animal working memory studies with different material (Goldman-Rakic 1987; Kowalska *et al.* 1991). Second, little is known of the reliability of measures of frontal lobe tests. Finally a characteristic found in many frontal lobe patients is variability of performance over sessions (Stuss *et al.* 1994); a suggested explanation is that this arises from impairments in the setting up stage of temporary schemas for task solution (see Stuss *et al.* 1995), given that by definition the task is not well learned.

Consideration of these factors means that for observations of low correlations across frontal tasks to be theoretically interesting the tasks must at least involve the same type of material. As an example consider the Hayling sentence completion test developed by us (Burgess & Shallice 1996*b*), which was discussed briefly in the previous section. Subjects are presented with a sentence minus the final word with the completion word being strongly cued by the sentence frame. For instance, 99% of subjects completed the sentence frame 'He mailed the letter without a ...' with the word 'stamp' (Bloom & Fischler 1980). In the first condition (A) the subject merely completed the sentence as quickly as possible. In the second condition (B) the subject had to complete the sentence with any word that made no sense given the sentence frame. In both Hayling A and B frontal patients performed significantly worse than either controls or patients with posterior lesions. Surprisingly there were no effects of hemisphere. Critically the correlation between Hayling A and Hayling B was only 0.19 which reduced to 0.07 when age and Wechsler Adult Intelligence Scale WAIS IQ were partialled out, both values being not significantly different from zero. Taking into account split-half reliabilities of the test, performance on the two parts doubly dissociate in individual frontal patients (e.g. patient X, A: 1 percentile, B: 76 percentile; patient Y, A: 66 percentile, B: 0.1 percentile). Here at least three of the conditions for separability are met, the possible exception being that test-retest reliability has yet to be established.

We see later that the relation between performance on this test and separability of function is more complex than it might seem. However from the theoretical standpoint the results are straightforward. Hayling A requires the operation only of the contention scheduling system since one must merely allow the prepotent response to occur. However, to produce an inappropriate response in Hayling B some temporary schema or novel strategy needs to come into operation and indeed as discussed in the previous section normal subjects typically develop a particular strategy such as using a heuristic to generate a response prior to the sentence presentation and use of such a heuristic is affected by frontal damage.

If one considers the two types of correct responses – those that fit with one of the two strategies and those that do not – they both correlate negatively with the number of completion errors (−0.66 and −0.45 respectively). However, they do not correlate with each other (−0.10) and their correlations with semantically related responses are very different (−0.65 and −0.16 n.s.). This suggest they arise from different processes. As partialling out the number of strategy-related responses still left an overall effect of lesion site this implies that there is indeed a second separable process in addition to those involved in strategy production and realization which was also frontally based. This second process is presumably related to the monitoring or error correction processes discussed in the previous section. Thus both process 1/4 and process 2/3 are impaired by frontal lesions but appear to be separable.

The Brixton spatial anticipation test (Burgess & Shallice 1996*c*) gives rise to a similar effect. The Brixton test is a non-verbal analogue of the Wisconsin card sorting test except that the rules are more abstract and unlike the Wisconsin no response is prepotently triggered by the stimulus situation. The subject is presented with a card containing a 2 × 5 display of circles numbered in sequence of which one only is filled, the rest being in outline only. The subject must predict where on the next card the circle would be completed. Nine simple rules exist which are each in operation for three to eight trials, typical examples are moving to the next lowest number and alternating between circle 4 and circle 10. On three different measures frontal patients score significantly worse then either posterior patients or controls. One measure is simply the number of correct responses (measure A) but two measures of error type are also significantly higher in frontal patients. Interestingly neither of these is related to perseveration of previous responses or rules. One is concerned with the number of responses never given by any normal control subject in a position (measure B) and the other is the number of times switching away from a rule that had been attained occurs without any negative reinforcement being given (measure C). All three measures are roughly equally sensitive to the anterior/posterior location of the lesion. Measures A and B correlate 0.6 with each other and with age and IQ. However, measure C correlates with neither of the other measures (A: 0.13; B: 0.13).

This strongly suggests that there are two separable frontal factors involved in performance on the Brixton test too and this is supported by structural equation modelling. Simple explanations of either factor in terms of distractibility are implausible since the frontal group were no worse than the posterior patients on WAIS IQ. We associate the first factor with an inability to produce a new hypothesis which would be equivalent to the strategy generation (process 1/4) factor discussed in the previous section. Guesses then would reflect the situation in which the patient cannot come up with an appropriate strategy. The measure C, by contrast, relates to behaviour observed on the Heaton version of Wisconsin card sorting test by Stuss *et al.* (1983). Within the theoretical framework laid out in the previous section these errors would relate to an error in selecting the appropriate processing mode (process 5) by being in temporary schema-search mode (stage 1) instead of realization of temporary schema mode (stage 2). More critically, however, a dissociation-related methodology supports fractionation of supervisory functions.

4. LOCALIZATION BY MEANS OF PET

Within neuroscience the standard way of inferring separability of different subsystems is through demonstrating that the corresponding processes have different localizations. However, this criterion like both the previous ones is not conclusive; in this case processing in different regions may be strongly correlated. The previous studies being based on patients with a variety of aetiologies were not very suitable for precise localization. In any case functional imaging is now the most suitable procedure for addressing issues of localization of function in the human brain. Recently Nathaniel-James *et al.* (1996) have given normal volunteers the Hayling sentence completion test in the positron emission tomography (PET) camera. Using reading the last word of the sentence as the control condition they find that Hayling A activates the left frontal operculum (Brodmann's area 45) and right anterior cingulate (Brodmann's area 32). Hayling B activates the very same regions to roughly the same extent.

Initially these results were surprising as Hayling B is much the more difficult of the two parts for frontal patients. However as Nathaniel-James *et al.* point out the localizations are very similar to those obtained by Warburton *et al.* (1996) for verb retrieval given the corresponding noun. Now this underlines a conceptual problem for localizing the processes involved in many frontal tests such as the Hayling test. Performance on the test of many normal subjects is not qualitatively stationary. As discussed in section 1 of this paper normal subjects frequently develop a strategy after which the on-line processing underlying task performance changes drastically. The typical strategy is to prepare a response before the sentence frame occurs for instance by looking round the room for objects, and then to check that the candidate word does not in fact make sense given the sentence frame. Once it is operative the process becomes that of generation from a given set and then checking. The similarity of activation sites with the Warburton *et al.* study becomes more comprehensible. However, this leads to a problem. Many severe frontal patients show no sign of using the strategy and it is more plausible that this is occurring because they failed to develop the strategy rather than because they cannot carry it out. Thus patient performance and normal subject PET performance would reflect different stages of task execution. Of course, the strategy development phase can occur in the normal subject too in the PET camera but it will occur relatively infrequently and possibly only once so it may occur in only one of the four experimental scans. The average PET activation results will be insensitive to it. Analogous problems will occur in attempting to interpret PET analysis of tasks like Wisconsin card sorting where the critical strategy-change process occurs only fairly rarely. Ideally what is required for critical processes to be detected by PET is to use a task where performance remains qualitatively stationary and critical processes occur on presentation of each stimulus. For this reason we will consider memory experiments.

In two recent PET studies (Tulving *et al.* 1994; Shallice *et al.* 1994) memory retrieval led to the activation of the right prefrontal cortex when related studies of memory encoding had led to activation of left prefrontal cortex. In the two studies different hypotheses were advanced for the processes underlying the right frontal activation, both being related to different supervisory system subprocesses discussed earlier. Tulving *et al.* argued that the critical factor was the subject being in retrieval mode (related to the mode-setting concept discussed earlier – process 5). The London group argued that the cause was monitoring and verification of putative responses-related to process 2/3.

A recent experiment (Fletcher *et al.* 1996) carried out for a different purpose indirectly provides strong evidence on the choice between the alternatives. The experiment principally investigated the contrast between retrieval of imageable and non-imageable word-pairs from memory. It was concerned with a hypothesis on the functions of the precuneus activated in our previous memory retrieval study. Variation in the semantic distance between stimuli and responses in the word pairs was included as a factor to check that

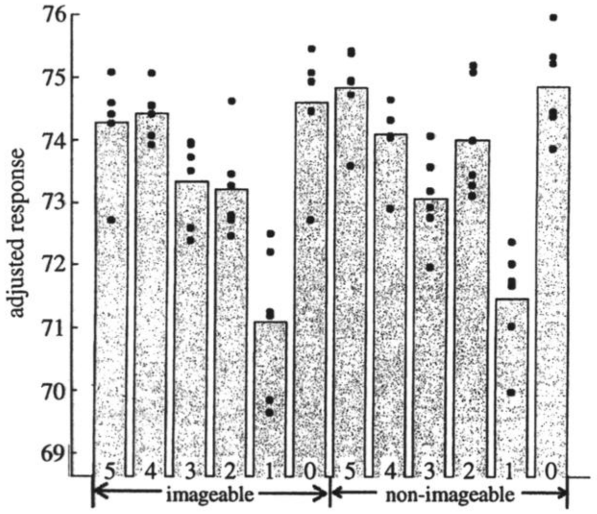

Figure 2 . rCBF equivalent values from a medial frontal pixel (Coordinates $x,y,z = -2, 50, 32$) showing that the frontal decrease in activity associated with weakening semantic linkage (figures shown at the base of rCBFbars) is relatively linear across the linked pairs (5 to 1) but that this is reversed for the unlinked pairs (0) predominantly in the right frontal region (reproduced from Fletcher *et al.* 1996).

differences in degree of training between the two types of word-pair was not critical. Sets of pairs with six different semantic distances were included – five with semantic relations going from close (5) to distant (1) and then a sixth set of randomly related pairs (0). For both imageable and non-imageable stimuli all pairs were given appropriate amounts of pre-training so that subjects were approximately equally accurate at retrieval for all semantic distances. This involved from 1 to 4 pre-scan presentations for the imageable pairs and from 1 to 8 for the non-imageable pairs.

The results were very striking. For related pairs there was a general decline in activation at retrieval with increasing amount of training (and increase in semantic distance) supporting the position of Raichle *et al.* (1994). However, for the random pairs there was a highly significantly reversal (see figure 2) particularly in the medial frontal and right prefrontal regions. Retrieval of randomly related pairs led to as high activation in that region as did retrieval of closely related pairs even though the former had been seen on many previous trials. Why should this be? It is difficult to account for this highly nonlinear effect on the retrieval mode explanation. However, random pairs make a much larger demand on verification processes than do related pairs. If a putative response is produced it can be simply determined with which stimulus it could be paired in the related condition but not for the random condition. As the response set can be learned partially independently of the S-R bonds, subjects will have a much more difficult verification process in the random conditions than in the otherwise comparable related conditions since they cannot easily be sure without checking whether the response elicited by the stimulus actually went with that stimulus or another one in the list. This suggests that verification processes are responsible for the activation shown in the right prefrontal cortex. They are the analogue in the memory domain of the monitoring processes in the tasks discussed earlier.

This would mean that one of the processes discussed in §2 is lateralized within the frontal lobes and that a program of localization of the subprocesses discussed in §2 may be practicable.

5. CONCLUSION

We have presented three lines of argument for the idea that the prefrontal cortex contains a set of subsystems which implement different processes. Arguments are derived from differences in the computations that are required to realize the processes, from the dissociations that occur between neurological patients who have frontal lobe lesions and from the possible specific localization of a particular process. Clearly this has been a very preliminary discussion. The computational distinctions between the processes the individual hypothesized sub-systems are held to carry out have essentially been asserted rather than proved. The group-study dissociation methodology adopted is experimental and only two pairs of dissociations were discussed. Moreover, as only one process was considered from a localization point-of-view, the argument was insufficient to show that processes localize differently. In addition, no systematic attempt was made to show that a consistent pattern occurs from all three types of argument. However a programme of research to investigate a possible convergence seems practicable.

Finally, if there are a variety of subsystems carrying out different processes and differently localized within prefrontal cortex, is it useful to characterize them as different parts of a single system? We would argue that it is if they have a common overall function within the overall processing system and if they are characteristically used in a related fashion. Both these criteria seem to apply. The processes hypothesized are ones involved in confronting situations which are not routine when routine processes are assumed to be controlled by contention scheduling. They are therefore the set of processes which modulate contention scheduling from above. Moreover in confronting a typical non-routine situation most of the processes would be involved. It seems appropriate to view them as subsystems of the supervisory system.

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Discussion

I. Robertson (*MRC Applied Psychology Unit, 15 Chaucer Road, Cambridge CB2 2EF, U.K.*). Your previous model involving the supervisory attention system and the contention scheduling system was a hierarchical one with the SAS exerting control over contention scheduling under conditions of novelty or conflict. In the present model you have a large number of control systems and my question is to what extent these systems can be regarded as being hierarchically organized. If they are not hierarchically organized, then how are the systems controlled?

T. Shallice. The relation between supervisory system processes and contention scheduling ones remains the same as before. However, within supervisory system processes no real hierarchical relation is held to exist except for the operation of the processing mode selector (process 5) which will activate the operation of other processes selectively. However, in no sense would this process operate as a high-level homonculus since its internal operation would be relatively simply determined by explicit signals from other supervisory system processes. Most other supervisory system processes are held to operate fairly selectively except for monitoring ones.