This excerpt from

Control of Cognitive Processes. Stephen Monsell and Jon Driver, editors. © 2000 The MIT Press.

is provided in screen-viewable form for personal use only by members of MIT CogNet.

Unauthorized use or dissemination of this information is expressly forbidden.

If you have any questions about this material, please contact cognetadmin@cognet.mit.edu.

Real-World Multitasking from a Cognitive Neuroscience Perspective

Paul W. Burgess

ABSTRACT This chapter examines the demands made by multitasking situations in the real world, and argues that the human brain systems critical in dealing with them may be surprisingly circumscribed. Four kinds of evidence are considered: single-case studies of patients with selective multitasking problems; group studies of the relationship between multitasking failures and other cognitive control problems; the neuroanatomical locus of multitasking deficits according to group lesion studies, and evidence from functional imaging. These studies suggest three distinct brain systems are involved in supporting the retrospective memory, prospective memory and planning demands of multitasking, and tentative suggestions for the neuroanatomical correlates of these systems are proposed.

In a recent television program, the U.S. astronaut Jerry Linenger described his experiences aboard the Mir space station: "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 to get everything accomplished."

Although, at first sight, Jerry Linenger's use of the term *multitasking* accords well with the *Compact Oxford English Dictionary* definition: the "ability to perform concurrent tasks or jobs by interleaving," his account suggests something more complex than interleaving tasks in a multipletask sense. The situation he faced also required further mental activities, such as prioritization, planning, and prospective memory (i.e., the realization of a delayed intention; Ellis 1996).

The ability to deal with such complex situations is clearly important to effectiveness in everyday life. Neurological patients who have lost this ability are severely handicapped, especially in work situations. However, although the present volume is testament to recent advances in understanding many situations which have some relevance to aspects of multitasking (e.g. dual- or multiple-task paradigms, task switching etc), more complex situations akin to those faced by Jerry Linenger have been rarely studied within an experimental psychology or cognitive neuroscience framework. Indeed, the complexity of such situations would seem to make them poor candidates for scientific investigation. However, recent findings, principally from human neuropsychology, suggest that, to the contrary, such multitasking makes demands on a relatively discrete set of resources, and thus may be experimentally tractable. Before examining these findings, let us briefly review the characteristics of these situations.

20.1 THE DEMANDS OF REAL-WORLD MULTITASKING

Although the multitasking situation that faced Jerry Linenger was highly atypical in its setting and its seriousness, its actual characteristics were not unlike those of situations commonly faced in everyday life:

1. *Numerous tasks:* A number of discrete and different tasks have to be completed.

2. *One task at a time:* Due to physical or cognitive constraints, it is not possible to perform more than one task at a time.

3. *Interleaving required:* Performance on these tasks must be dovetailed; the most time-effective course of action is not to completely finish one task before moving to another, but to switch between them as appropriate.

4. *Delayed intentions:* The time for a switch or return to a task is not signaled directly by the situation. Jerry Linenger adopts the use of watch alarms in order to reduce this problem.

In addition, most busy everyday multitasking situations will share three further characteristics:

5. *Interruptions:* Occasionally, interruptions and unforeseen circumstances will occur.

6. *Differing task characteristics:* Tasks usually differ in terms of priority, difficulty, and the length of time they will take.

7. *No feedback:* People decide for themselves what constitutes adequate performance, and there is no minute-by-minute performance feedback of the sort that participants receive in, for instance, a typical "psychological refractory period" (PRP) dual-task experiment, where errors are apparent.

Although not every multitasking situation will have all these characteristics, it is arguably easier to think of generic everyday activities lasting several minutes or more (e.g., cooking, shopping) that have these characteristics than it is to think of ones that do not.

20.2 SINGLE-CASE STUDIES: PATIENTS WITH SELECTIVE MULTITASKING IMPAIRMENTS

The assertion that there may be discrete brain systems supporting performance in these situations is initially based on neurological patients with "strategy application disorder" (Shallice and Burgess 1991; Goldstein et al. 1993; Levine et al. 1998), a cluster of symptoms whose cardinal feature is an impairment that manifests itself particularly in multitasking situations of the kind just outlined. Shallice and Burgess (1991) described three patients, all of whom had suffered frontal lobe damage, but who had superior IQs and no significant deficits in language, memory, or visual-perceptual functions, and at least one of whom was unimpaired on a wide range of cognitive tests traditionally considered sensitive to frontal lobe lesions (e.g., Wisconsin Card-Sorting Test, Tower of London, Cognitive Estimates, Verbal Fluency). Despite their lack of apparent disability on traditional psychometric examination, all three had made unsuccessful attempts to return to work, with employers complaining of tardiness, disorganization, and inability to meet deadlines or to finish lengthy projects.

Shallice and Burgess demonstrated these patients' problems by constructing two multitasking tests. The first, called the "Multiple Errands Test" (MET) was a real-world shopping task, where the subjects also had to follow a series of rules such as "No shop should be entered other than to buy something" or "On leaving a shop you must always inform an experimenter what you have bought there" while purchasing a series of items, finding out some information (e.g., Where was the coldest place in Britain yesterday?), and meeting the experimenters at a certain place at a prespecified time.

In the second multitasking test, designed for use in the laboratory and called the "Six Element Test" (SET), subjects were faced with three different tasks, (describing memorable events; writing the answers to simple arithmetic sums; and writing the names of items shown in simple line drawings), each of which is split into two sections, A and B. Subjects were told that they had 15 minutes to score as many points as they could, given that (1) within each section, earlier items scored more points than later ones and (2) they were not permitted to perform section A of a particular task directly followed by section B of that same task.¹ The subjects were told that otherwise they were free to organize their performance in any way they liked, and they were not given any other information (e.g., about the exact "point value" of items). In this way, their tasks met all the characteristics of everyday multitasking situations outlined above except characteristic 5 (unforeseen interruptions).

Shallice and Burgess's frontal lobe patients (1991) all showed impairments on both these multitasking tests, compared with age- and IQmatched controls. Of especial interest was the finding that their work rates on the SET were normal: their difficulties consisted of failures to switch tasks and to follow the simple task rules. Similar cases have been reported by Penfield and Evans (1935); Eslinger and Damasio (1985); Goldstein et al. (1993) and Duncan, Burgess, and Emslie (1995; see also Levine et al. 1998).

20.3 GROUP STUDY: DYSEXECUTIVE PATIENTS

If tests like the Six Element Test measure processes specific to multitasking, one should be able to demonstrate their discriminative validity by finding stronger relationships between performances on these tests and everyday multitasking problems than occurs with other measures, such as memory or IQ tests or even other executive tests (e.g., Wisconsin Card-Sorting Test, Verbal Fluency) traditionally associated with frontal lobe damage.² In a study of this kind (Burgess et al. 1998), the caregivers or close relatives of 92 neurological patients of mixed etiology were asked to rate the frequency of occurrence of twenty of the most common dysexecutive symptoms in the patients they knew well. When the results were subjected to factor analysis (orthogonal rotation), five factors appeared: inhibition (deficits in response suppression and disinhibition); intentionality (deficits in planning, plus distractibility and poor decision making that could be expected to interfere particularly with real-world multitasking); executive memory (e.g., confabulation, perseveration); positive affective changes; and negative affective changes. Of all the tests given, which included measures of intelligence, memory, language, and visual perception, as well as ten measures of executive function, only one-the Six Element Test-correlated significantly with the factor scores for intentionality: r = 0.46, p < 0.001 criterion. This occurred despite many significant relationships between the other neuropsychological tests and the inhibition and executive memory factors. Thus it would seem that the Six Element Test measures something not measured by other neuropsychological tests and that this function is relevant to intentionality in everyday life. A related finding is that multitasking deficits are not necessarily accompanied by other symptoms of the dysexecutive syndrome (e.g. confabulation, perseveration).

20.4 GROUP STUDIES OF PATIENTS WITH CIRCUMSCRIBED CEREBRAL LESIONS

Together, the results of these single-case and group studies provide strong evidence that multitasking impairments can be seen independently of other neuropsychological impairments and of other problems in everyday life. They do not explain, however, why the multitasking impairments are occurring or indicate the lesion locations causing them.

Burgess et al. (2000) have examined these issues directly by administering a multitasking test (closely resembling the Six Element Test) to 60 patients with circumscribed cerebral lesions to isolate the particular stage or stages of failure in the patients, and to see whether different lesion locations were associated with decrement at different stages.

First, before the task was attempted, we measured the speed and accuracy with which the subjects learned the task rules. Subjects were then

asked how they intended to perform the task, and the appropriateness and complexity of the plan they produced was scored. Next, they performed the test itself, and this was scored as the number of task switches minus the number of rule breaks. A measure of "plan following" was derived by comparing actual test performance with the reported plan. Finally, after the task was completed, subjects were asked to recall (1) what they had done (a measure of autobiographical recollection) and (2) what the task rules were (delayed recall). In this way, it was possible to examine the relative contributions to multitasking performance of task learning and remembering, planning, plan following, and remembering one's actions.

Lesions to the left posterior cingulate and regions in the vicinity of the forceps major gave deficits on all measures except planning. Remembering task contingencies after a delay was also affected by lesions to the left anterior cingulate, and rule breaking and failures of task switching were additionally found in patients with lesions affecting the medial aspects of Brodmann's areas 8, 9, and 10 in the left frontal lobe. Planning deficits were associated with lesions to right dorsolateral prefrontal cortex. Examination of the relationship between the individual task components by structural equation modeling of the data from the patients and 60 age- and IQ-matched healthy controls suggested that there are three primary constructs that underpin multitasking: retrospective memory, prospective memory, and planning.

The data further suggested that the second and third draw on the products of the first. The left anterior and posterior cingulates (plus regions surrounding and the forceps major) appear to play some part in the retrospective memory demands of multitasking (e.g., learning and remembering task rules), whereas prospective memory (e.g., rule following and task switching) makes demands on the processes supported by left frontal areas 8, 9, and 10, with the right dorsolateral prefrontal cortex playing a critical part in planning.

20.5 FUNCTIONAL IMAGING STUDIES

Although current functional imaging technology cannot examine entire multitasking performance on tests with the complexity and duration of the Six Element Test, it can examine specific contributory components in isolation, and a recent study of this kind in our laboratory shows promising concordance with the lesion studies already outlined.

We (Burgess, Quayle, and Frith forthcoming) used positron-emission tomography (PET) to examine the brain regions involved in maintaining and realizing a delayed intention (known as "prospective memory"). The behavioral analogues in the Six Element Test would be plan following, rule following, and task switching. In this study, eight healthy subjects were given four different prospective memory tasks under two randomized conditions. In the "expectation condition," subjects were expecting to see a prospective memory (PM) stimulus, but during the PET scanning period one never occurred. In the "realization condition," subjects were expecting a PM stimulus, and it did occur. In both conditions, subjects were engaged in a foreground task of sufficient difficulty to prevent conscious intention rehearsal; a baseline condition involving only the foreground task was also given.

For the expectation condition, relative to the baseline, regional blood flow (rCBF) increased in Brodman's area 10 of the frontal lobes bilaterally, right dorsolateral prefrontal cortex (RDLPFC), precuneus, and inferior regions of the right parietal lobe. In the realization condition, relative to the expectation condition, rCBF increased in the thalamus and decreased in RDLPFC. The findings for area 10 and RDLPFC are concordant with data from our group lesion study described in the previous section. We concluded that these regions are involved in the creation and maintenance of intentions, with other regions, such as thalamus, anterior and posterior cingulates, and forceps major, supporting retrospective and prospective memory (see Burgess and Shallice 1996 for discussion of the relationship between prospective and retrospective memory).

20.6 CONCLUSIONS

Although the apparent complexity of multitasking would seem to make scientific investigation of this human activity problematic, recent results from cognitive neuroscience suggest that this may not be the case. This chapter has reviewed a series of investigations observations of behavior in real-world situations, covering the development and validation of experimental tasks designed to make similar demands, examination of the brain regions that, when damaged, lead to poor multitasking performance and their relative roles in performance, and (functional imaging) results that show promising cross-method concordance. The two principal conclusions to emerge from all of this are (1) the control processes involved in multitasking may be usefully seen as distinct from many other control and general cognitive functions; and (2) there may be a more straightforward mapping between these processes and the activity of specific brain regions than might initially be supposed.

There are, however, many aspects of multitasking in ill-structured situations which would be most appropriately investigated by the methods of cognitive and experimental psychology. The present chapter is intended as an appeal to my colleagues in this field to consider them scientifically tractable.

NOTES

This work was supported by Wellcome Trust grant 049241/Z/96/Z/MRE/HA/JAT.

1. In the version of SET now in common clinical use (Burgess et al. 1996), the test period is 10 minutes, and the first rule is simplified: "You must attempt at least some of all the six subtasks."

2. The terms executive tests or tests of executive function are used in the neuropsychological literature to designate tests that have a strong "cognitive control" component (e.g., response suppression, planning tests). Although such tests were often referred to as "frontal lobe tasks" because deficits on them were most often seen in patients with frontal lobe damage, Baddeley and Wilson (1986) pointed out that doing so confused anatomical and psychological descriptions. They proposed the alternative, now more common "executive tasks,"; patients (usually with frontal lobe damage) who show a range of executive control deficits are referred to as "dysexecutive."

REFERENCES

Baddeley, A. D., and Wilson, B. A. (1986). Amnesia, autobiographical memory, and confabulation. In D. C. Rubin (Ed.), Autobiographical memory, pp. 225-252. Cambridge: Cambridge University Press.

Burgess, P. W. (1997). Theory and methodology in executive function research. In P. Rabbit (Ed.), Methodology of frontal and executive functions, pp. 81-116. Hove, U.K.: Psychology Press.

Burgess, P. W., Alderman, N., Evans, J., Emslie, H., and Wilson, B. A. (1998). The ecological validity of tests of executive function. Journal of the International Neuropsychological Society, 4, 547-558.

Burgess, P. W., Alderman, N., Evans, J. J., Wilson, B. A., Emslie, H., and Shallice, T. (1996) The simplified six element test. In B. A. Wilson, N. Alderman, P. W. Burgess, H. Emslie, and J. J. Evans (Eds.), Behavioural assessment of the dysexecutive syndrome, Bury St. Edmunds, U.K.: Thames Valley Test Company.

Burgess, P. W., Frith, C. D. and Quayle, A. (Forthcoming). Brain regions involved in prospective memory according to positron-emission tomography.

Burgess, P. W., and Shallice, T. (1997). The relationship between prospective and retrospective memory: Neuropsychological evidence. In M. A. Conway (Ed.), Cognitive models of memory, pp. 247-272. Hove, U.K.: Psychology Press.

Burgess, P. W., Veitch, E., de Lacy Costello, A. and Shallice, T. (2000) The cognitive and neuroanatomical correlates of multitasking. Neuropsychologia, 38, 848-863.

Duncan, J., Burgess, P. W., and Emslie, H. (1995). Fluid intelligence after frontal lobe lesions. Neuropsychologia, 33, 261–268.

Goldstein, L. H., Bernard, S., Fenwick, O., Burgess, P. W., and McNeil, J. E. (1993). Unilateral frontal lobectomy can produce strategy application disorder. Journal of Neurology, Neurosurgery and Psychiatry, 56, 271-276.

Ellis, J. (1996). Prospective memory or the realization of delayed intentions: A conceptual framework for research. In M. Brandimonte, G. O. Einstein, and M. A. McDaniel (Eds.), Prospective memory: Theory and applications, pp. 1-22. Mahwah, NJ: Erlbaum.

Eslinger, P. J., and Damasio, A. R. (1985) Severe disturbance of higher cognition after bilateral frontal lobe ablation: Patient E.V.R. Neurology, 35, 1731-1741.

Kimberg, D. Y., and Farah, M. J. (1993). A unified account of cognitive impairments following frontal lobe damage: The role of working memory in complex, organized behavior. *Journal of Experimental Psychology: General*, 122, 411–428.

Levine, B., Stuss, D. T., Milberg, W. P., Alexander, M., Schwartz, M., and Macdonald, R. (1998). The effects of focal and diffuse brain damage on strategy application: Evidence from focal lesions, traumatic brain injury and normal ageing. *Journal of the International Neuropsychological Society*, *4*, 247–264.

Penfield, W., and Evans, J. (1935) The frontal lobe in man: A clinical study of maximum removals. *Brain*, 58, 115–133.

Shallice, T., and Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain*, *114*, 727–741.

This excerpt from

Control of Cognitive Processes. Stephen Monsell and Jon Driver, editors. © 2000 The MIT Press.

is provided in screen-viewable form for personal use only by members of MIT CogNet.

Unauthorized use or dissemination of this information is expressly forbidden.

If you have any questions about this material, please contact cognetadmin@cognet.mit.edu.