Psychologica Belgica
2010, 50-3&4, 309-326.

We are grateful to Matthew Logie for undertaking the programming to create the EVET environment. We also are grateful to Fergus Craik for permission to use the Craik and Bialystock (2006) breakfast task in our research and to their programmer Perry Tohn for providing a copy of the programme and for help with its implementation in our laboratory. We acknowledge the support of Leverhulme Trust research grant number F/00 158/W. Robert Logie and Jack Nissan are members of the University of Edinburgh Centre for Cognitive Ageing and Cognitive Epidemiology, funded by the UK Lifelong Health and Wellbeing Initiative, Grant number G0700704/84698 that also supported some of the research reported here.

Robert H. LOGIE[1], Anna LAW[2], Steven TRAWLEY[1], & Jack NISSAN[1]
[1]*University of Edinburgh, UK*
[2]*Liverpool John Moores University, UK*

Multitasking refers to the performance of a range of tasks that have to be completed within a limited time period. It differs from dual task paradigms in that tasks are performed not in parallel, but by interleaving, switching from one to the other. It differs also from task switching paradigms in that the time scale is very much longer, multiple different tasks are involved, and most tasks have a clear end point. Multitasking has been studied extensively with particular sets of experts such as in aviation and in the military, and impairments of multitasking performance have been studied in patients with frontal lobe lesions. Much less is known as to how multitasking is achieved in healthy adults who have not had specific training in the necessary skills. This paper will provide a brief review of research on everyday multitasking, and summarise the results of some recent experiments on simulated everyday tasks chosen to require advance and on-line planning, retrospective memory, prospective memory, and visual, spatial and verbal short-term memory.

The adult human mind is remarkably adept at selecting and implementing a wide range of mental functions for multiple interactions with the world. These interactions may be planned or spontaneous, but are constrained by physical and mental capacities or by time and the physical environment, often requiring multiple tasks or multi-part tasks. Successful implementation requires the efficient ordering or interleaving of tasks, and occasionally performing tasks in parallel. Every-day examples are cooking a meal, a time-limited shopping trip, or completing a range of different office based tasks. Despite its ubiquitous everyday requirement, there is limited insight into how everyday multitasking is achieved by healthy adults and how performance might be constrained or enhanced. Key to multitasking success is the ability to draw on a wide range of cognitive functions acting in concert to achieve multiple goals or multi-layered goals. These widely varying and frequent demands on the whole cognitive system are in contrast to the majority of research on human cognition that tends to focus on individual cognitive functions in relative isolation, such as perception, attention, prospective memory, semantic and episodic memory or working memory.

Everyday multitasking of this kind is very different from the laboratory based paradigms that examine the microstructure of rapid switching between laboratory tasks (e.g. Koch, Gade, Schuch & Philipp, 2010; Logan, 2006; Meyer, Evans & Rubenstein., 2001; Monsell, 2003). These paradigms typically focus on response time costs in tens of milliseconds when switching between two simple tasks that can be performed indefinitely, such as classifying numbers as odd or even, or classifying letters as consonant or vowel. These performance costs are apparent whether the experimenter determines when task switches should occur or if the participant themselves decides when to switch. In the latter case, participants have a tendency to perseverate on one of the tasks as well as showing a cost when they do switch to the alternate task (e.g. Arrington & Logan, 2004; Vandamme, Szmalec, Liefooghe & Vandierendonck, in press; Vandierendonck, Liefooghe & Verbruggen, 2010). Everyday multitasking involves much longer time scales where rapid and accurate response times are less crucial, multiple different and multi-part tasks are involved, and most tasks have a clear end point, with participants performing a series of tasks in a particular order and switching as each task is completed. For similar reasons, everyday multitasking is also very different from paradigms that explore the ability to carry out two laboratory tasks concurrently when they do not involve bottlenecks in stimulus input, cognitive processing or response output (e.g. Logie, Cocchini, Della Sala & Baddeley, 2004; Van der Meulen, Logie & Della Sala, 2009; Wickens, 2008), and when tasks are chosen to ensure that such bottlenecks are in place (e.g. Logan & Gordon, 2001; Logan, Schneider & Bundesen, in press; Ruthruff, Pashler & Klaassen, 2001).

One general approach has been to consider expert multitasking in specific domains, for instance emergency medicine and medical decision making (e.g. Chisholm, Dornfeld, Nelson & Cordell 2001; Law et al., 2005; van der Meulen et al., 2010), military and aviation (e.g. Loukopoulos, Desmukes & Barshi, 2009), management (Seshadri & Shapira, 2001), navigation (e.g. Spiers & Maguire, 2006), or driving (e.g. Levy & Pashler, 2008; Strayer, Drews & Crouch, 2006). However, these studies do not consider non-expert everyday multitasking of the kind addressed in this chapter. Other studies have explored non-expert planning and implementation of subgoals within problem solving domains such as use of the Tower of London or Tower of Hanoi (e.g. Phillips, Gilhooly, Logie, Della Sala & Wynn, 2003; Shallice, 1982; Ward & Allport, 1997). However, these laboratory based tasks are somewhat artificial and also do not address the broader demands of multitasking.

Although there is almost no literature on everyday multitasking in healthy adults, there are relevant studies on everyday multitasking deficits of patients with acquired brain injury (e.g., Crépeau, Belleville & Duchesne, 1996; Levine, Dawson, Boutet, Schwartz & Stuss, 2000; Miotto, & Morris, 1998; Shallice & Burgess, 1991). The Multiple Errands Test (MET) originally developed by Shallice and Burgess (1991), involved taking participants to a real shopping centre and asking them to complete a list of tasks of varying difficulty, for example buying a loaf of bread (easy) or finding the name of the coldest place in Britain the day before (more difficult). They had to spend as little money as possible and not go to any shop more than once. The multitasking demand arose from having to complete all the errands as quickly as possible, and so required the participant to decide which shops to visit and find an efficient route between them. Some of the results of that study (adapted from Burgess et al., 2006) are illustrated in Figure 1, which shows (to the left) a typical route taken by a control participant, and (to the right) the route taken by one of the brain damaged patients. The routes are dramatically different and show clearly the problems encountered by the patient in carrying out this everyday set of tasks. In that same study, Shallice and Burgess (1991) showed another test, the Six Elements Test, to be equally sensitive to the brain damage. This involved swapping between tasks carried out in a laboratory/clinic such as describing aloud two recent journeys, writing down the names of pictures, and solving arithmetic problems, with an overall time limit of 15 minutes. It is particularly striking that the Multiple Errands Test and the Six Elements Test were both much more sensitive to the effects of frontal lobe damage than were standard neuropsychological measures of executive function. This suggests that multi-

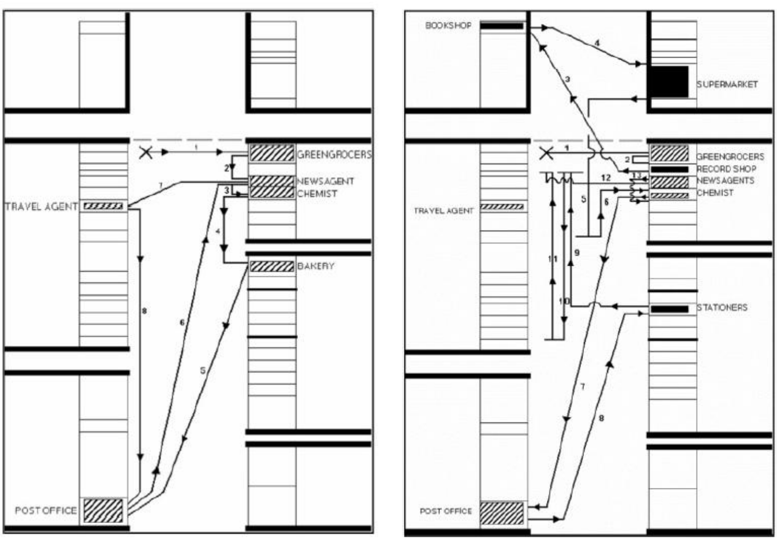

Figure 1

The left figure shows a typical route taken by a healthy control participant in completing errands in a shopping centre in Shallice and Burgess (1991). The right figure shows the route taken by a patient with frontal lobe damage. (Reproduced from Burgess et al., 2006, with permission) tasking might not simply be considered an executive function in healthy adults. In both tests, the patients tended to spend too long on individual tasks. Shallice and Burgess concluded that the patients had a problem with keeping track of and/or implementing their intentions to swap to other tasks.

For the purposes of exploring multitasking in healthy adults, the Multiple Errands test has a major advantage over the Six Elements Test and standardised neuropsychological tests in that it is close to real life multitasking. However, healthy participants tend to perform at ceiling on the version originally used, although the test is sufficiently flexible that it could be made more challenging. More important, for testing both patients and healthy controls, there are obvious drawbacks in the administration of tasks conducted in real-life settings (Bailey, Henry, Rendell, Phillips & Kliegel, 2010; Elkind, Rubin, Rosenthal, Skoff & Prather, 2001; Tranel, Hathaway-Nepple & Anderson, 2007). First, this type of task is both costly and time consuming as it requires consent from local businesses in the testing area, participants have to be transported to and from the test session, and research staff must be present at all times. Second, there is a lack of experimental control in that a crucial shop might spontaneously close at the time of testing, and members of the public or maintenance and repair works can compromise the safety of participants, as well as the reliability with which the same experimental procedures can be followed on different testing sessions or with different participants. For example, one of the patients in the Shallice and Burgess study started an argument with one of the shop assistants while trying to get a postcard without paying. Third, some participants may be more familiar than others with the particular shopping centre chosen, and the task set would have to be adjusted for use in shopping centres in other towns or cities if the procedure is to be of more general use. As a result, it cannot easily be adapted for other clinical or research settings. Finally, data collection is labour intensive in that it involves at least one experimenter (Shallice & Burgess used two experimenters) following the participant and noting manually where they go and what they do. Moreover, the fact that they are being observed so closely could affect how the participants undertake their tasks. For all of these reasons, the Multiple Errands test has not been widely used in clinical or research settings, despite its real-life relevance and sensitivity to frontal lobe damage.

A number of multitasking studies on brain damaged patients were carried out in the decade subsequent to the seminal paper by Shallice and Burgess (1991). Reviews of these studies are given in Burgess (1997; 2000; Burgess, Alderman, Evans, Emslie & Wilson, 1998). Burgess, Veitch, de Lacy Costello and Shallice (2000) were the first to offer a statistical model of multitasking. This was based on a study of 60 individuals with frontal lobe damage and 60 age-matched healthy controls. Given the practical difficulties with the Multiple Errands Test, they focused on a laboratory table-top set of three tasks, labelled collectively as The Greenwich Test. This comprised making small models from plastic meccano, sorting beads by colour, and tracing tangled lines on paper. Participants switched between the tasks when they wished, and the goal was to maximise the score for all three tasks over a period of ten minutes. The requirements for the Greenwich test incorporated voluntary switching between tasks and planning strategies to maximise overall test score. Scores were generated for test performance, for ability to learn and remember the task instructions, to make and follow a plan, and to later recount actions that had been taken. The patients performed more poorly than controls, but Burgess et al. (2000) noted that the data for both groups appeared to have the same basic factor structure. They constructed a structural equation model that identified contributions from retrospective memory for the task and task rules, intentionality or the ability to act on future intentions often referred to as prospective memory, and planning. This is illustrated in Figure 2. In their model planning and intentionality drew on the products of retrospective memory for successful performance. The model offered a good fit with the data for both groups, but a two-factor model (without planning) was also a good fit. Planning was included nevertheless to account for their additional neuroanatomical evidence. Specifically, Burgess et al. had Computerised Tomography scans of all of the brain damaged patients and observed that planning deficits were associated with lesions to the right dorsolateral prefrontal cortex, but not with damage to other frontal areas such as the left posterior cingulate which affected all measures except planning. Damage to very anterior regions such as Brodmann's areas 8, 9 and 10 also did not affect planning, but did affect task switching and breaking rules of the tasks. Subsequently, Burgess, Simons, Coates and Channon (2005) suggested that planning is itself multifaceted and supported by a range of cog-

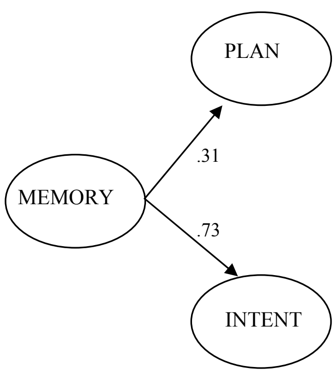

Figure 2

A simplified illustration of the Burgess et al. (2000) structural equation model of multitasking based on 60 brain damaged patients and 60 healthy controls performing The Greenwich Test. Reproduced with permission nitive abilities; a view shared by a range of other authors (see reviews in Morris and Ward, 2005). Therefore it would be important to identify those individual cognitive abilities rather than use the umbrella concept of planning.

One candidate not considered by Burgess and colleagues is working memory capacity: the system thought to store and manipulate information relevant to immediate sub-tasks (Baddeley, 1986; Baddeley & Logie, 1999; Logie, 1995; 2003; Logie & van der Meulen, 2009). Where the individual sub-tasks in multitasking occupy more of the capacity of working memory, it may be more difficult to remember to act on future intentions or develop an efficient strategy. In the Greenwich test all three tasks were in full view and it was obvious how much of each task had been completed throughout test performance. As a result, there would have been very limited involvement of working memory to keep track of test progress, although working memory might have been required for on-line planning of which task to do next and how long to stay with the current task in order to maximise overall score. König, Bühner and Mürling (2005) found that working memory was a more important predictor of performance than fluid intelligence or attention on a simultaneous capacity/multitasking test named SIMKAP. However, this involved swapping between artificial laboratory tests such as matching number or letter sequences, and answering factual questions based on semantic memory or arithmetic knowledge, with inclusion of only one everyday simulation of checking appointments against commitments in a calendar. The task requirements for the working memory tests were not dramatically different in that, for example, the verbal working memory test involved factual questions based on semantic memory and memory for word sequences. It could then be argued that strong correlations might have been expected between the SIMKAP battery and the chosen measures of working memory when considering task requirements.

The Greenwich Test used by Burgess et al. (2000) involved tasks that could be performed in any order chosen by the participant. In real life multitasking the sub-tasks often have an optimum order; when cooking for example, it makes sense to begin with the dish that will take the longest to heat. Craik and Bialystock (2006) addressed this issue in a study of cognitive aging. They used computer simulated breakfast making in which participants had to set a simulated table by clicking on and moving cutlery and plates on the computer screen as many times as possible. In addition, they had to switch to alternate screens for starting and stopping the preparation of five different foods each with different cooking times (sausages, eggs, toast, coffee, pancakes). A screen shot illustrating the table and each of the food screens is shown in Figure 3. There were prospective and retrospective memory components but the focus was on prospective memory for starting and stopping the foods at the correct time. An age-related impairment in performance was clear in their data when comparing 18-30 year olds with 60-80 year olds. They also found that older participants who happened to be bilingual showed less of an impairment than did monolingual participants who were of a similar age. They suggested that being bilingual might be beneficial in countering the effect of age on the cognitive requirements of the task.

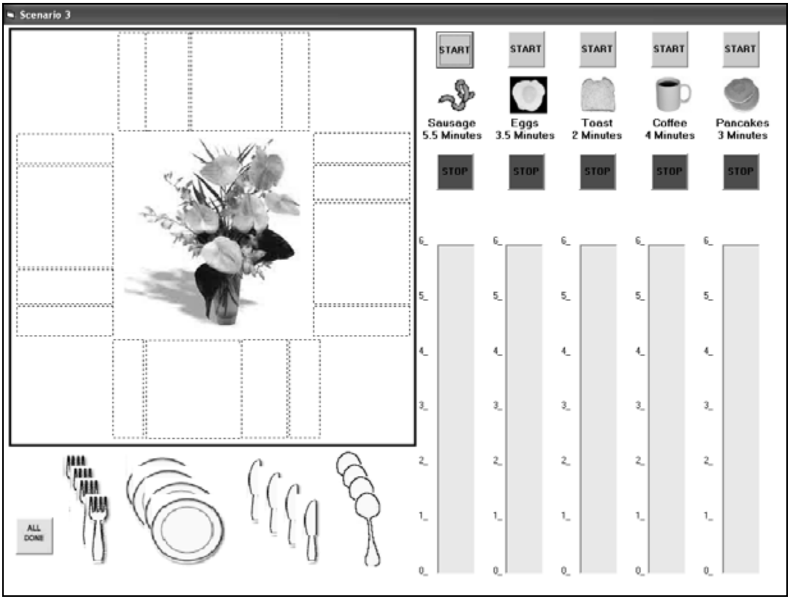

Figure 3
Screenshot of the Craik and Bialystock (2006) breakfast task

Fergus Craik kindly provided our laboratory with a copy of the breakfast task which we have used to explore the measures of individual differences in cognition that best predict performance (Logie, Law, Trawley & Nissan, 2009). First, we compared 50 healthy young (aged 18-25) with 50 middle aged (aged 45-60) participants, the latter being a largely neglected group in studies of cognitive ageing. The middle aged group had significantly poorer breakfast making performance, as measured by the delays in starting each of the five foods relative to their ideal starting time. In a further, as yet unpublished laboratory study in collaboration with Feinkohl, we ran a more realistic simulation of the breakfast task in which participants placed real cutlery and plates on a real table, while they started the ‘cooking’ of each of five foods set up as five separate video recordings of real foods being cooked. Again, the older group performed more poorly than the younger group, but the age effect was smaller with the realistic simulation on the measure of table setting, suggesting that the older people were disadvantaged by interacting with the computer simulation.

Our very recent studies, described briefly above, on prospective memory in the multitasking setting of the breakfast making simulation are in the process of being prepared for publication. However, the results on ageing are consistent with a separate, very large scale published study carried out via the internet in collaboration with the British Broadcasting Corporation (Logie & Maylor, 2009; Maylor & Logie, 2010). This involved 318,614 participants, aged 8-80 years who undertook a range of working memory tasks, within which were embedded a one-shot prospective memory and a one-shot retrospective memory test. This then comprised a multitasking scenario with participants swapping from one task to another, except that each task had to be completed before the next one was started and tasks had to be performed in the order determined by the experimenter while retaining the prospective intention and the retrospective episodic details. Both prospective and retrospective memory showed a decline across middle age, but there was a much steeper decline for prospective memory.

A range of individual difference measures were also collected in the Logie et al. (2009) study on the breakfast simulation, including verbal working memory span (Baddeley, Logie, Nimmo-Smith & Brereton, 1985) and choice reaction time, as well as backwards digit span and digit-symbol coding from the Wechsler Adult intelligence Scale, the Wechsler Test of Adult Reading, and Matrix Reasoning from the Wechsler Abbreviated Scale of Intelligence.

Among the 50 younger participants, only the Backwards Digit Span predicted breakfast task performance (r=0.313), whereas among the 50 middle aged participants, only Choice Response Time was a significant predictor (r=0.323).

In sum, middle age appears to result in performance reductions in tests of prospective memory embedded within multitasking paradigms. Striking, however, was the lack of a correlation in either group between the simulated breakfast making and a measure of working memory that has been shown to correlate with a wide range of demanding cognitive tasks, including measures of fluid intelligence. From these results, we might conclude that working memory makes no contribution to breakfast task performance, nor indeed did measures from standard tests of intelligence. However, it is important to note that measures of individual differences reflect, by definition, the maximum score that each individual can achieve on the tests that they perform. This does not allow for the possibility that several cognitive functions might nevertheless be crucial for performance, but without being required at the maximum for each individual. For example, assuming a basic competence with auditory comprehension, and adequate functioning of the auditory sensory system, a measure of individual differences in hearing ability among a group of people would most likely be a poor predictor of spoken language comprehension. However, this does not mean that a minimum level of hearing ability is not required for the task. It simply means that the task requires much less than the maximum auditory sensitivity of which each person is capable in order for them to understand the spoken input stream.

Following the above argument in the current context, working memory might well be involved in simulated breakfast making, but the latter task might not require all of the working memory capacity that is available within each individual tested. In an as yet unpublished collaboration with Fiore and Floyd, we asked younger healthy participants to perform the breakfast task on its own or to perform it at the same time as listening to a series of sentences and remembering the final words of each sentence. This secondary task load was very similar to the task used to measure working memory ability in the previous experiment. A further group of young healthy participants was asked to repeat aloud random sequences of eight digits spoken to them by the experimenter while they were doing the breakfast task. Results showed that breakfast task performance was very seriously impaired when it had to be performed with a concurrent working memory task or with oral recall of digit sequences. In other words, when working memory resources are required to perform some other task at the same time, the breakfast task suffers. Therefore, some minimum level of working memory capacity is essential for breakfast task performance, but this does not require all of the working memory capacity available. So, an individual differences analysis based on assessment of maximum capacity limits is not sensitive to this contribution to task performance.

The breakfast task is useful is simulating an everyday activity, and has shown promise in initial attempts to explore the effects of cognitive ageing on aspects of everyday multitasking. However, it involves relatively simple planning with task order based on cooking times, while swapping between tasks that are very similar to one another. As such, there is heavy reliance on prospective memory and much less reliance on memory for task instructions or strategic planning of the task order. This makes it less well suited for assessment of broader forms of everyday multitasking, and the cognitive functions required to support multitasking in younger healthy adults remain to be explored. A number of researchers have advocated the potential benefits of using more complex simulated real-life tasks in a virtual environment that are easily manipulated and modified to suit the experimental situation. For example, Burgess et al., (2005) reported a laboratory based 'Shopping Plan Test' in which brain damaged patients and controls are shown a map layout of buildings such as a post office, medical centre, newsagent, pond etc. and are asked to plan the most efficient route to achieve a series of goals such as send a birthday card or feed the ducks at the pond. This task requires route planning but lacks the test of implementing the planned activities in the environment. One study to address this was reported by Morris, Kotitsa and Bramham (2005) who used a virtual bungalow or warehouse, navigated using a joystick. Patients with frontal lesions showed impairments in the implementation of plans to move furniture or goods between rooms, but this has not been used in studies of healthy adults.

McGeorge and colleagues (2001) created a virtual version of the Multiple Errands Test that retained many advantages of the real environment while achieving experimental control. In this Virtual Errands Test (VET), the environment (a university building) was presented as virtual 3-D on a computer screen, and navigated using a mouse. The errands were tasks such as buy milk, collect a book or meet a colleague, and the errands were completed in the real university building as well as in the virtual building. The virtual environment was just as sensitive as the real environment to executive dysfunction in brain damaged patients, showing very similar performance when real-life and virtual versions of the same task were compared with healthy adults as well as with brain damaged individuals. Thus, virtual environments may offer a more appropriate, safer, and better controlled setting for assessment of multitasking abilities (see also Morris & Ward, 2005; Law, Logie & Pearson, 2006), although our initial studies with healthy older people, mentioned earlier, suggest that poorer performance might arise from unfamiliarity with the use of computers or with using a mouse to control movements through a virtual environment on screen. So, further development work will be needed to use these approaches in studying healthy ageing as well as for assessing patients. However, the focus of all of these studies has been on impairments of multitasking and planning, rather than how these requirements of everyday life are achieved by healthy adults.

The McGeorge et al. (2001) VET was subsequently modified to be challenging for healthy adults in a study by Law et al. (2006) who asked participants to perform the VET with and without secondary tasks. Performance on a secondary task thought to place heavy demands on working memory (random generation) was poorer when performed along with multitasking in a virtual environment than when performed on its own, although the multitasking itself was unaffected by the dual task demand, with overall score being the same in single and dual task conditions. However, there are limitations to the VET (originally developed in the late 1990s) in that the graphics were somewhat unrealistic and the mouse based interface required a considerable amount of practice to ensure smooth movement around the building. Collection of performance measures involved taking a video recording of each test session with subsequent manual scoring by the experimenter. Moreover, the software platform used to programme the VET is no longer supported by the commercial company concerned.

More recently, we have developed a new version of the VET to study everyday multitasking in a controlled, laboratory setting, the Edinburgh Virtual Errands Test (EVET). This has used a widely available commercial games platform that permits non profit development of virtual environments, and that is well suited to creating an environment for multitasking with realistic graphics and a smooth interface as well as the capability to record participant performance automatically. The EVET comprises a virtual four storey building with five rooms and a set of stairs on each side of an open stairwell. There is an elevator and there are lockable doors on each of the stairs. A screen shot of the ground floor area is shown in Figure 4. The software records all the actions taken by each participant and when they complete each errand. It also records the position of each participant in the virtual building ten times per second, illustrated in Figure 5.

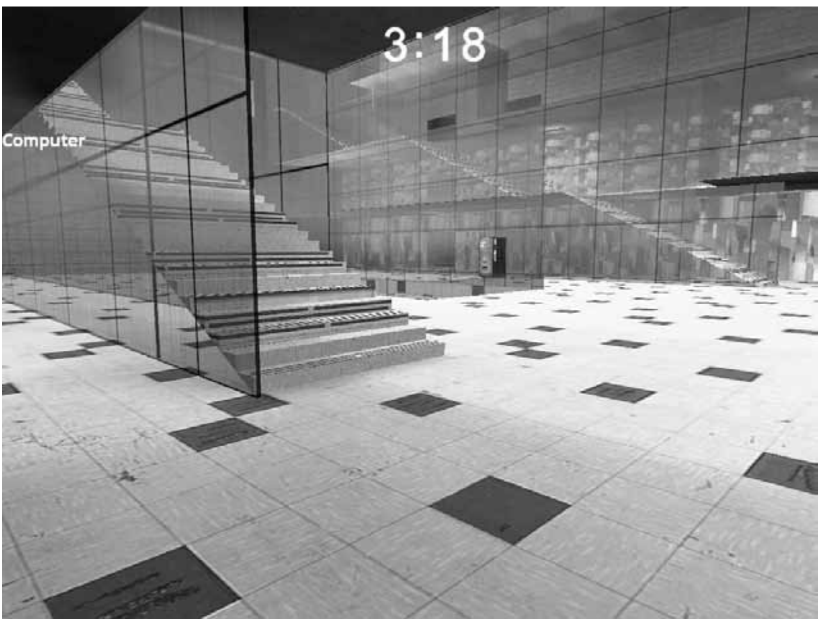

Figure 4
Screenshot of the ground floor of the EVET virtual building

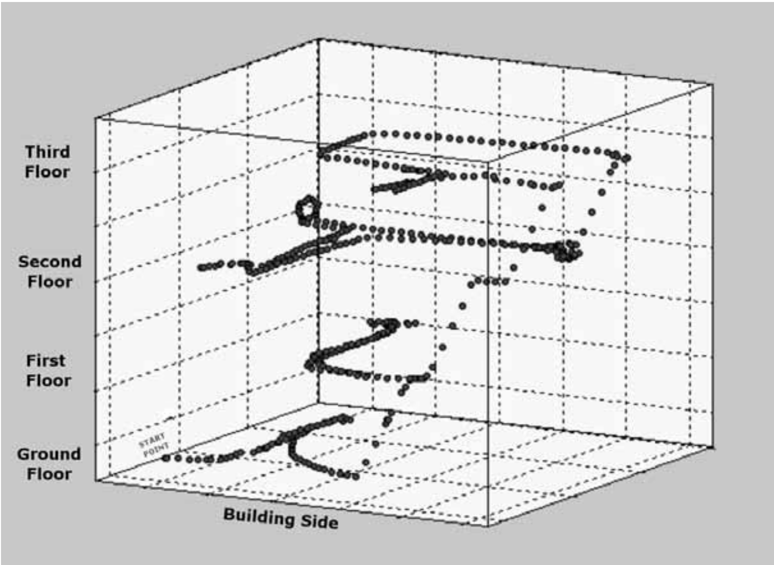

Figure 5
Sample recording of a participant's movements around the EVET virtual building, plotted as x,y,z co-ordinates

In a recent set of studies (Logie, Trawley and Law, 2010), we have used the EVET with a paradigm similar to the Shallice and Burgess (1991) Multiple Errands Test, but in a virtual rather than a real environment. Participants were given a list of errands to complete in the virtual building such as 'Pick up the brown package in room T4 and take it to room G6' or 'Get the door security code from room G8 and use it to unlock the door on the stairwell'. Some errands involved timed operations such as 'Turn on the cinema in room S7 at 5:30 minutes'. There were eight errands in total, some with two or more sub tasks, and the overall task was to complete all of the errands within eight minutes. The errands were given in a random order and participants had to generate as efficient a route and sequence of errands as possible. In addition, participants completed tests of verbal working memory capacity (sentence span based on Baddeley et al., 1985), of spatial working memory (Shah & Miyake, 1996), free recall of word lists to assess retrospective episodic memory (Capitani, Della Sala, Logie & Spinnler, 1992), and a new version of the Travelling Salesman Problem which requires planning of the most efficient route to visit a specified set of locations in a large array.

A total of 153 healthy young participants (18-35) completed the experiment. Multiple regression analysis showed that EVET performance was significantly and independently predicted by the Travelling Salesman task

(β=0.291), by Word List recall (β=0.229), and by Spatial Working Memory (β=0.209). Verbal working memory did not make a significant contribution to the variance. Follow up experiments with smaller groups of healthy participants demonstrated that a demanding verbal working memory task (random generation of months of the year) performed concurrently with EVET resulted in a significant reduction in EVET performance.

In summary, simulated everyday multitasking, as measured by this new form of paradigm, based on a virtual environment relies heavily on planning (Travelling Salesman Task), on retrospective memory and on spatial working memory. Verbal working memory is involved in task performance, but makes its contribution well within the capacity of the individuals taking part.

An exploratory factor analysis was then carried out on the whole data set that included additional measures of EVET performance as well as overall score. This identified three factors, namely Memory, Planning and Intentionality or prospective remembering. We then constructed a Structural Equation Model including these three factors as latent variables, and this showed a good fit with the data. This is illustrated in simplified form in Figure 6. The model includes the same factors as did the Burgess et al. (2000) model illustrated in Figure 2, and is consistent with that earlier model in suggesting that Memory drives both Intentionality and Planning. However, the relationship among the factors is different in that Planning also drives Intentionality and the relative weightings between the factors are rather different.

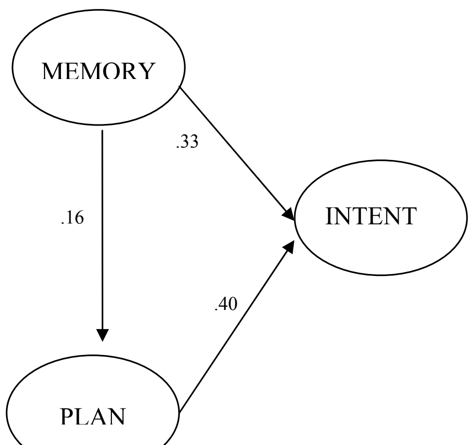

Figure 6

A simplified illustration of a structural equation model of multitasking based on 153 healthy young adults performing The Edinburgh Virtual Errands Test

This study gives us some insight into the nature of the cognitive functions that are important for simulated everyday multitasking based on those individual difference measures that were included. However, taking these results together with the experimental dual-task studies, it remains likely that additional, independent cognitive functions are important for successful performance, but the contribution from those functions is well within their capacity limits. What also seems clear is that there are differential contributions from a range of different cognitive functions, and performance is not driven by one overall factor such as general attention. This general conclusion is consistent with the substantial literature on expert multitasking which has identified multiple domain-specific cognitive functions that act in concert to achieve task performance (e.g. Wickens, 2008). It is also consistent with a view of cognition drawn from the working memory literature that points to multiple, domain-specific resources (Baddeley & Logie, 1999; Logie, 2003; Logie & van der Meulen, 2009) rather than a domain general attentional system (e.g. Cowan, 2005).

This chapter set out to explore the ubiquitous everyday requirements of multitasking; the ability to accomplish a range of tasks by swapping between them strategically or by planning the order in which they should be performed most efficiently. It is clear that much of the previous literature on the topic has tended to focus on various forms of expert multitasking in which people learn domain-specific skills for managing the performance of domain specific tasks, or response time and accuracy costs of switching between simple laboratory tasks. Studies of non-expert, everyday multitasking have tended to focus on performance impairments in individuals with focal brain damage, given that failures of multitasking are more sensitive to the effects of the damage than are many standard neuropsychological tests of executive function. Here, I have argued that we can draw on the paradigms developed to study brain damaged individuals to study everyday, non expert multitasking in healthy adults, and using virtual environments and virtual tasks to do so. Moreover, the technology required to develop this approach is readily available and inexpensive, making it widely accessible for future research. In some senses, this could be described as a 'paradigm' shift in studying healthy cognition in that the experimental setting is more complex and entails the use of multiple aspects of cognition acting together. This is in contrast to the traditional approach to experimental cognitive psychology that tends to focus rather more on the microstructure of very specific cognitive functions individually such as visual attention, auditory attention, rapid task switching, verbal short-term memory, visual short-term memory, prospective memory, episodic memory, language comprehension or production. Humans operate in the world effectively because they can bring to bear all of these aspects of cognition in a co-ordinated way to achieve everyday goals, and rarely do we draw on a single function in isolation, even in experiments designed to explore how we do so.

References

Arrington, C. M., & Logan, G. D. (2004). The cost of a voluntary task switch. *Psychological Science, 15, 610-615.*

Baddeley, A.D. (1986). *Working Memory*. Oxford, UK: Oxford University Press.

Baddeley, A.D. & Logie, R.H. (1999). Working memory: The multiple component model. In A. Miyake & P. Shah (eds.) *Models of Working Memory*, pp28-61. New York: Cambridge University Press.

Baddeley, A.D., Logie, R.H., Nimmo-Smith, I and Brereton, N.(1985) Components of fluent reading. *Journal of Memory and Language, 24*, 119-131.

Bailey, P.E, Henry, J.D., Rendell, P.G., Phillips, L.H., & Kliegel, M. (2010). Dismantling the "age-prospective memory paradox": The classic laboratory paradigm simulated in a naturalistic setting. *Quarterly Journal of Experimental Psychology.*

Burgess, P.W. (1997). Theory and methodology in executive function research. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 81–116). Hove, U.K.: Taylor and Francis.

Burgess, P.W. (2000). Real-world multitasking from a cognitive neuroscience perspective. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 465-472). Cambridge, MA: MIT Press.

Burgess, P.W., Alderman, N., Evans, J., Emslie, H., & 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., Forbes, C., Costello, A., Coates, L. M-A., Dawson, D.R. Anderson, N. D., Gilbert, S. J., Dumontheil, I., & Channon, S. (2006),The case for the development and use of «ecologically valid» measures of executive functions in experimental and clinical neuropsychology. *Journal of International Neuropsychological Society 12*, 194-209.

Burgess, P.W., Simons, J.S., Coates, L.M.-A., & Channon, S. (2005). The search for specific planning processes. In R. Morris & G. Ward (Eds.), *The cognitive psychology of planning* (pp. 199-227). Hove, U.K.: Psychology Press.

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

Capitani, E., Della Sala, S., Logie, R., & Spinnler, H. (1992). Recency, primacy and memory: Reappraising and standardising the serial position curve. *Cortex, 28*, 315-342.

Chisholm, C.D., Dornfeld, A.M., Nelson, D.R., & Cordell, W.H. (2001). Work interrupted: A comparison of workplace interruptions in emergency departments and primary care offices. *Annals of Emergency Medicine, 38*, 146-151.

Cowan, N. (2005). *Working Memory Capacity.* Hove, UK: Psychology Press.

Craik, F.I., & Bialystok, E. (2006). Planning and task management in older adults:

cooking breakfast. *Memory & Cognition, 34*, 1236-1249.

Crépeau, F., Belleville, S., & Duchesne, G. (1996). Disorganisation of Behavior in a Multiple Subgoals Scheduling Task Following Traumatic Brain Injury. *Brain and Cognition, 32*, 266-268.

Elkind, J.S., Rubin, E., Rosenthal, S., Skoff, B., Prather, P. (2001). A simulated reality scenario compared with the computerized Wisconsin Card Sorting test: An analysis of preliminary results. *CyberPsychology and Behaviour, 4*, 489-496.

Koch, I., Gade, M., Schuch, S. & Philipp, A.M. (2010). The role of inhibition in task switching: A review. *Psychonomic Bulletin and Review, 17*, 1-14.

König, C.J., Bühner, M. & Mürling, G. (2005). Working Memory, Fluid Intelligence, and Attention Are Predictors of Multitasking Performance, but Polychronicity and Extraversion Are not. *Human Performance, 18*, 243-266.

Law, A. S., Freer, Y., Hunter, J., Logie, R. H., McIntosh, N., & Quinn, J. (2005). A comparison of graphical and textual presentations of time series data to support medical decision making in the Neonatal Intensive Care Unit. *Journal of Clinical Monitoring and Computing, 19,* 183-194.

Law, A., Logie, R.H., & Pearson, D.G. (2006). The impact of secondary tasks on multitasking in a virtual environment. *Acta Psychologica, 122,* 27-44.

Law, A.S., Logie, R.H., Pearson, D.G., Cantagallo, A., Moretti, E., & Dimarco, F. (2004). Resistance to the impact of interruptions during multitasking by healthy adults and dysexecutive patients. *Acta Psychologica, 116*, 285-307.

Levine, B., Dawson, D., Boutet, I., Schwartz, M.L., & Stuss, D.T. (2000). Assessment of strategic self regulation in traumatic brain injury: Its relationship to injury severity and psychosocial outcome. *Neuropsychology, 14,* 491-500.

Levy, J., Pashler, H. (2008) Task prioritization in multitasking during driving: Opportunity to abort a concurrent task does not insulate braking responses from dual-task slowing. *Applied Cognitive Psychology, 22*, 507-525.

Liefooghe, B., Demanet, J. & Vandierendonck, A. (2010). Persisting activation in voluntary task switching: It all depends on the instructions. *Psychonomic Bulletin & Review, 2010, 17(3)*, 381-386.

Logan, G. D. (in press). What it costs to implement a plan: Plan-level and task-level contributions to switch costs. *Memory & Cognition*.

Logan, G. D. (2006). Out with the old, in with the new: More valid measures of switch cost and retrieval time in the task span procedure. *Psychonomic Bulletin & Review*, *13*, 139-144.

Logan, G. D. & Gordon, R. D. (2001). Executive control of visual attention in dual-task situations. *Psychological Review, 108,* 393-434.

Logan, G. D., Schneider, D. W., & Bundesen, C. (in press). Still clever after all these years: Searching for the homunculus in explicitly-cued task switching. *Journal of Experimental Psychology: Human Perception and Performance*.

Logie, R.H. (1995). *Visuo-Spatial Working Memory*. Hove, UK: Lawrence Erlbaum Associates.

Logie, R.H. (2003). Spatial and Visual Working Memory: A Mental Workspace. In D. Irwin and B Ross (Eds.) *Cognitive Vision: The Psychology of Learning and Motivation* (Vol 42, pp. 37-78). Elsevier Science (USA).

Logie, R.H., Cocchini, G., Della Sala, S., & Baddeley, A.D. (2004a). Is there a specific executive capacity for dual task co-ordination? Evidence from Alzheimer's

Disease. *Neuropsychology, 18,* 504-513.

Logie, R.H., Law, A.S., Trawley, S. & Nissan, J. (2009). Multitasking for breakfast and in the shopping mall. Presentation at the 50th meeting of the Psychonomic Society, Bostaon, MA. USA. November 2009.

Logie, R.H. & Maylor, E.A. (2009). An internet study of prospective memory across adulthood. *Psychology and Aging,* 24, 767-774

Logie, R.H., Trawley, S., & Law, A.S., (2010). Multitasking: Multiple, Domain-Specific Cognitive Functions in a Virtual Environment. Manuscript submitted for publication.

Logie, R.H. & van der Meulen, M. (2009). Fragmenting and integrating visuo-spatial working memory. In J.R. Brockmole (Ed.) *Representing the Visual World in Memory*, pp 1-32. Hove, UK: Psychology Press.

Loukopoulos, L.D., Dismukes, K. & Barshi, I. (2009). *The Multitasking Myth: Handling Complexity in Real-World Operations*. Farnham, UK: Ashgate.

Maylor, E.A. & Logie, R.H. (2010). A Large-Scale Comparison of Prospective and Retrospective Memory Development from Childhood to Middle-Age. *Quarterly Journal of Experimental Psychology*, 63, 442-451.

McGeorge, P., Phillips, L.H., Crawford, J.R., Garden, S.E., Della Sala, S., & Milne, A.B. (2001). Using virtual environments in the assessment of executive dysfunction. *Presence, 10,* 375-383.

Meyer, D.E., Evans, J.E., & Rubinstein, J.S. (2001). Executive Control of Cognitive Processes in Task Switching. *Journal of Experimental Psychology: Human Perception and Performance*, *27,* 763-797.

Miotto, E.C., & Morris, R.G. (1998). Virtual planning in patients with frontal lobe lesions. *Cortex, 34,* 631-657.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7,* 134-140.

Morris, R., Kotitsa, M. & Bramham, J. (2005). Planning in patients with focal brain damage: From simple to complex task performance. In R. Morris & G. Ward (Eds.), *The Cognitive Psychology of Planning* (pp. 153–179). Hove, U.K.: Psychology Press.

Morris, R. & Ward, G. (Eds.), *The Cognitive Psychology of Planning* (pp. 199-227). Hove, U.K.: Psychology Press.

Phillips, L.H., Gilhooly, K.J., Logie, R.H., Della Sala, S. & Wynn, V. (2003). Age, working memory, and the Tower of London task. *European Journal of Cognitive Psychology, 15*, 291-312.

Ruthruff, E., Pashler, H. E. & Klaassen, A. (2001). Processing bottlenecks in dual-task performance: Structural limitation or voluntary postponement? *Psychonomic Bulletin and Review, 8*, 73-80.

Seshadri, S. & Shapira, Z. (2001). Managerial Allocation of Time and Effort: The Effects of Interruptions. *Management Science*, *47*, 647-662.

Shah, P., Miyake, A. (1996) The Separability of Working Memory Resources for Spatial Thinking and Language Processing: An Individual Differences Approach. *Journal of Experimental Psychology: General,* 125, 4-27.

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London, 298*, 199-209.

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

Spiers, H.J. & Maguire, E.A. (2006). Thoughts, behaviour, and brain dynamics during navigation in the real world. *Neuroimage, 31*, 1826-1840.

Strayer, D.L., Drews, F.A., & Crouch, D.J. (2006). Comparing the cellphone driver and the drunk driver. *Human Factors, 48*, 381-391.

Tranel, D., Hathaway-Nepple, J., & Anderson, S.W. (2007). Impaired behavior on real-world tasks following damage to the ventromedial prefrontal cortex, *Journal of Clinical and Experimental Neuropsychology, 29,* 319-332.

Vandamme, K., Szmalec, A., Liefooghe, B., & Vandierendonck, A. (in press). Are voluntary switches corrected repetitions? *Psychophysiology.*

Van der Meulen, M., Logie, R.H. & Della Sala, S. (2009). Selective interference with image retention and generation: Evidence for the workspace model. *Quarterly Journal of Experimental Psychology, 62,* 1568-1580.

Van der Meulen, M., Logie, R.H., Freer, Y., Sykes, C., McIntosh, N. and Hunter, J. (2010). When a Graph is Poorer than 100 Words: A Comparison of Computerised Natural Language Generation, Human Generated Descriptions and Graphical Displays in Neonatal Intensive Care. *Applied Cognitive Psychology, 24*, 77-89.

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task Switching: Interplay of Reconfiguration and Interference Control. *Psychological Bulletin, 136(4)*, 601-626.

Ward, G. & Allport, D.A. (1997). Planning and problem solving using the five disk Tower of London. *Quarterly Journal of Experimental Psychology*, 50A, 49-78.

Wickens, C.D. (2008). Multiple Resources and Mental Workload, *Human Factors, 50,* 449-455.