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ORIGINAL ARTICLE

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Strategy application disorder: the role of the frontal lobes in human multitasking

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Abstract Strategy application disorder is a term used to describe a pattern of deficits, usually associated with frontal lobe dysfunction, where people show disorganisation, absentmindedness and problems with planning and decision making in everyday life despite normal performance on traditional neuropsychological tests. It is argued that the prototypical situation which presents problems for these cases are those which require multitasking, and although good cases are rare in the literature, those that do exist show a characteristic neuropsychological pattern. Moreover, this pattern is confirmed in recent group studies of multitasking and of the relationship between multitasking tests (such as the Six Element Test), failures in everyday life and other neuropsychological measures. At present the evidence suggests that the potential frontal brain regions most implicated in multitasking are the anterior cingulate; B.A. 10 and immediately adjacent areas; and the right dorsolateral prefrontal cortex, with each making a unique contribution to different aspects of performance. Furthermore, recent studies show striking dissociations between performances on multitasking tests and two of the most commonly administered measures of executive function: the verbal fluency test and the Wisconsin Card Sorting Test, which sets a minimum level for a fractionation of the executive syndrome in humans.

Introduction

Deficits in purposive goal-directed behaviour associated with frontal lobe damage date back at least 150 years, to Harlow's famous case Phineas Gage described as "devising many plans of future operation, which are no sooner arranged than they are abandoned in turn for others appearing more feasible" (Harlow, 1868). Gage's problems were, however, part of a wider cluster of symptoms, which became known as the "frontal lobe syndrome". Only recently has empirical evidence emerged that suggests that the functions of the frontal lobes ("executive functions") may fractionate (e.g. Burgess & Shallice, 1996a, 1996b; Burgess, Alderman, Ernslie, Evans & Wilson, 1998; Robbins, James, Owen, Sahakian, McInnes & Rabbitt, 1997).

Perhaps the most surprising findings related to this fractionation are those from single cases who show the circumscribed deficits termed the "strategy application disorder" (Shallice & Burgess, 1991; Goldstein, Bernard, Fenwick, Burgess & McNeil, 1993; Levine, Stuss, Milberg, Alexander, Schwartz & Macdonald, 1998). This is a pattern of problems which manifest themselves most in real-life complex situations which require the organisation and structuring of goal-related behaviour in situations with few external constraints. Prototypical situations of this kind in everyday life are those involving "multitasking", such as shopping (Shallice & Burgess, 1991) or preparing a formal meal for many guests (see Penfield & Evans, 1935). That frontal lobe damage might cause impairments in these situations is perhaps not, prima facie, surprising since their very complexity might suggest that they require a great number of different cognitive resources any of which might be damaged in any one case. It is made surprising, however, by the fact that these cases may show their deficits not only in the context of unimpaired IQ, memory, language and visuo-perceptual functions, but even where performance on a wide range of "executive tests" known to be sensitive to frontal lobe damage is normal (Shallice & Burgess, 1991; Goldstein et al., 1993; Duncan, Burgess & Emslie, 1995; Eslinger & Damasio, 1985). Thus, these cases suggest that there may actually be a small set of processes which are critical to multitasking in humans: an activity which is at the very heart of competency in everyday life. The aim of the present paper is to outline how recent evidence from a number of sources suggests

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that it may soon be possible to isolate the cognitive and neuroanatomical systems which support multitasking.

Empirical characteristics of patients with circumscribed multitasking deficits

There are a number of recent case reports of patients with circumscribed multitasking deficits. By "circumscribed" it is meant that their disability in real-life situations involving multitasking was not reflected in their (largely intact) performance on clinical tests of neuropsychological functions which did not involve multitasking: a pattern referred to by Shallice and Burgess (1991) as the "strategy application disorder" (see also Goldstein et al., 1993). A summary of these cases is given in Table 1. None of these cases had any language or visuo-perceptual impairments and all scored within the superior range on tests of current general intellectual functions. Four of the seven cases showed no impairment on any memory test and two showed no impairment on a range of clinical executive function tests which are known to be sensitive to frontal lobe lesions.

Table 1, however, shows an interesting pattern in those cases who did fail an executive task. While there is no individual test which has been failed by even half the patients, there are some small hints at consistency, despite the fact that the tasks administered to each case differed. Thus, two cases each have failed Tower of Hanoi tasks, proverb interpretation, and the Self-Ordered Pointing Test. It remains to be seen if this pattern is meaningful or relates to an anatomical proximity artefact (Shallice, 1988). Whatever the reason, it is unlikely to reflect the frequency with which the tasks have been administered, since at least two tasks which have been administered to them all – the Wisconsin Card Sorting test (WCST) and Verbal Fluency (VFT) tests – have been performed well by every case. This issue will be returned to later.

The unifying feature of all of these cases, however, is a marked impairment in everyday life. For instance, following his operation for excision of a bilateral frontal meningioma, EVR's poor financial decisions led to bankruptcy, and he was unable to hold down a job (Saver & Damasio, 1991). Patients AP, DN, DS and PF also lost their jobs following their frontal lobe damage, with employers reporting tardiness and disorganisation with even simple tasks left unfinished. The other cases (FS, JD, and GL) maintained some gainful employment, but at a greatly reduced level, and with some difficulty. In the case of GL, this was despite 12 months of intensive rehabilitation (von Cramon & von Cramon, 1994). While not all cases show exactly the same problems in everyday life, there are some remarkable similarities. For instance, EVR is reported as taking hours to performs simple matters because of his indecisiveness: to go out to dinner required that he consider the seating plan, menu, atmosphere and management of each restaurant and he might even drive to see how busy each of them was, but still be unable to come to a decision. Consider now the description of JD by Goldstein et al. (1993): "He had difficulty making decisions, culminating in his taking 2 weeks to decide which slides to use for a work presentation; the decision was never reached" (p. 274).

For other cases the most prominent feature is failure of prospective memory, which shows itself as an inability to follow time constraints, to meet deadlines or keep appointments. An additional feature that has been noticed many times in our laboratory but never fully quantified is that patients will sometimes be quite content to abandon a task even though it is clearly incomplete. This may be related to the set abandonment seen in frontal patients in more straightforward situations (Burgess & Shallice, 1996a). When this happens, the patients appear completely satisfied with what they have accomplished even when it is pointed out to them that the task is unfinished. We have never seen a control exhibit this behaviour.

To quantify these problems, Shallice and Burgess (1991) devised two tasks which were intended to make analogous demands to the situations in everyday life which present problems for these cases. The first was called the Multiple Errands Test (MET). This was a real-life task based around a shopping precinct. Three patients with a strategy application disorder, and a

Table 1 Summary of neuropsychological profiles of recent cases with multitasking deficits in everyday life despite high IQ

Measure Intelligence[b]		EVR[a] Superior	AP[a] Superior	DN[a] Superior	FS[a] Superior	JD[a] Superior	GL[a] Superior	DS[a] Superior	PF[a] Superior
Memory[c]:	Tasks administered	4	7	7	9	4	12	6	2
	Tasks impaired	0	0	2	3	0	0	0	0
Executive[d]:	Task administered	6	12	12	12	9	13	14	4
	Tasks impaired	0	0	SOP[e]	SOP trails[f]	Proverbs[g]	ToH[h] 20 Qs	Proverbs	ToH

[a] EVR (Eslinger & Damasio, 1985); AP, DN and FS (Shallice & Burgess, 1991); JD (Goldstein et al., 1993); GL (von Cramon & von Cramon, 1994); DS (Duncan et al., 1995); PF (Goel & Grafman, submitted)
[b] Tests vary
[c] WMS is counted as one test. Digit Span is not included. Where there are two forms of a test (e.g. immediate and delayed recall) this is counted as one test only
[d] Tests vary. Multitasking tests (e.g. the SET) are not included
[e] Self-Ordered Pointing Test of Petrides and Milner (1982)
[f] Trail-Making Test, letters & numbers (Reitan, 1958)
[g] Proverb Interpretation (e.g. Gorham, 1956)
[h] Tower of Hanoi (Simon, 1975)

group of age and IQ-matched controls were given some money and an instruction sheet. The instructions asked them to buy various items, find out certain information, and be at a certain location at a specific time while observing a number of rules such as "you must not enter a shop other than to buy something". The second task, the Six Element Test (SET) was designed to tap a subset of the same cognitive components, but do so in the laboratory. Subjects were presented with three subtasks, each split into two sections. They were told that they were not permitted to carry out the first section of a given subtask followed by the second section of that same task, and that earlier items within a task scored more points than later ones. They were told that otherwise they were free to organise their efforts in any way they saw fit, with the overall objective being to score as many points as possible within a permitted 15-min period.

Shallice and Burgess's patients (Shallice & Burgess, 1991) showed a variety of errors on the MET, tending to break the rules, leave items unfinished and forget to carry out the prospective memory items. They also made several departures from social convention[1].

Failures on the SET were more easily characterised, consisting either of a low number of subtasks attempted or of rule-breaks. The patients' failures could not be explained as a consequence of poor motivation: when the work-rates of the patients on the individual test items was measured, they were found to be equivalent to the controls.

Of the other five cases outlined in Table 1, two others have been given both the SET and MET. JD (Goldstein et al., 1993) failed the MET, and DS (Duncan et al., 1995) failed both. In other words, of all the reported cases of strategy application disorder who have been given these tests, all have failed at least one of them. This stands in stark contrast to the results from the traditional neuropsychological tests shown in Table 1.

The circumscribed nature of these patients' problems suggests that at least some of the brain systems critical for performance on these multitasking tests may be, therefore, isolable and scientifically tractable. This is not to say that these processes are only used in multitasking situations, nor that the entire presentation of these cases can be reduced to multitasking deficits. Instead, the proposition that will be explored here is that multitasking situations tap particularly well a specific set of processes which are essential to competency in everyday life and which are damaged in these patients, and that there is cause for optimism regarding discovering the neuroanatomical correlates of this important human behaviour. However, a requirement of any such enquiry is first the determination of the characteristics of the situation under examination.

[1]Studies are recently emerging which show the SET to be particularly sensitive to other disorders with everyday life implications such as depression (Channon & Green, 1999) and schizophrenia (Evans, Chua, McKenna & Wilson, 1997). Particularly important, however, as regards understanding the social behaviour disturbances seen in many (if not all) of the strategy application disorder patients is a recent finding of a particularly strong correlation between SET performance and aspects of social problem-solving (Channon and Crawford, 1999). A full examination of the relationship between multitasking problems and social behaviour disturbances is not possible here, but two possibilities seem likely given the remarkably consistent co-occurrence: either that the brain regions implicated in both disorders are anatomically close or that there is some overlap in the processes required in both sets of situations. For the moment, however, it has been argued (e.g. Shallice & Burgess, 1991; Burgess et al., 2000) that social behaviour disturbances cannot be a sole explanation for multitasking problems in patients with the strategy application disorder since tests like the SET require no social interaction or judgement.

Characteristics of everyday multitasking situations

In a recent television programme (BBC 'Horizon' programme 23/4/98) the US astronaut Jerry Linenger was describing his experiences aboard the Mir space station when he said the following:

> We had many system failures and they were in need of your constant attention. Many days I'd start an experiment in the morning and then I'd run over and help hacksaw through a pipe and plug the ends and then run back to my experiments. I'd have three or four watches on with alarms set to different things that I'd have to run back to. So I was *multitasking* in order to try and get everything accomplished.

This lucid description provides an excellent definition of what the term "multitasking" means to this astronaut. It is a term which has only recently (within the last 10 years or so) lost its roots in information technology, and become more widely applied to human activity. The most basic definition is perhaps "the ability to perform concurrent tasks or jobs by interleaving" (Compact OED). However, such a definition ignores the motivation for this interleaving, and the context in which it occurs.

In fact, the situation Jerry Linenger was facing, and many less exotic everyday situations, have the following features (Burgess, in press):

1. Many tasks: A number of discrete and different tasks have to be completed.
2. Interleaving required: Performance on these tasks needs to be dovetailed in order to be time-effective.
3. One task at a time: Due to either cognitive or physical constraints, only one task can be performed at any one time.
4. Interruptions and unexpected outcomes: Unforeseen interruptions, sometimes of high priority will occasionally occur, and things will not always go as planned.
5. Delayed intentions: The time for a return to a task which is already running is not signalled directly by the situation. (Jerry Linenger wisely uses watch alarms to reduce this demand.)

Characteristic 5 is of particular interest from a theoretical perspective. It signals a requirement of multitasking to be "prospective memory" or the creation and realisation of delayed intentions (Ellis, 1996). In these situations, a combination of the length of time over which a task has to be deferred (or an intention maintained) and the degree of attention required by the current task means that active rehearsal of the intention to return to the deferred task is prevented.

There are additional characteristics of most everyday multitasking situations:

6. Differing task characteristics: Task usually differ in terms of priority, difficulty and the length of time they will occupy.
7. Self-determined targets: People decide for themselves what constitutes adequate performance.
8. No immediate feedback: There is no minute-by-minute performance feedback of the sort that participants in many laboratory experiments will receive. Typically, failures are not signalled at the time they occur.

Many apparently simple everyday situations will also share most, if not all, these characteristics. Consider the situation which presented difficulties for the case of Penfield and Evans (1935): one person preparing a formal meal for a number of guests. Here there are many dishes and components of them to be achieved (characteristic 1). These dishes/ingredients have to be prepared in a certain order, and some things will have to be left to cook, while others are prepared (characteristic 2). The physical constraints of the kitchen will generally mean that only one operation can be performed at a time (characteristic 3). Unexpected occurrences and interruptions may occur in the form of early guest arrival, irritable children or dishes that do not turn out as intended (characteristic 4). Returns to dishes which are cooking or need to be started are not directly signalled by the situation (characteristic 5). In addition, not all dishes or operations which need to be carried out may be of the same priority (characteristic 6); there is no one "right" or "wrong" meal to give guests or way of preparing and presenting a meal (characteristic 7) and mistakes (e.g. forgetting an ingredient) are not directly signalled at the time they occur (characteristic 8).

A similar analysis can be performed for the shopping scenario (the MET) which was performed so poorly by the patients described above, and these characteristics can be contrasted with those of the executive tasks where the patients did not generally have problems (e.g. the Stroop procedure; the Wisconsin Card Sorting Test), which do not share this quality of being "ill-structured" (Goel & Grafman, in press). The argument is, therefore, that everyday multitasking situations make demands upon different cognitive processes from those stressed by traditional executive ("frontal lobe") tests. If this is correct, it is unsurprising that patients can be found who show impairments in everyday life despite apparently normal performance on executive tasks (Burgess, 1997).

An exception as regards clinical neuropsychological tests is, however, the Six Element Test (SET). The original version (Shallice & Burgess, 1991) was simplified for use with general clinical populations (Burgess, Alderman, Evans, Wilson, Emslie & Shallice, 1996a) and published as part of the BADS battery (Wilson, Alderman, Burgess, Emslie & Evans, 1996), a standardised battery of executive tests. The test has all the characteristics outlined above excepting characteristic 4 (interruptions and unexpected outcomes). It is likely, therefore, that studies using this test are providing invaluable insights into the cognitive neuroscience of a set of cognitive processes which have until now been largely unexamined.

Studies of the Six Element Test (SET)

So far, only the results from single cases who show relatively circumscribed multitasking deficits have been considered. The complimentary neuropsychological method is the consideration of groups of patients who have a range of cognitive deficits. If it is the case that the SET measures processes crucial to everyday multitasking which are not measured by traditional neuropsychological executive measures, one should be able to demonstrate: (i) low correlations (relative to other tests) between SET performance and those traditional tests which were not failed by the single cases above, and (ii) stronger relationships between behavioural signs of multitasking deficits in everyday life and the SET than occurs with other executive tasks.

Evidence of the first kind was given by Duncan, Johnson, Swales, and Freer (1997). As part of this study, 24 head-injured people were given the SET plus two executive tests which have been given to a number of the single cases reported above: Self-Ordered Pointing (SOP) task (Petrides & Milner, 1982) and the Verbal Fluency test (VFT; Benton & Hamsher, 1971). Duncan et al. (1997) found a correlation of $r = 0.01$ between the SET and VFT, with $r = 0.64$ between the SET and the SOP tests. (The correlation between VFT and SOP tasks was 0.30.) Both findings (i.e. the high correlation between the SET and the SOP tests, and the low correlation between the SET and VFT) are strikingly reminiscent of the findings from the single cases reported above[2].

[2]The claim here is not that there need necessarily be a double dissociation between multitasking measures (including the SET) and traditional executive tests. Currently, there are some studies (e.g. Levine et al., 1998) which indicate a single dissociation only: i.e. that patients with multitasking problems may or may not show impairments on traditional executive tests, but every case who fails a wide range of the traditional tasks will also show multitasking deficits. This is perhaps the common sense view. However, there are undoubtedly some cases (e.g. the case JW of Worthington, 1999) who performs normally in some multitasking situations (e.g. the SET) despite clearly impaired performance on executive measures such as the modified WCST (MWCST), VFT or Hayling Test (Burgess & Shallice, 1997). The true extent of the possible dissociation remains to be discovered. This is likely to be a fruitful area of enquiry, although currently the methodological problems involved are considerable (see Burgess, 1997, for discussion).

Evidence of the second kind is reported by Burgess et al. (1998), who examined the relationship between poor performance on the SET (and other neuropsychological tests) and individual symptoms of the dysexecutive syndrome. In this study, carers or relatives of a group of 92 mixed aetiology neurological patients were given a questionnaire (the DEX; Burgess, Alderman, Wilson, Evans & Emslie, 1996b) which asked them to rate the frequency of occurrence of 20 of the most common dysexecutive symptoms in the patients they knew well. When the results were subjected to factor analysis (orthogonal rotation), five factors were selected: "Inhibition" (deficits in response suppression and disinhibition); "Intentionality" (everyday deficits in planning and decision making); "Executive Memory" (e.g. confabulation, perseveration); and two purely affective factors – positive and negative affective changes. A range of neuropsychological tests were also administered to the patients, which allowed for examination of the relationships between the scores for these behavioural factors and individual neuropsychological test performances. It is the second factor, Intentionality, which is of interest here. Of all the tests given, which included measures of intelligence, memory, language and perception as well as ten measures of executive function, only the SET was significantly related to the factor scores for Intentionality ($r = 0.46$; $p < 0.001$ criterion). These results provide confirmation of the relationship between performance on the SET and everyday situations involving planning and organisation (which would be expected to interfere with multitasking) and suggest that the processes underlying multitasking may operate independently from other executive functions.

Interestingly, previously unpublished data from this study also confirms the findings described above – of little or no relationship between performance on the SET and both the WCST and VFT. Consider Table 2, which shows the correlations between scores on these three tests and the factor scores for the first three behavioural factors: the correlations therefore represent relationships between the tests and different symptom clusters in everyday life.

The second column gives the data just described, showing a significant relationship between SET performance and problems with planning, decision-making and distractibility in everyday life. Performance on the other two tests did not reflect these problems. However, the results for factors one and three show a quite different pattern. The MWCST and VFT are significantly predictive of problems with "executive memory" (e.g. confabulation) in everyday life, but the SET is not. Furthermore, the VFT is more strongly related than the SET to symptoms of disinhibition, with WCST performance not reflecting these problems. Thus, it would seem that not only may there be little relationship etween these tests at both the group and single-case level, but also that the symptoms in everyday life which poor performance signifies are different for the tests.

This pattern is confirmed by a recent study by Knight (1999), who found a similar pattern for relationships between the MET and the VFT and MWCST.

Table 2 Pearson's correlations between neuropsychological tests and behavioural symptom clusters (factor scores) from the study of Burgess et al. (1998) (some values previously unpublished)

	Factor 1 Inhibition	Factor 2 Intentionality	Factor 3 Executive memory
Six Element Test	0.24*	0.46***	0.20 ns
Verbal Fluency Test (FAS)	0.35**	0.02 ns	0.30**
MWCST Categories[a]	0.14 ns	0.22 ns	0.54***

[a] Modified Wisconsin Card Sorting Test (MWCST) (Nelson, 1976). Other MWCST measures showed a similar pattern
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; *ns* not significant

The cognitive components of multitasking

The evidence considered so far has shown first that patients with multitasking deficits need not have other neuropsychological deficits (e.g. case AP in Table 1), and second that patients with a range of neuropsychological deficits need not necessarily show multitasking problems. Both sets of evidence suggest that the resources underlying multitasking may constitute a relatively discrete cognitive system. However, they do not describe the organisation of this system and how this might relate to the stages in the complex behaviour which they support.

Burgess et al. (2000) have recently attempted such an analysis. In this study, 60 people with circumscribed cerebral lesions and 60 age- and IQ-matched (for both current and pre-morbid IQ) controls were given an analogue of the SET. In this task, called the Greenwich Test, subjects are presented with three different simple tasks and told that they have to attempt at least some of each of the tasks in 10 min, while following a set of rules. One of these rules relates to all subtests, ("in all three tasks, completing a *red* item will gain you more points than completing an item of any other colour") and there are four different task-specific rules (e.g. "in the tangled lines test you must *not* mark the paper other than to write your answers down"). Thus, this test is a close analogue of the SET with the principal differences being relatively fewer required task switches with a greater number of rules to follow.

This procedure was given in a form which allowed consideration of the relative contributions of task learning and remembering, planning, plan following and remembering one's actions to overall multitasking performance. Specifically, before participants began the test, their ability to learn the task rules (by both spontaneous and cued recall) was measured; this measure was called "learn". They were then asked how they intended to do the test, and a measure of the complexity and appropriateness of their plans was gained (a variable called "plan"). The participants then performed the task itself and by comparing what they did with what they had planned to do a measure of "plan following" was made. Overall task performance (the number of task switches minus the number of rule breaks) was referred to as the test "score". Following performance of the test, the subjects' ability to recollect their own performance was measured by asking them to describe in detail what they had done ("recount"). Finally, memory for the task rules was tested again ("remember").

The relationships of these six behavioural measures to each other was examined in relation to a simple theory about the minimum number of latent constructs (i.e. sets of procedures or brain systems) that might underlie multitasking, and how they may relate to each other in these situations. A three-construct (i.e. factor) structural equation model was fitted to the data; the constructs being:

1. Retrospective memory: This represents ability to learn and remember the task rules. The indicators for this construct were "learn" and "remember".
2. Planning: The ability to form an appropriate plan (indicator = "plan").
3. Intentionality: This construct represents the ability to follow one's plan and the task rules. It is assumed that this represents realisation of delayed intentions (Ellis, 1996) (indicators = "score", "follow" and "recount").

Furthermore, the model specified that latent constructs two and three should be downstream from construct one: in other words that while planning and intentionality resources are orthogonal, they both draw upon the products of the retrospective memory resources.

The model fitted the data well (χ^2 with $5df = 2.9$, $p = 0.72$), with the results therefore supporting the notion that multitasking problems might arise due to depletion in any one of these three resources (retrospective memory, planning, intentionality), with the resource most closely linked to overall performance on the test being that relation to intentionality. Furthermore, these resources may well be supported by different brain systems. So what might the candidate brain regions involved in these systems be?

The neuroanatomy of multitasking deficits

Burgess et al. (2000) analysed the brain scans (CT, MRI) of their patients according to the Damasio and Damasio (1989) procedure and found that failure at different stages of their multitasking test was associated with damage to different brain regions.

First, impairments in the retrospective memory demands (i.e. learning and remembering of task contingencies) of multitasking were seen following damage to the left anterior and posterior cingulates and immediately adjacent areas [in particular the forceps major of the corpus callosum (regions LF2; LO7; LF1; LF9 of Damasio & Damasio, 1989)]. Second, impairments in planning were seen in patients with right dorsolateral frontal lesions (region RF7 of Damasio & Damasio). Third, damage to a left frontal lobe region (LF4 of Damasio & Damasio) corresponding mainly to Brodmann area 10 (but also parts of 8 and 9) was associated with poor task switching and plan- and rule-following, i.e. the intentionality component of multitasking.

A caveat should be made when describing these results. In this study not all possible brain regions were equally represented, nor was it possible using this method of scan analysis to assess involvement of many subcortical structures, damage to which may well interfere with multitasking (see Robbins, Shallice, Burgess, James, Rogers, Warburton & Wise, 1995). Thus, a simple-minded view of these results as suggesting that only these regions are involved in multitasking should be avoided. However, these results do show remarkable concordance with the regions damaged in the single cases with the strategy application disorder (Table 1). Thus, all of them for whom we have comparable data (i.e. all except DS and GL) show involvement of at least one of the frontal areas identified in the group study: EVR has damage to regions LF1, LF4 and RF7 (anterior cingulate, medial aspects of areas 10, 8 and 9; and right dorsolateral prefrontal cortex respectively); AP also had damage to these regions; FS, JD and PF had damage to LF4 with FS and JD having additional LF1 damage. DN and PF both had involvement of region RF07. In summary, there was involvement of frontal lobe region LF4 (mainly B.A. 10), in 5 of 6 cases, with 4 of 6 cases each for frontal regions LF1 (anterior cingulate) and RF7 (RDLPFC). All cases had involvement of at least one of these three regions (one region in one case; two regions in three cases; three regions in two cases). This concordance is striking[3]. However, is there support elsewhere for the roles which have been suggested for these regions?

In the group study, lesions to the anterior and posterior cingulates caused deficits in rule learning and remembering. A role in memory for this region has received support from many forms of investigation, including functional imaging (e.g. Grasby, Frith, Friston, Bench, Frackowiak & Dolan, 1993; Nyberg, McIntosh, Cabeza, Nilsson, Houle, Habib & Tulving, 1996), human neuropsychology (e.g. Mattioli, Grassi, Perani, Cappa, Miozzo & Fazio, 1996) and animal work (e.g. Bussey, Everitt & Robbins, 1997a; Bussey, Muir, Everitt & Robbins, 1997b). Interestingly the finding that while both the anterior and posterior cingulate were involved

[3]It is unlikely that the multiple sites of damage in these patients suggests a simple correlation between extent of (any) frontal damage and severity of the multitasking deficit since an analysis of this type in the group study showed no such relation beyond what could be expected by chance.

in mnemonic aspects of the task, the anterior cingulate was involved in remembering after a delay rather than initial rule learning supports arguments for different roles for these brain structures (Bussey et al., 1997b), although they are thought to be anatomically connected both with themselves and other medial frontal regions (Barbas & Pandya, 1991; Goldman-Rakic & Friedman, 1991).

The relation between right dorsolateral prefrontal (RDLPFC) lesions and planning problems has also received recent support, principally from human neuropsychology. As part of the study of Levine et al. (1998) 16 patients with frontal cerebral lesions were given a SET analogue, using a procedure where the efficiency of the subjects' approach to the task (which must reflect planning) could be measured. They found that the right hemisphere lesion group, which included more frontal than posterior lesions showed an impairment on this measure. This finding is reminiscent of that of Miotto, Bullock, Polkey, and Morris (1996) who showed that the poor performance of right frontal patients on a spatial working memory task was due to their failure to apply an appropriate strategy (see also Cardesbak, Demonet, Valliard, Faure, Puel & Celsio, 1996, for a similar finding using a VFT).

One of the most dramatic demonstrations of the relation between everyday life-planning problems and RDLPFC lesions is, however, a case which has already been mentioned: PR (see Table 1; Goel & Grafman, in press). This man was an accomplished architect who suffered a meningioma principally affecting the RDLPFC. When Goel and Grafman (in press) gave him a simple architectural planning task and compared his performance to that of a healthy architect, they found that the patient's plans were erratic and denuded of detail, with no sensible progression of ideas through the task, despite PF spontaneously remarking that the problem should be easy for him. Towards the end of his design, he commented:

> You see, normally, what I would have, even as a student, I'd be – there would be sketches on top of sketches. And I could – it would be progressive. Here I seem to be doing several different thought on the same piece of paper in the same place, and it's confusing me. So instead of the one direction that I had at the beginning, I have three or four contradicting directions with not a kind of anchor to work from... (Goel & Grafman, in press).

Similarly, there is some evidence for the involvement of medial aspects of the prefrontal cortex, especially Brodmann area 10, in executive aspects of memory (e.g. Tulving, Kapur, Craik, Moscovitch & Houle, 1994; Fletcher, Frith, Grasby, Shallice, Frackowiak & Dolan, 1995; Grady, 1998; Kapur, Craik, Brown, Houle & Tulving, 1995; Nyberg et al., 1996). Usually, however, this relates to retrospective memory; there is less evidence relating to its role in the creation and maintenance of goals and intentions: i.e. prospective memory. Two recent functional imaging studies, however, make this link directly. In a PET study by Yamadori, Okuda, Fujii, Kawashima, Kinomura, Ito, and Fukuda (1997) (see also Okuda, Fujii, Yamadori, Kawashimi, Tsukiura, Fakatsu, Suzuki, Masatosji & Fukuda, 1998), subjects were taught a set of ten nouns ("targets") before the scanning began. There were two scanning phases: "experimental" and "control". During the experimental scanning phase the subjects were required to repeat verbally a series of five nouns that were presented to them auditorily. Occasionally one of the stimuli they heard was one of the target words they had learnt before scanning, and subjects were instructed to tap with their left hand when they heard such a target. The control scanning phase consisted mainly of the word string repetition task alone. The subjects repeated both tasks in random order. Yamadori et al. (1997) found that, compared with the control task, regional cerebral blood flow (rCBF) increases occurred in the experimental (i.e. the PM) condition in the following regions: right dorsolateral and inferior frontal regions (B.A. 8, 9 and 47); left superior frontal gyrus (B.A. 10), the anterior cingulate gyrus (B.A. 24), medial midline frontal areas (B.A. 8) and the left parahippocampal gyrus. These regions show good concordance with the results from the lesion study, as regards B.A. 8 and 10, the RDLPFC and the anterior cingulate.

These regions were also implicated in a recent PET study of prospective memory (P. W. Burgess, A. Quayle & C. D. Frith, submitted). Brain regions involved in prospective memory as determined by positron emission tomography where the experimental tasks were designed in such a way as to be able to distinguish better the individual roles these regions play. In this study, eight healthy subjects were given four different prospective memory tasks under two randomised conditions. In the first, subjects were expecting to see a PM stimulus but one never actually occurred ("expectation condition"). In the second, subjects were expecting a PM stimulus and it did occur ("realisation condition"). (In both conditions, subjects were engaged in a foreground task of sufficient difficulty as to prevent conscious intention rehearsal.) A baseline condition was also given which did not involve a delayed intention.

The results showed rCBF increases, relative to the baseline, in the expectation condition in B.A. 10 bilaterally, plus RDLPFC, precuneus and right parietal lobe inferiorly. In the realisation condition (relative to the expectation one) there were rCBF increases in the thalamus, accompanied by decreases in the RDLPFC. Thus, this study confirms the role of B.A. 10 and RDLPFC in goal-related behaviour, and suggests that B.A. 10 is involved more in the maintenance of an intention that its realisation.

Overall, if the account of the regions involved in multitasking presented here is correct, it becomes less surprising that performance on tasks like the SET may dissociate from performance on the WCST or VFT. The frontal lobe regions most often implicated in performance of the WCST are either more posterior or inferior than those we have identified (e.g. Tien, Schlaper, Orr & Pearlson, 1998; Catefau, Parellada, Lomena, Bernardo, Setoain, Catarineu, Pavia & Herranz, 1998; Barcelo, Sanz, Molvia & Rubia, 1997). Similarly, the frontal regions implicated in verbal fluency performance include Brodmann areas 6, 11, 44 and 46 of the left hemisphere (e.g. Warburton, Wise, Price, Weiller, Hadar, Ramsay & Frackowiak, 1998; Phelps, Hyder, Blamire & Shulman, 1997; Paulesu, Goldacre, Scifo, Cappa, Gilardi, Castiglioni, Perani & Fazio, 1997; Frith, Friston, Herold, Silbersweig, Fletcher, Cahill, Dolan, Frackowiak & Liddle, 1995), but not area 10, (nor generally 8 or 9) and Stuss, Alexander, Hamer, Palumbo, Dempster, Binns, Levine, and Izukawa (1998) specifically exclude potential involvement of the RDLPFC in fluency tasks in their study of focal brain lesion patients. Thus, while these are clearly early findings, it does seem possible that anatomical-level evaluations of the behavioural dissociations described above might soon be achieved.

Conclusion

It is less than 15 years since Mesulam (1986) articulated as a primary mystery of frontal lobe function that some neurological patients apparently only show their deficits when outside the laboratory. This pattern has been observed for many years, but there was little agreement as to the empirical characteristics of the syndrome. Moreover, there existed little explanation of these patients' difficulties beyond Luria's (1976) general assertions that the frontal lobes were involved in the regulation and control of behaviour. Almost from that point, however, theoretical interpretations (e.g. Duncan, 1986; Norman & Shallice, 1986) of frontal lobe function which could be applied to these patients' deficits began to emerge (e.g. Shallice & Burgess, 1991b, 1996; Burgess et al., 2000; Duncan et al., 1995; Grafman, Sirigu, Spector & Hendler, 1993; Stuss, 1992; Damasio, Tranel & Damasio, 1991). In addition there are theories more applicable to other executive phenomenon (e.g. Goldman-Rakic, 1987; Petrides, 1996; Robbins, James, Owen, Sahakian, McInnes & Rabbitt, 1998). The accounts most relevant to strategy application disorder mostly share characteristics either of an implied organisation of cognition and behaviour or some notion of a failure to respond to signals (or both) (e.g. Shallice & Burgess, 1996; Duncan et al., 1995; Goel & Grafman, in press; Damasio et al., 1991). In this way there are actually few points of necessary disagreement between them and this gives hope that an agreed account might be reached. As yet, however, the majority of these theories have the status of being frameworks rather than detailed models which have predictive validity for understanding specific fractionations of the executive system (but see Stuss, Shallice, Alexander & Picton, 1995; Shallice & Burgess, 1996; Burgess et al., 2000). This state of affairs exists for three primary reasons: first, our poor understanding of the precise demands of executive tests (for which there are in turn a number of reasons); second, our poor understanding of the limits of the fractionations; third, the methodological problems inherent in this difficult area are considerable (see Burgess, 1997, for review). Study of cases with the strategy application disorder, and the characteristics of multitasking, however, promises to provide a rich seam of empirical evidence upon which theorising can be based. Ironically, the degree of concordance in the findings (even across methods) actually suggests that what was once the most puzzling aspect of frontal lobe function might well come to be one of the best understood, and that the brain systems underlying one of the most complicated human behaviours might actually be readily identified. These largely theoretically oriented studies have also yielded some important implications for clinical practice. These are straightforward: the present evidence suggests that successful performance on the WAIS (or variants), VFT and WCST cannot be taken as evidence of unimpaired multitasking abilities.

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