



2808905072

REFERENCE ONLY

UNIVERSITY OF LONDON THESIS

Degree Pnd Year 2006 Name of Author ZLOTOWITZ Sally Anne

COPYRIGHT

This is a thesis accepted for a Higher Degree of the University of London. It is an unpublished typescript and the copyright is held by the author. All persons consulting the thesis must read and abide by the Copyright Declaration below.

COPYRIGHT DECLARATION

I recognise that the copyright of the above-described thesis rests with the author and that no quotation from it or information derived from it may be published without the prior written consent of the author.

LOANS

Theses may not be lent to individuals, but the Senate House Library may lend a copy to approved libraries within the United Kingdom, for consultation solely on the premises of those libraries. Application should be made to: Inter-Library Loans, Senate House Library, Senate House, Malet Street, London WC1E 7HU.

REPRODUCTION

University of London theses may not be reproduced without explicit written permission from the Senate House Library. Enquiries should be addressed to the Theses Section of the Library. Regulations concerning reproduction vary according to the date of acceptance of the thesis and are listed below as guidelines.

- A. Before 1962. Permission granted only upon the prior written consent of the author. (The Senate House Library will provide addresses where possible).
B. 1962 - 1974. In many cases the author has agreed to permit copying upon completion of a Copyright Declaration.
C. 1975 - 1988. Most theses may be copied upon completion of a Copyright Declaration.
D. 1989 onwards. Most theses may be copied.

This thesis comes within category D.

[ ] This copy has been deposited in the Library of UCL

[ ] This copy has been deposited in the Senate House Library, Senate House, Malet Street, London WC1E 7HU.



# **Cognitive Control of Internally-guided Behaviours**

**Sally Anne Zlotowitz**

Department of Psychology  
University College London

Thesis submitted for the degree of Doctor of Philosophy (Ph.D) at  
the University of London

February 2006

UMI Number: U593293

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



UMI U593293

Published by ProQuest LLC 2014. Copyright in the Dissertation held by the Author.  
Microform Edition © ProQuest LLC.

All rights reserved. This work is protected against  
unauthorized copying under Title 17, United States Code.



ProQuest LLC  
789 East Eisenhower Parkway  
P.O. Box 1346  
Ann Arbor, MI 48106-1346



# Abstract

Acting according to one's own internal goals is crucial to flexible behaviour. Clinical and lesion studies of patients with frontal lobe damage have demonstrated syndromes potentially resulting from deficits in the cognitive control system for internally-guided behaviours. Some patients can perform well on tasks that are well-constrained by the environment, including standard measures of IQ, yet show impairments in everyday life and laboratory equivalent ill-structured tasks that make planning and self-cueing demands. This thesis is concerned with the executive control of such tasks in the healthy population. Eight experimental studies are reported which consider the role of endogenous and exogenous cueing in prospective memory (PM) and multitasking. Experiments 1-4 integrated the two standard laboratory-based paradigms of task-switching and PM to assess the independence of processes involved in externally-cued task-switching and self-initiated (i.e. internally-generated) PM task switches. These experiments suggested that these two types of task switches are enabled by independent processes. Focusing only on PM, Experiments 5-6 manipulated the degree of internal cueing required by the PM task and analysed the effects on performance of the ongoing task. Participants exhibited poorer ongoing task performance in a time-based PM task without the presence of a clock (internally-cued) compared with PM tasks with stronger external cues (with a clock and event-based). The results support the view that the executive processes recruited for PM tasks reflect the demands made on internal control. In Experiments 7-8, individual differences in internally-guided control processes were explored after development of an advanced multitasking test (AMT) for the healthy population. AMT performance correlated with some real-life outcome measures. The evidence in this thesis supports the suggestion that different executive processes are employed depending on the demand for internally-generated behaviour. Individual variation in the cognitive control system for internally-guided behaviour may relate to everyday functioning.

# Table of Contents

<b>Chapter 1 The Frontal Lobes, Executive Functions and Internally-Guided Behaviours</b>	12
1.1. Introduction	12
1.2. Theoretical Models of Cognitive Control	16
1.2.1. The Supervisory Attentional System	16
1.2.2. Fractionation of the Executive Control System	17
1.3. Rostral PFC and Internally-guided Behaviours	25
1.3.1. Self-Regulation and Multitasking	25
1.3.2. Functions of Rostral PFC	32
<b>Chapter 2 A Review of Prospective Memory Research</b>	37
2.1. Summary	37
2.2. Introduction to Prospective Memory	37
2.3. Methodologies	41
2.4. Cognitive accounts of Intention Retrieval	43
2.4.1. Automatic-association Accounts	43
2.4.2. Noticing + Search Model	45
2.4.3. Multiprocess Framework	46
2.4.4. PAM Theory	50
2.5. Cognitive accounts of TB PM	51
2.6. Ageing studies and PM	54
2.7. The Role of Executive Processes in PM	56
2.7.1. Complex PM Paradigm	57
2.7.2. PM and Neuropsychological Studies	60
2.7.3. PM and Neuroimaging Studies	63
2.8. Summary	64
2.9. Focus of Thesis Research	65
2.9.1. Broad Overview of Experiments	65
<b>Chapter 3 Cognitive Control of Internally-generated and Externally-cued Task-switches</b>	67

3.1. Introduction .....	67
3.2. Task-switching and the Study of Cognitive Control .....	67
3.3. PM and Task-switching .....	70
3.4. Internally- and Externally-cued Task-switching .....	72
3.5. Voluntary Task-switching Paradigm .....	73
3.6. Further Evidence for a Dissociation between Internally- and Externally-cued Task-switching .....	75
3.7. The Experimental Paradigm .....	76
3.8. Experiment 1 .....	77
3.8.1 Method .....	78
3.8.2. Results .....	82
3.8.3. Discussion .....	86
3.9. Experiment 2 .....	87
3.9.1. Method .....	87
3.9.2. Results .....	89
3.9.3. Discussion .....	94
3.10. Experiment 3 .....	96
3.10.1. Method .....	96
3.10.2. Results .....	97
3.10.3. Discussion .....	100
3.11. Experiment 4 .....	102
3.11.1. Method .....	102
3.11.2. Results .....	104
3.11.3. Discussion .....	107
3.12. General Discussion .....	107
3.12.1. Time-Based and Event-Based PM .....	112
3.13. Summary .....	118
<b>Chapter 4 Internal Control in Prospective Memory .....</b>	<b>120</b>
4.1. Introduction .....	120
4.2. Time-Based Prospective Memory .....	121
4.2.1. Neural Basis of Time-Based PM .....	121
4.2.2. Cognitive Accounts of TB PM with Respect to the Nature of the Clock .....	123
4.2.3. Clocks in previous TB PM Research .....	124

4.3. Experiment 5 .....	126
4.3.1. Aims and Hypotheses.....	126
4.3.2. Method .....	128
4.3.3. Results .....	134
4.3.4. Discussion .....	142
4.4. Experiment 6 .....	151
4.4.1. Aims and Hypotheses.....	151
4.4.2. Method .....	153
4.4.3. Results .....	157
4.4.4. Discussion .....	164
4.5. Summary .....	169
<b>Chapter 5 Individual Differences in Internally-guided Control Processes in a Healthy Population .....</b>	<b>171</b>
5.1. Self-Regulation & Multitasking Revisited .....	171
5.2. Self-Regulation in the Healthy Population .....	172
5.3. Experiment 7 .....	174
5.3.1. Advanced Multitasking Test (AMT).....	174
5.3.2. The Effects of Interruptions .....	175
5.3.3. Prospective Memory Load .....	177
5.3.4. Other Design Elements of the AMT .....	178
5.3.5. Cognitive and Real Life Measures.....	178
5.3.6. Summary of Hypotheses .....	179
5.3.7. Method .....	180
5.3.8. Results .....	186
5.3.9. Discussion .....	193
5.4. Summary & Limitations.....	202
5.5. Experiment 8 .....	204
5.5.1. Introduction.....	204
5.5.2. Method .....	209
5.5.3. Results .....	212
5.5.4. Discussion .....	220
<b>Chapter 6 General Discussion .....</b>	<b>228</b>
6.1. General Aims and Hypotheses Reviewed .....	228

6.2. Summary of Chapter 3 - Experiments 1 – 4.....	228
6.2.1. The Relationship Between Task-switching and Prospective Memory .....	230
6.2.2. The Effects of the Prospective Memory Task on Ongoing Task Performance	232
6.2.3. Explaining the Pattern of RT Data Across the Retention Interval in Experiments 1-6 .....	234
6.3. Summary of Chapter 4 – Experiments 5 & 6.....	238
6.3.1. Experiment 5 .....	238
6.3.2. Experiment 6 .....	241
6.3.3. Evaluation of the Hierarchy Theory.....	244
6.4. Summary of Chapter 5 - Experiments 7 & 8.....	246
6.4.1. Experiment 7 .....	246
6.4.2. Experiment 8 .....	248
6.4.3. Correlations Between The AMT and Cognitive Measures in Experiments 7 & 8 .....	249
6.4.4. Correlations Between The AMT and Real-life Measures in Experiments 7 & 8 .....	252
6.5. Cognitive Control of Internally-guided Behaviours .....	253
6.5.1. Broader Implications and Conceptual Considerations.....	253
6.5.2. Future Directions.....	256
References.....	259
Appendix A .....	300
Appendix B .....	304

# List of Figures

<b>Figure 2.1</b>	<i>Factors affecting degree of self-initiated processing in PM</i>	p.49
<b>Figure 3.1.</b>	<i>The screen design for experiment 1. In the PM conditions the clock was functioning, in the externally-cued side switch conditions the clock hands flipped between quarter-to and quarter-past.</i>	p.80
<b>Figure 3.2.</b>	<i>Factorial design – list of block types each participant performed</i>	p.82
<b>Figure 3.3.</b>	<i>Overall mean RTs as a function of task-switching and PM trial type.</i>	p.83
<b>Figure 3.4.</b>	<i>Overall mean RTs as a function of task-switching, PM and time band trial type.</i>	p.85
<b>Figure 3.5.</b>	<i>The screen design for experiment 2. The clock face remained empty in all conditions, but in the PM conditions the clock hands could be revealed for 1.5 secs.</i>	p.88
<b>Figure 3.6.</b>	<i>Overall mean RTs as a function of task-switching and PM trial type.</i>	p.90
<b>Figure 3.7.</b>	<i>Overall mean RTs as a function of PM and time band trial type</i>	p.92
<b>Figure 3.8.</b>	<i>Overall mean RTs as a function of task-switching and time band trial type</i>	p.92
<b>Figure 3.9.</b>	<i>Number of clock checks in the PM conditions (collapsed across task-switching conditions) as a function of time band</i>	p. 94
<b>Figure 3.10.</b>	<i>Overall mean RTs as a function of task-switching and PM trial type.</i>	p.98
<b>Figure 3.11.</b>	<i>Overall mean RTs as a function of task-switching, PM pre and post trial type.</i>	p.100
<b>Figure 3.12.</b>	<i>Overall mean RTs as a function of task-switching and PM trial type.</i>	p.105
<b>Figure 3.13.</b>	<i>Overall mean RTs as a function of task-switching, PM pre and post trial type.</i>	p.106
<b>Figure 4.1.</b>	<i>The screen design in the PM clock conditions in experiment 5</i>	p.131



<b>Figure 4.2.</b>	<i>Mean error rates of ongoing tasks – collapsed across tasks and 2 blocks</i>	p.137
<b>Figure 4.3.</b>	<i>Mean RTs of ongoing tasks - collapsed across tasks and 2 blocks</i>	p.137
<b>Figure 4.4.</b>	<i>Mean RTs of trials within 3 time bands of PM retention intervals in clock blocks - collapsed across 4 ongoing tasks</i>	p.139
<b>Figure 4.5.</b>	<i>Mean RTs of trials within 3 time bands of PM retention intervals in no clock blocks - collapsed across 4 ongoing tasks</i>	p.140
<b>Figure 4.6.</b>	<i>The screen design in the EB PM conditions – the red stimuli signifies the PM cue</i>	p.155
<b>Figure 4.7.</b>	<i>List of block types each participant performed</i>	p.157
<b>Figure 4.8.</b>	<i>Mean error rates of trials within PM different PM blocks - collapsed across 4 ongoing tasks and single and dual intention blocks</i>	p.160
<b>Figure 4.9.</b>	<i>Mean RTs of trials within PM different PM blocks - collapsed across 4 ongoing tasks and single and dual intention blocks</i>	p.161
<b>Figure 4.10.</b>	<i>Mean RTs of trials within 3 time bands of PM retention intervals in different PM blocks - collapsed across 4 ongoing tasks</i>	p.161
<b>Figure 5.1.</b>	<i>Rule breaks frequency chart (subtask order rule breaks).</i>	p.188
<b>Figure 5.2.</b>	<i>Rule following: attempted all 6 subtasks?</i>	p.188

# List of Tables

<b>Table 4.1.</b>	<i>Displays the mean total number of PM responses and the mean RI lengths in each of the PM blocks in experiment 5.</i>	p.141
<b>Table 4.2.</b>	<i>Mean number of PM responses and length of retention intervals in each PM condition in experiment 6.</i>	p.163
<b>Table 5.1.</b>	<i>Descriptive statistics of the AMT measures.</i>	p.187
<b>Table 5.2.</b>	<i>Spearman Rho correlation coefficients between RM tasks and the AMT scores</i>	p.190
<b>Table 5.3.</b>	<i>Spearman Rho correlation coefficients between RM tasks and the percentage opt score only including participants who scored 7 or more on rule recall measure</i>	p.191
<b>Table 5.4.</b>	<i>Spearman Rho correlation coefficients between Raven's Scores and the AMT scores</i>	p.192
<b>Table 5.5.</b>	<i>Significant Spearman Rho correlation coefficients between time management questionnaire and the AMT scores</i>	p.193
<b>Table 5.6.</b>	<i>Descriptive statistics of cued-rule recall scores</i>	p.213
<b>Table 5.7.</b>	<i>Frequent task-switchers – descriptive statistics of AMT2 scores</i>	p.214
<b>Table 5.8.</b>	<i>Infrequent task-switchers – descriptive statistics of AMT2 scores</i>	p.215
<b>Table 5.9.</b>	<i>Correlation coefficients between AMT2 measures and cognitive variables – collapsed across 2 groups</i>	p.216
<b>Table 5.10.</b>	<i>Correlation coefficients between AMT2 measures and cognitive variables – separate groups</i>	p.217
<b>Table 5.11.</b>	<i>Correlation coefficients between academic measures and AMT2 measures – collapsed across 2 groups</i>	p.218
<b>Table 5.12.</b>	<i>Correlation coefficients between academic measures and the AMT2 measures – separate groups</i>	p.218
<b>Table 5.13</b>	<i>Correlation coefficients between real life measures and AMT2 measures – collapsed across 2 groups</i>	p.219

# Acknowledgements

I would like to express my gratitude to everyone who has helped me. Firstly, I sincerely thank my supervisor, Professor Shelley Channon, for her patient and thorough guidance over the last three years. I appreciate all her time and energy dedicated to making me a better scientist. I am also grateful to my second supervisor, Dr. Paul Burgess, who has contributed many ideas and much enthusiasm for the research. I am also deeply indebted to Dr. Sam Gilbert, whose advice, support and technical help has gone far beyond the call of duty. He is a truly kind-hearted intellect and I offer him my sincere and warm thanks and wish him all the success he so well deserves in the future. Other members of Shelley and Paul's teams have also generously given their time and support, including Andrea, Jessie and Dr. Jon Simons. Thank you also to the MRC for funding.

To my fellow thesis survivors, Dr. Celia Morgan, Rosa Hoshi and Lee Rowland, and the rest of the Marlborough Army, I cannot thank you enough for making the last three years so 'amazing'. Celia and Rosa thanks so much for embracing my rubbish drinks and being my absolute rocks during all the highs and lows. Thanks to Lee for his inspirational discussions about all aspects of psychology and beyond. I have learnt a great deal from him.

So many friends have been incredibly kind and supportive, and some even genuinely interested in my research. I thank them for their unflinching patience when I have so often repeated the phrase 'just one more month till I'm finished'. My spinster housemates, Cecilia, Louise, Alex, Leigh-anne, Cath, Amie and Laura, thanks for all the homemade dinners and constant entertaining distractions. Thanks to the S-Club girls for always 'reaching' with me. Adam, Marc and the rest of the Glasgow crew have immeasurably reduced the thesis struggle and I am grateful for all their hilarious antics and friendship.

Finally, my greatest debt of thanks must be to my family for their unceasing belief and support, even during my occasional return to adolescent tendencies. Stuart and family, Joe, Betty, Jerry and Merry - thank you. My parents have consistently reminded me of the bigger picture and it is only thanks to them I have had the opportunities to follow my passion for psychology. Comparatively, it is a tiny gesture but I dedicate this thesis to them.

# **Selected Abbreviations & Acronyms**

AMT – Advanced Multitasking Test

DLPFC – Dorsolateral Prefrontal Cortex

EB PM – Event-based Prospective Memory

MET – Multiple Errands Test

OMPFC – Orbital/medial Prefrontal Cortex

PAM theory - Preparatory Attentional and Memory Processes Theory

PFC – Prefrontal cortex

PM – Prospective Memory

RIs – Retention Intervals

RM – Retrospective Memory

RSI – Response-stimulus interval

RTs – Reaction Times

SAD – Strategy Application Disorder

SAS – Supervisory Attentional System

SET – Six Elements Test

SIT – Stimulus Independent Thoughts

SOT – Stimulus-Orientated External Cognitions

SRD – Self-Regulatory Disorder

TB PM – Time-based Prospective Memory

WCST – Wisconsin Card Sorting Test

# Chapter 1

## ***The Frontal Lobes, Executive Functions and Internally-Guided Behaviours***

*'Human cognition is forward-looking, proactive rather than reactive. It is driven by goals, plans, aspirations, ambitions, and dreams, all of which pertain to the future and not to the past.'*

Goldberg, 2001, p. 24.

### **1.1. Introduction**

Voluntary, willed behaviours are the keystone to humans' unique abilities. Being able to follow one's own internal goals and intentions, rather than reacting robotically to stimuli, allows for flexible and intelligent behaviour. Behaviours can be viewed as lying on a continuum between being strongly externally controlled (for example, reflexes) and strongly internally controlled or self-initiated (for example, planning how one should spend the day) (Miller & Cohen, 2001; Pashler et al., 2001). This thesis is concerned with the cognitive control of behaviours that are especially internally-driven, in other words behaviours for which there are few (if any) cues in the environment to prompt or guide it and which are directed by internal goals. The basic premise of the thesis is that internally goal-directed behaviours are at the top of our behavioural repertoire; indeed, they are several abstractions away from stimulus-response actions. As such, they require 'top-down' control to coordinate the necessary cognitive operations. The pervasive distinction within cognitive psychology between 'top-down' (internally-generated) and 'bottom-up' (stimulus-driven) or 'controlled' and 'automatic' processes, is an important assumption of much of the research presented. Automatic processing occurs with little or no cognitive control, that is, without volitional control (Posner & Synder, 1975; Schneider & Shiffrin, 1977), whereas 'top-down' processes are effortful and require conscious control (e.g. Shallice & Burgess, 1991; Miller & Cohen, 2001).

'Executive functions' is a term that has arisen as a metaphor for these top-down processes that control and coordinate lower-order cognitive processes in order to achieve internal

goals. Lezak (1995) defines executive functioning as underpinning four key components of behaviour: 1) volition (intentional behaviour) 2) planning 3) purposive action and 4) effective performance. From this description, the importance of executive functioning for everyday life is evident. Measuring and assessing executive functions is thus essential to understanding much of human behaviour (e.g. Phillips, 1997). However, the mechanism(s) by which executive functions operate is a core debate in cognitive psychology and cognitive neuroscience, and some of the various theoretical positions concerning this are discussed below.

Nonetheless, an almost universal principle of executive function research is the association of these cognitive control processes with the frontal lobes. Thus, the successful performance of self-initiated, voluntary behaviours has been specifically related to the functioning of the prefrontal cortex (PFC) of the frontal lobes (e.g. Duncan, 1986; Stuss & Benson, 1986; Shallice, 1988; Passingham, 1993; Shallice & Burgess, 1996; Miller & Cohen, 2001; Stuss & Knight, 2002; Stuss and Levine, 2002; Wood & Rutterford, 2004), defined as Brodmann areas 8-13 and 44-47 (Fuster, 1997). According to another metaphor, these frontal regions act as the 'conductor' of the brain's orchestra (Goldberg, 2001) in that *'rather than themselves performing specific cognitive operations such as memorising, learning or reasoning, [the frontal regions] are instead concerned with the deployment of the capacity to carry out such processes, which take place elsewhere in the brain.'* (Baddeley et al., 1997, p. 61).

The link between cognitive control and the frontal lobes essentially derived from neuropsychological studies of patients with damage to these areas (e.g. Harlow, 1868; Stuss & Benson, 1986; Shallice, 1988). Shallice (1988) argued that the behaviours of patients with damage to the frontal lobes reflect the executive dysfunction stemming from deficits in supervisory control. Indeed, considering patients in whom cognitive control appears to be failing to operate remains an effective means of understanding these executive control processes. Utilisation behaviour is a good example (Lhermitte, 1983; Shallice et al., 1989). Lhermitte (1983) first described five patients with utilisation behaviour after they presented with unilateral and bilateral frontal lobe lesions. These patients feel compelled to 'utilise' an object even when they have no need or intention to do so, and indeed the context may be completely inappropriate. For instance, they might put on a pair of spectacles placed in



front of them despite not requiring glasses or having any instructions to do so. They may even place another pair of spectacles on top of the other if presented with more than one pair (Schott & Rossor, 2003). These are behavioural errors arising from a lack of inhibition of overlearned responses. The lower-level processes to produce the behaviour are intact; instead, there is a weakening of intentional action control by the executive processes. Reason (1984) described similar slips and lapses of action produced by healthy individuals in everyday life. 'Capture errors' such as going upstairs to change and actually getting into bed, or 'substitution errors' such as placing the kettle in the fridge instead of the milk after making tea, are commonly cited examples of executive failure in healthy participants. Action slips such as these occur when the individual is distracted, so that conscious control is otherwise engaged and the environment triggers a routine, automatic response (see also Schwartz et al., 1991). Another feature of frontal damage is repetitive behaviour or 'perseveration' stemming from impairments in initiating switches between tasks (see Joseph, 1999, for review). This inflexibility of behaviour is also due to a disruption of control processes that allow for disengagement from a previous response. Thus, damage to the PFC disrupts the executive control system that allows for internally generated goals, acting according to intentions and the overriding of automatic responses (Duncan, 1986; Shallice, 1988).

The frontal lobes, comprising 25-33% of the human brain, are larger in humans than in any other animal (see Stuss & Knight, 2002). The PFC in non-human primates such as gorillas, for instance, only occupies 10-12% of the cortical area (Fuster, 1989). These properties, combined with their extensive reciprocal connections (Miller & Cohen, 2001; Stuss & Knight, 2002) make them an ideal candidate for accommodating the higher-order, 'human' cognitive functions. Indeed, the neurologist Tilney (1928) believed that the 'age of the frontal lobe' could describe human evolution in its entirety. Current theories of the role of the PFC in executive functioning propose functional and anatomical distinctions between the dorsolateral prefrontal cortex (DLPFC) and the more orbital and medial prefrontal cortex (OMPFC; see Stuss & Knight, 2002; Stuss & Levine, 2002). The DLPFC, encompassing Brodmann areas 9 and 46, has been associated with working memory (Goldman-Rakic, 1987; Fuster, 1997; Smith & Jonides, 1999; Levy & Goldman-Rakic, 2000), planning (Goel & Grafman, 2000), task-switching (Meyer et al., 1998; McDonald et al., 2000) and more broadly with general intelligence or IQ (Duncan, 2000a; Gray et al.,

2003). The OMPFC (also termed ventromedial PFC), which includes in its entirety Brodmann areas 8,9,10,11, 12, 13, 25 and 32, has been implicated in social and emotional higher order functioning (e.g. Damasio et al., 1990; Rolls et al., 1994; Tranel & Damasio, 1994; Grafman et al., 1996; Stone et al.,1998; Anderson et al., 2000; O'Doherty et al., 2001; Stuss & Levine, 2002; Wood & Rutterford, 2004) and self regulatory behaviours (Shallice & Burgess, 1991; Levine et al., 2000; Burgess et al., 2000). Deficient OMPFC processing has been associated with several clinical disorders, including psychopathy and anti-social personality disorder (Blair, 2004), frontotemporal dementia (Lough et al., 2001), addiction (Volkow and Fowler, 2000) autism (Baron-Cohen et al., 1994) and alexithymia (Berthoz et al., 2002).

The accuracy and extent of these functional distinctions is under constant discussion (e.g. Duncan & Owen, 2000; Wager et al., 2004; Collette et al., 2005). Further subdivisions are often considered, for instance, research investigating the contribution of specific areas of the PFC, such as BA 10, to cognitive control has recently expanded (see section 1.3. below). Moreover, the fractionation of the executive processes and their contribution to different types of tasks is of great interest for theoretical and clinical purpose (e.g. Stuss & Levine, 2002; Burgess & Simons, 2005), although separating the cognitive control processes from the processes they control remains a complex methodological issue (see Burgess, 1997; Burgess et al., in press). By investigating two types of tasks that depend heavily on internal guidance for completion, multitasking and prospective memory, the objective of the thesis is to understand more fully the cognitive processes involved in achieving such higher-order behaviours. Multitasking is the self-initiated switching between several subtasks or as defined by the dictionary: '*the ability to perform concurrent tasks or jobs by interleaving*' (see Burgess, 2000, p. 465). Prospective memory (or 'the realisation of delayed intentions', Ellis, 1996), is the ubiquitous task of remembering to do something in the future.

This literature review will therefore cover the following ground, 1) introduce the theories of cognitive control of self-initiated (or volitional) behaviours. This will include a review of the major theories of cognitive control including a discussion of the potential fractionation of these executive processes. 2) A review of the literature concerning tasks that load heavily on self-initiated processes, specifically multitasking, and the neural mediation of

these tasks, and 3) a review of the prospective memory literature, which is the focus of six of the eight experiments presented in this thesis and thus is covered in some depth in a separate Chapter. 4) Finally, I outline the broad aims of this thesis.

## **1.2. Theoretical Models of Cognitive Control**

### **1.2.1. The Supervisory Attentional System**

The idea of ‘top-down’ controlled processing is inherent to the influential and widely accepted theory of cognitive control developed by Norman and Shallice (1986 and also Shallice, 1988; Shallice, 1994; Shallice & Burgess, 1991; 1996; Burgess & Shallice 1997; Burgess et al., 2000; Cooper & Shallice, 2000; Cooper & Shallice, 2002; Shallice, 2002). This theory has argued that the PFC is the neural basis of the Supervisory Attentional System (SAS), a system that modulates lower-level cognitive processes according to both internal goals and environmental demands. Accordingly, the SAS is therefore the cognitive control system responsible for internally-guided behaviours.

This model distinguishes quite clearly between well-rehearsed, or routine, situations and novel, ill-structured situations arguing that they make different demands on the cognitive control system, as such the model is based on a hierarchal organisation of cognitive processing. Very routine behavioural sequences (such as brushing one’s teeth) may only make demands on the basic cognitive ‘actions or units’, requiring little executive control. As behaviours become more complex and flexible, enabling us to deal with novel scenarios, they require more cognitive control. In this sense, the term ‘attention’ within SAS is broad and refers to the allocation of processing resources (Burgess & Robertson, 2002). Behaviour is comprised of many ‘schemata’, or sets of actions that have become associated together through reoccurrence. For example, a set of schema might represent the actions involved in making a cup of tea, such as boiling the kettle and pouring the water. Internal and external triggers can activate these sets of schema, and a mechanism of ‘contention scheduling’ is posited to control them at a lower level. Contention scheduling quickly selects the most appropriate set of schema based on prior knowledge or habit, as well as on the current level of activation of each schema (e.g. when last used or how frequently used). Contention scheduling is effective when the behaviour required is routine

or well determined by the environment. However, the SAS operates (rather than contention scheduling) under the following specified conditions (Norman and Shallice, 1986):

- 1) situations that involve planning/decision-making
- 2) situations that involve error correction or trouble-shooting
- 3) situations in which responses are not well-learned or contain novel sequences of actions
- 4) situations which are dangerous or technically difficult
- 5) situations that require inhibition of a strong prepotent response or temptation

The SAS functions to activate certain actions and thoughts (i.e. schemas) whilst inhibiting others, according to an individual's own internal drives, goals and conscious deliberations, by biasing the contention scheduling mechanism. This system then is concerned with effortful or controlled processing that relate to internal goal-directed behaviour (Shallice & Burgess, 1991). It is not (or at least less) involved with automatic, stimulus-driven processes.

A common example cited for understanding the need for this type of cognitive control system is crossing the road in a country in which the cars drive on the opposite side of the road. As I am from England, I would automatically look right as I approach crossing a road, but if I were visiting the U.S. this automatic behavioural routine would need overriding. The SAS would have access to my internal knowledge and thus would (hopefully!) bias the schema set, such that I inhibited the automatic response, chose the correct response and safely cross the road. There are also classic neuropsychological tasks used to demonstrate the influence of top-down processes on routine behavioural output, the Stroop Task (Stroop, 1935; MacLeod, 1991) and the Wisconsin Card Sorting Task (WCST, Grant & Berg, 1948) are two tasks frequently employed for their association with 'top down' PFC control, these are discussed in detail below.

### **1.2.2. Fractionation of the Executive Control System**

The question then, is how does the SAS operate to produce these top-down influences?

Although originally the SAS was described as a single system, recently researchers have attempted to fractionate the executive processes that the SAS implements (Stuss et al., 1995; Shallice & Burgess, 1996; Cooper & Shallice 2000; Shallice 2002; Stuss et al., 2005). For example, Shallice & Burgess (1996) elucidated the functioning of the SAS further by arguing eight processes are required to produce schema appropriate for novel situations. These eight processes are, working memory, monitoring, rejection of schema, spontaneous schema generation, adoption of processing mode, goal setting, delayed intention marker realisation and episodic memory retrieval. As mentioned, this fractionation of the executive control processes, and indeed the PFC, is a key supposition in the field of cognitive psychology and cognitive neuroscience (e.g. Logan, 1985; Baddeley, 1996; Robbins, 1996; Fletcher & Henson, 2001; Ward et al., 2001; Fuster, 2002; Royall et al., 2002; Faw, 2003; Burgess & Simons, 2005). However, the ‘unity or diversity’ (Miyake et al., 2000) of the executive control system remains a healthy debate since some theorists argue that the executive control system precedes in a unitary manner (e.g. Duncan, 2001; Miller & Cohen, 2001; Grafman, 2002). Assessing these various theories is difficult because of methodological difficulties associated with this field of research, such as the widely acknowledged difficulty of ‘task impurity’ (see Baddeley et al., 1997; Burgess, 1997; Stuss & Alexander, 2000).

Consider the commonly used executive tasks, the Stroop and the WCST. In the Stroop task the participants are presented with a colour-word stimulus and they must name the ink colour the word is written in (Stroop, 1935). For example, the word RED might be written in blue ink. Naming the ink requires the inhibition of the prepotent tendency to read out the colour word. This is therefore a cardinal executive (or SAS) task because the novel non-routine response is selected over the routine, automatic response, as a result of internal goals. There are several reports of frontal patients with deficits on the Stroop tasks (e.g. Perrett, 1974; Vendrell et al., 1995; Stuss et al., 2001). Neuroimaging studies have also demonstrated the role of PFC in performance of the Stroop Task (e.g. Pardo et al., 1990; Bench et al., 1993; Banich et al., 2000). The Stroop effect (the cost of inhibiting the word naming response) is robust and well-documented, but the causal basis is still debated, with researchers arguing it taps various functions, including working memory, inhibition and selective attention (Miller & Cohen, 2001; Royall et al., 2002). Moreover, although it is indicative of frontal pathology, a neuroimaging study has shown that there is non-frontal

involvement (Peterson et al., 1999) such that the authors attributed several processes (e.g. error monitoring, working memory, motor planning) to distributed neuronal networks.

The same is true of the WCST; multiple processes are also assumed to be contributing to performance on this task. Participants must sort cards on the basis of the colour, shape or the number of symbols appearing on them. The rule for the dimension by which the cards must be sorted changes intermittently and the participant must learn and adapt to these changes in sorting dimension through a process of trial and error and examiner feedback. Milner (1963) reported impairments on this task in frontal lobe patients and the test is now widely used and characterised as a pre-eminent measure of executive functioning (Heaton et al., 1993; Royall et al., 2002). Frontal patients often perseverate on a particular rule, showing a lack of flexibility in their processing. Concept generation, sustained attention, working memory, set shifting and response inhibition are all likely candidates for successful performance of this task. Unsurprisingly therefore, the task is also associated with a variety of frontal regions, including the DLPFC (e.g. Berman et al., 1995) and anterior PFC (e.g. Marenco et al., 1993). Moreover, damage to posterior regions of the brain can also lead to impairment on the WCST (Anderson et al., 1991).

Thus, the Stroop and the WCST demonstrate well the difficulties in assessing executive control and the localization of this control system, or systems (see also Reitan & Wolfson, 1994; Baddeley et al., 1997). Firstly, that it is difficult to find a 'pure' measure of executive functioning (Baddeley et al., 1997; Burgess, 1997). Executive tests necessarily entail the recruitment of other (lower-level) cognitive processes such as language or memory, and thus performance may be affected by disruption to processes unrelated to executive or frontal function, for example comprehension (Stuss et al., 1995; Stuss & Alexander, 2000). The point here is that it is difficult to dissociate the executive processes from the lower level cognitive processes they putatively control (Stuss & Alexander, 2000). Secondly, as part of the same issue, executive tasks are frequently complex, engendering it difficult to separate failure from task difficulty from failure from executive dysfunction. There is evidence that as complexity increases so does recruitment of frontal regions (Stuss & Levine, 2002). It has been therefore difficult to find one 'gold standard' measure of executive functioning (see Royall et al., 2002) because of these difficulties in dissociating the control processes. This might be better demonstrated with a further example from the



WCST literature. Schizophrenic patients have shown impairments on this task but show great improvement if they are cued during the procedure (Goldman et al., 1992). The patients thus are able to produce the concepts required to complete the task, but do not apply these unless cued. Can concept generation therefore be considered an executive function when it seems to be the application of the concepts that is impaired? The question is really striking at the heart of the difficulty with multiple process theories; there is no real agreed taxonomy of executive processes, making it easy for researchers to continue to append new processes as required to explain their empirical evidence (Burgess & Simons 2005; see Uttal, 2001 for a more general discussion on this point).

Before discussing the benefits of multiple process (i.e. fractionation) theories, I will first consider a unitary account of cognitive control. Several unitary theories exist (e.g. Duncan, 2001; Grafman, 2002), but as I have discussed the Stroop Task I will consider an account that has explicitly modelled the function of the PFC in this test. Miller & Cohen (2001) argue that performance on the WCST may be tapping a variety of processes, but these are all essentially dependent on the overall function of the PFC, which is *'the active maintenance of patterns of activity that represent goals and the means to achieve them* (p. 171). The role of PFC is to modulate or bias other sensory modalities in order to direct *'the flow of neural activity along pathways that establish the proper mappings between inputs, internal states, and outputs needed to perform a given task'* (p. 171). In situations of ambiguity and multiple response options, this function becomes particularly crucial. This is achieved by the PFC representing context information (Braver et al., 2002; see also Cohen et al., 1996), which is any task relevant information stored internally such that it can produce biasing to the necessary neural pathways that are performing the task. This context information is maintained online (and in this way is a subset of working memory) and always available to influence processing by resolving competition between local networks (by supporting one activation pathway (e.g. one schema) over another) (Braver et al., 2002). The system works then under the assumption that the processing in the brain is essentially competitive and they argue that it subsumes other putative control processes, such as inhibition. From this description, it seems Cohen and his colleagues are advocating the PFC as both the seat of the SAS and the contention scheduling mechanism (at odds with the original SAS theory, which maintains these as qualitatively different mechanisms). They convincingly argue that the PFC has many of the properties necessary for such an

illustrious position, for example diverse and abundant connections to other areas, the plasticity to maintain many learned associations (or rules), the feedback mechanisms to other neural areas and the capacity to maintain representations over time. Moreover, they provide evidence for this action of the PFC from computational modelling of the Stroop Task (e.g. Cohen et al., 1990), as mentioned earlier, and for the example of crossing the road in a foreign country (see Miller & Cohen, 2001 for schematic diagram).

Another significant unitary account of PFC is the adaptive coding model of Duncan (2001) who argues that neurons within the PFC have the ability to code many kinds of information. These neurons are able to adapt themselves to the current task context, acting as a 'global workspace' and producing a wide range of functions. Evidence for this position stems from neuroimaging studies that show similar patterns of PFC activation despite different cognitive demands (Duncan & Owen, 2000). In addition, electrophysiological studies have demonstrated this apparent neural adaptation of PFC neurons as task boundaries change (e.g. Freedman et al., 2001). This alternative conception of PFC function is considered in more depth in Chapter 5, but for now the discussion of these unitary accounts brings a number of issues pertaining to the study of cognitive control into focus. Perhaps the most striking difficulty for these accounts is the lack of explanatory power to account for all the data on executive function, particularly the wide range of neuropsychological data. For example, there is little discussion of how the PFC is functionally organised in the theory put forward by Cohen and colleagues (although see Miller & Cohen, 2001 for discussion), and indeed they note it as a shortcoming. Several possibilities are posited in the literature, including regional functional specialisation (as described above), modality of information (e.g. Smith & Jonides, 1999) and a hierarchal organisation according to the degree of abstraction (e.g. Passingham, 1993 and see section 1.3 below). Braver et al. (2002) discuss evidence that seems to suggest that this context representation mechanism could have a neural basis in DLPFC, (see also Kane & Engle, 2002), rather than constitute the function of the entire PFC. Clearly, this issue can only be resolved with further neuroimaging research.

Anderson et al., (2002) argue that developmental studies are consistent with multiple process theories, rather than unitary accounts, because executive functions possess *'different developmental trajectories and possibly maturing at different rates. These*

*varying patterns may reflect mediation by specific areas within the frontal lobes, which also mature at different rates'* (p. 509). Levin et al., (1991) for example, administered a battery of executive tests with children of various age ranges and identified three executive factors with individual developmental patterns, concept formation, problem-solving and impulse control (see also Welsh et al., 1991; Anderson, 1998). Methodological difficulties apply with these developmental studies however, primarily the problem of divorcing the development of the lower-order cognitive processes in children from the higher-order executive skills. Moreover, it is not to say that a single system theory could not eventually account for this evidence, but that current positions are underspecified with regards to these data.

Burgess & Robertson (2002) and Burgess & Simons (2005) outline other empirical data that unitary accounts are often unable to account for. Firstly, correlations between executive tasks are often reported as low, rather than high, as would be expected from a unitary account (e.g. Robbins, 1996; Miyake et al., 2000). This supports multiple processes tapped by different tests, with no overarching executive process. Royall et al., (2002) conducted a metaanalysis of executive control studies containing factor analyses, and concluded that four factors presented most commonly: rule discovery (e.g. in WCST), working memory (e.g. Digit Span), attentional control (e.g. Digit Cancellation) and response inhibition (e.g. Stroop). This is broadly consistent with Miyake and colleagues' (2000) assertion that the three executive processes asserted the most reliably by diverse researchers are: shifting of mental sets, monitoring and updating of working memory and inhibition of prepotent responses. The study by Miyake et al. also demonstrated that these control processes appear separable. They conducted a factor analysis of executive measures and found mildly correlated but discriminable factors that each contributed differently to three executive tests (WCST, Tower of Hanoi and Random Number Generation). This evidence fits with multiple process theories; although the outcomes of these studies do not necessarily encompass all the executive processes that exist (e.g. Burgess & Shallice, 1996; Burgess et al., 2000).

Secondly, the neuropsychological evidence speaks against the unitary accounts on many fronts. In a study with a group of mixed aetiology neurological patients Burgess et al. (1998) found that their symptoms of dysexecutive syndrome were inclined to cluster, rather

than load onto a single factor. Moreover, these clusters of symptoms were associated with impaired performance on specific, and different, executive tasks (this study is described in more detail below). Burgess & Simons (2005) also provide examples in which the same executive tests were used with a group of frontal lobe patients and a diverse collection of errors were committed (Burgess & Shallice, 1996; Stuss et al., 2000). Indeed, Burgess & Shallice (1996) demonstrated a double dissociation between errors associated with response suppression and those associated with initiation in one frontal patient. Neuropsychological double dissociations are strong forms of evidence for process separation and localisation (Shallice, 1988), providing a robust case for executive fractionation. Patients with very specific executive deficits are also reported in other case studies (e.g. Shallice & Burgess, 1991; Burgess & McNeil, 1999), including patients with multitasking deficits, as I will now describe.

#### *1.2.2.1. Neuropsychological Studies Using Ill-structured Tasks*

Of major theoretical and clinical interest are the patients that demonstrate many everyday difficulties and yet show intact performance on several executive and clinical tests, including IQ, memory and language tests (e.g. Eslinger & Damasio, 1985; Mesulam 1986; Shallice & Burgess, 1991; Goldstein et al., 1993; Von Cramon & Von Cramon, 1994; Duncan et al., 1995; Goel & Grafman, 1997; Levine et al., 1998). For instance, Eslinger & Damasio's (1985) famous patient, EVR, was a high functioning accountant with an IQ of over 130 despite the removal of an orbitofrontal meningioma six years prior to testing. He also performed within normal limits on a battery of neuropsychological tests. In everyday life, however, EVR behaved erratically and exhibited difficulties in organising and planning. He would take hours deciding on a restaurant for example, and more worryingly became bankrupt as well as suffered two divorces in 2 years. Shallice & Burgess (1991) described three case studies of patients with similar intact neuropsychological performance (including high IQ), but who also exhibited poor organisational capabilities in everyday life, with two of the three patients losing their jobs because of *'tardiness and disorganisation'* (Burgess et al., 2000, p. 280). A patient described by Goldstein and colleagues (1993) showed no impairments on four memory tasks and a deficit on only one out of nine executive tasks (Proverb Interpretation), and yet manifest decision-making deficits *'culminating in his taking 2 weeks to decide which slides to use for a work*

*presentation; the decision was never reached'* (p. 274). In these cases the cognitive profile the patients display are not indicative of their psychosocial outcomes.

Shallice and Burgess (1991) identified a potential reason for this dissociation between executive function test scores and real life behaviours. They have argued that in many of the tests utilised to measure executive functioning, clinically and experimentally, there are still many external cues present in the test framework, moreover, there is often only one correct answer (e.g. in the Stroop task, participants must still attend to the external stimulus to name the correct ink colour). The examiner themselves or the test structure may therefore 'become the frontal lobes' of the participant (Stuss & Alexander, 2000). In this way, the tests fail to evaluate frontal patients' key deficits, to initiate and organise behaviours from internal cues and goals, and similarly partly fail to measure these processes in cognitive studies with healthy participants. As discussed, this is the fundamental role of the executive system and is essential in everyday life, in which tasks are often open-ended and driven by internal goals. Consequently, in order to improve the ecological validity of the neuropsychological tests, Shallice & Burgess (1991) designed laboratory-based multiple subgoal tests or multitasking tests that increased demands on participants' self-organisation capabilities by being ill-structured. Reitman (1964) first discussed the qualities of tasks that are ill-structured, arguing they have poorly specified start states, goal states and transformation functions (the latter explains how to achieve the goal states; see Goel & Grafman, (2000) for further discussion on qualities of ill-structured tasks). Accordingly, in multitasking tests participants must initiate their own plans and strategies and carry out their intentions with little external guidance. As well as being ecologically valid, we can perhaps also be more certain of measuring executive control functions rather than the lower-level processes using these tests. Testing brain-injured patients on these ill-structured and multiple subgoal tasks has thus become a fruitful area of executive function research (e.g. Bechara et al., 1994; Whyte et al., (1996); Crepeau et al., 1997; Robertson et al., 1997; Bisiacchi et al., 1998; Schwartz et al., (1998; 1999); Burgess et al., 1998; 2000; Levine et al., 1998; 2000; Goel & Grafman., 2000; Spikman et al., 2000; Manly et al., 2002; Law et al., 2004). Assessment of these types of behaviour prior to these new types of tests focussed on observational or interview data (e.g. of social awareness) and on the separate elements, such as planning (e.g. Tower of London test) and flexibility (e.g. Alternate Uses Test) (Lezak, 1995). These ill-structured tests load highly on planning,

prospective memory, self-initiated task-switching and decision-making and thus quantified what are arguably the most internally-guided behaviours, and as such, the most real life. Indeed, I took this approach in this thesis, assuming that executive control functions are best assessed in tasks that have little environmental support, that is in which responses must be almost entirely self-initiated (see Arrington & Logan, 2004, 2005) for a similar argument with regards to task-switching).

Strategy Application Disorder (SAD; Shallice & Burgess, 1991; Burgess et al., 2000) and Self Regulatory Disorder (SRD; Levine et al., 1998, 1999) are ‘frontal lobe’ syndromes associated with these patterns of performance. That is, they show the specific executive self-regulation (i.e. internally guided behaviour) deficits on ill-structured tests but perform at normal levels on many other neuropsychological tasks. The studies suggest the patients suffer from specific impairments to a cognitive control system that coordinates these highly self-initiated behaviours (rather than other executive tests) and in this way are consistent with multiple process theories (Burgess et al., 2000; Burgess & Simons, 2005). Is there evidence for a set of dissociable processes, and neural areas, that mediate strongly internally-generated behaviours? The next section will discuss relevant neuropsychological and experimental evidence detailing the studies with multitasking (and ill-structured tasks) so far discussed, as well as neuroimaging evidence, to assess this question.

### **1.3. Rostral PFC and Internally-guided Behaviours**

*‘An individual must have the flexibility to adopt different perspectives on the same situations at different times. The organism must be able to disambiguate the same situation in multiple ways and have the capacity to switch between them at will. Dealing with inherent ambiguity is among the foremost functions of the frontal lobes.’*

Goldberg, 2001. p. 79

#### **1.3.1. Self-Regulation and Multitasking**

##### *1.3.1.1. Cognitive and Neuroanatomical Bases*

At the beginning of this review, I briefly discussed neuropsychological patients who seemed to show over-responsivity to stimuli in the environment, such as utilisation behaviour. This is quite an extreme example of disordered behaviour in which patients have



damage to various areas of the frontal lobes (Lhermitte, 1983; Eslinger, 2002) and environmental stimuli dominate behaviour. SAD and SRD patients are not necessarily dominated by environmental stimuli but they do show a pattern of behaviour in which they show '*an inability to regulate behaviour according to internal goals*' (Levine et al., 2002, p. 451). In other words, they exhibit marked impairments at the most 'top down' end of the continuum. As discussed, this becomes most apparent in ill-structured situations in which there are many and different ways to approach a task and participants must decide for themselves how they allocate their efforts (Shallice & Burgess, 1991; Stuss & Levine, 2002; Alderman et al., 2003; Knight et al., 2003). Daily time and task management in the workplace, everyday tasks such as preparing a meal and most social scenarios are common situations fitting this bill.

Shallice & Burgess (1991) introduced the Six Elements test (SET) and the Multiple Errands test (MET) to assess these patients. In the SET participants must earn as many points as possible by completing items from six subtasks (e.g. naming pictures, recounting a journey into a cassette recorder, basic arithmetic). Participants are told certain order rules about which subtasks they can attempt consecutively and which items are worth more points (instructions and rules are available throughout the test). They are then given fifteen minutes to complete the task without any further instructions or constraints, ensuring participants must use their own strategies and organisational skills. Similarly, the MET is a self-organising ecologically valid test in which participants follow a set of instructions and rules (again available throughout the test) in order to complete a series of 'errands' in a real life shopping area. Participants are given money and a series of instructions to buy various items (e.g. buy bread), find out certain information (e.g. a shop closing time) and a place to be at a certain time (e.g. by the exit after 20 minutes), as well as certain rules (e.g. do not go into a shop except to buy something). The order in which they complete these errands, how long they spend on each, and where and how they complete them is left to the participant to decide.

Shallice & Burgess reported a variety of errors committed by their frontal patients on these multitasking tests that resembled their poor planning and organisation in everyday life. Errors included rule breaks, such as going into irrelevant shops, social rule breaks, such as trying to leave without paying for items, leaving tasks unfinished, and failing to carry out

prospective memory items. These errors could not be attributed to motivation, memory (or rule understanding) difficulties or other cognitive deficits. Indeed, the subtasks themselves are very simple in comparison to the other tasks patients accomplished (e.g. the Wechsler Adult Intelligence Scale; Wechsler, 1955). Instead, difficulties were attributed to defective processes of the SAS, specifically inaccurate plan formation or modification, faulty marker creation or triggering and/or poor evaluation and goal articulation. The study thus demonstrated the usefulness of these tests in capturing patients' difficulties. Planning and the realisation of delayed intentions are highly implicated in these tests, but this study was unable to localise these functions to brain areas or be more specific about which processes were impaired in their patients.

To rectify this, Burgess et al., (2000) carried out a study, involving 60 head-injured patients and matched controls, which utilised a variety of scores on a new multitasking test to investigate the cognitive and neuroanatomical components of multitasking. Burgess et al., (2000) identified several key features of multitasking situations in the development of this new test, entitled the Greenwich test. These are as follows, as described in Burgess et al., (2000, p. 281):

- 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 physical or cognitive constraints, only one task can be performed at any one times.
- 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 (prospective memory).
- 6) Differing task characteristics: Tasks 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.

Much like the SET, the Greenwich test comprises of three open-ended, simple subtasks with specific rules on maximising points (e.g. separating beads by colour, constructing a simple object from Meccano parts). The participants must coordinate and organise their own subtask performance, with the only constraint that they must attempt part of all three subtasks at some point during the whole test. The subtasks themselves also have specific rules for completion, giving this test a larger number of rules but fewer task switches. Participants were scored on several elements of the test, including how successfully they learnt the rules, how efficiently they planned their strategy before beginning, how successfully they followed their plan, and overall task performance. They found that patients with specific lesions showed deficits on measures of the Greenwich Test compared to a control group, despite being well matched on IQ measures. Using a statistical modelling technique with the dependent measures from the Greenwich Test, Burgess and colleagues identified three constructs, and thus posited three specific cognitive systems that interact to support multitasking – retrospective memory, prospective memory and planning, with the last two processes drawing on the first. The prospective memory or intentionality construct was identified as the most associated with overall performance on the task.

Burgess and associates also proposed that different neural bases might mediate these three cognitive constructs. Patients with damage to the medial PFC (BA 10) showed particularly poor overall task performance and poor plan following (i.e. impaired prospective memory). Patients with damage to DLPFC showed poor planning, and damage to posterior cingulate/forceps major resulted in retrospective memory deficits. Burgess et al., (2000) describe some caveats to the results, including difficulties in precise lesion localisation (subcortical areas could not be assessed) and note that a two construct model also fitted the data, albeit not as well. Despite this, Burgess et al. note that the results do have consistency with previous research into the function of these neural areas. For instance, retrospective memory has been associated with anterior and posterior cingulates (e.g. Mattioli et al., 1996; Nyberg et al., 1996). Similarly, the link between DLPFC and planning is relatively well established (Goel et al., 1997; Goel & Grafman, 2000, although see Burgess et al.,

(2005) for a discussion regarding planning processes). Finally, the implication of prospective memory residing in rostral PFC is also consistent with other studies of the neural basis of prospective memory (e.g. Yamadori et al., 1997; Okuda et al., 1998; Burgess et al., 2001). This issue shall be discussed further in the section 2.7.3 below.

There is further support for the role of the ventromedial or rostral PFC in these types of multitasking tests. Levine et al. (1998; 1999; 2000) tested various groups of participants on modified versions of the SET and Greenwich test. Levine et al., (1998) developed a Strategy Application Test (SAT) that requires participants to develop their own strategic approach to the task to maximise their score and administered this test, along with other neuropsychological tasks, to various participant groups (focal frontal patients, TBI and normal aging plus young control group). As in the Greenwich Test, three subtasks (split into part A and B) that were well within the capabilities of the groups tested were employed (picture naming, arithmetic, figure-copying). All other rules were similar to the SET (e.g. cannot complete part A and B of the same subtask consecutively, some items are worth more points, identified by a box around them). An efficiency score was devised from the SAT that reflected the number of high payoff subtask items completed as a proportion of the total number of items completed. A high score was thus linked to successful executive control; the SAS was assumed to have inhibited the prepotent response to complete all subtask items in spatial order so that items worth more points could be completed first. A low strategic score was *'assumed to reflect unmodulated contention scheduling'* p. 253). Low strategic scorers possessed an inability to hold a mental representation of the self online and to use this self-related information to inhibit inappropriate responses. Every participant with a focal medial PFC lesion (Brodmann areas 10,11,12,25 and 32) obtained impaired efficiency scores on the SAT, despite some having intact performance on other executive and neuropsychological tasks (including the WCST and the Stroop). The latter tasks were argued to tap essentially the DLPFC and thus provide evidence for fractionation of the PFC (Levine et al., 2002). Some patients with damage to other areas of the PFC also presented with non-strategic performance, and some non-strategic performers also showed deficits on other executive tests. Levine and colleagues thus described two subgroups of SRD patients, those with standalone strategic deficits and those with general diminished executive abilities. Thus, the presence of a SAD standalone group in the Levine et al.,

(1998) study provides support for the suggestion that multitasking processes are relatively circumscribed (Burgess et al., 2000).

Further evidence for this suggestion stems from a study showing low correlations between head injured patients' scores on other executive tests (e.g. Verbal Fluency) and the SET (Duncan et al., 1997). In addition, Burgess et al. (1998) conducted a study that correlated patient carers or family members' ratings of the patient on the Dysexecutive Syndrome questionnaire (DEX; Burgess et al., 1996) with the patients' performance on the SET. The DEX assesses common symptoms associated with frontal lesions, such as perseveration, organisation difficulties and social inappropriateness. Interestingly, only the patients' performance on the SET was significantly correlated with 'intentionality', a factor from the DEX analysis relating to everyday problems with organisation and planning (including prospective memory). No other measures employed (including executive and intelligence measures) correlated with this factor.

The weight of the evidence then, seems to lie in favour of dissociating executive processes involved in highly endogenously controlled tasks, and those involved in more externally-cued tasks. However, a few caveats should be mentioned here. Firstly, there remains a possibility that impairments on other executive or cognitive tests may have emerged with these SAD/SRD patients, but the appropriate tests were simply not included in the battery. For example, Worthington (1999) reports a patient, JW, who showed typical SAD characteristics but also impaired autobiographical memory, an extra test they included in the battery. Thus, Worthington argued these patients should not be cast as showing specific prospective memory deficits, but instead as 'dysexecutive paramnesics', that is a disorder of *'the executive control of instantiation or utilization of contextual material necessary for eventual retrieval of target information'* (p.54). In other words, they suffer a general deficit in using self-initiated strategies for retrieval, which are also required for autobiographical recall.

Secondly, although these ill-structured tasks may be more sensitive to deficits in internally-generated behaviours, and thus executive functions, than other tests, a difficulty still holds. The tasks are still complex and multicomponential and interpretation of the processes involved and thus impaired, is varied. Levine et al., (1998) discuss sustained attention,

inhibition of prepotent responses, maintenance and execution of intentions (i.e. prospective memory processes) and flexibility as processes contributing to strategy application, compared to planning, retrospective memory and prospective memory proposed by Burgess and colleagues. Indeed, Levine et al., (1999) also describe the role of inhibition and episodic memory impairments in a single case study with SRD. Another follow-up study by Levine and colleagues (2000) documented the usefulness of a revised version of the SAT test for its sensitivity to traumatic brain injury and ventral (rostral) PFC lesions. However, the authors argued the R-SAT also required '*inhibition or reversal of the response pattern reinforced at the beginning of the test*' (Stuss & Levine, 2002, p. 419). Reversal learning is a process also associated with ventromedial areas of the PFC (e.g. Dias et al., 1996; Freedman et al., 1998).

It is likely that all of these processes contribute to successful performance on these tasks but the difference in emphasis may arise partly from the different dependent measures that are analysed. In Levine et al., (1998; 1999; 2000) the principal measures were the strategy scores, compared to Burgess et al., who examined performance on a variety of measures including planning and plan-following. This is an argument for either simplifying the tasks (but risk reducing their sensitivity) or including a variety of scores. Another means to approach this issue is to attempt to control one demand of the task (e.g. the planning or task-switching demands) and monitor the effects on the other test elements, an approach I discuss further and utilise in Chapter 5. An overarching commonality between these studies however, is the implication of prospective memory processes in these tests, and more generally a role for rostral PFC in internally-guided tasks.

These multitasking tests do comprise the need to delay internally-guided intentions (e.g. remember to switch sub-tasks in 2 minutes time). Some of the SAD patients' key failures on multitasking tests are interpreted as failures of this 'intent' or prospective memory component (Burgess et al., 2000). The key idea being that the patients have difficulties implementing the executive aspects of the prospective memory requirements (e.g. self-initiated retrieval). This deficit in prospective remembering is also reflected in the everyday behaviour of the SAD patients, who miss appointments and fail to follow their plans (Burgess et al., 2000). Researching the cognitive processes involved in prospective memory is thus a tractable means of understanding the control of a highly self-initiated behaviour

(Craig, 1986). Moreover, prospective memory is associated with the functioning of BA 10 of the rostral PFC (Yamadori et al., 1997; Okuda et al., 1998; Burgess et al., 2000, 2001), rather than DLPFC, this suggests a possible dissociation of function based, at least partly, on the endogenous/exogenous continuum (see e.g. Dreher et al., 2002 for a similar suggestion and Lauwereyns (1998) for similar suggestion in visual attention). Before turning to a review of the cognitive processes involved in prospective memory, I will briefly review the theories of rostral PFC function in order to evaluate the validity of this claim.

### **1.3.2. Functions of Rostral PFC**

The major organisational system of the primate cortex is hierarchal (Passingham, 1993; Ramnani & Owen, 2004), with primary cortical areas as the basis of this system and information moving through processing pathways from these areas until it reaches the prefrontal cortex. The hierarchy is associated with increasing levels of abstraction, with the PFC processing information at its most abstract level (Passingham, 1993). The motor and visual systems both share this common organising feature, and comparatively to the cognitive control system, are well elucidated. Consider the motor system, information can feedback from the prefrontal cortex to the primary cortex areas, via a pathway of intermediate premotor areas. This mechanism is acting to feed information about abstract rewards from the PFC to generate a series of motor plans in the premotor system, these are turned into concrete motor actions in the primary motor cortex (Passingham, 1993). Moreover, the literature clarifies a further organisational principle. There appears to be some dissociation between the neural areas that process predominantly endogenously selected motor sequences and those that are involved in predominantly stimulus-driven movement sequences (e.g. Dieber et al., 1991; Chen et al., 1995; Thaler et al., 1995; Gerloff et al., 1998; Dieber et al., 1999). This organising principle is assumed to be replicated across the brain, including within the PFC (Christoff & Gabrieli, 2000; Koechlin et al., 2000; Pollmann 2004) and more specifically within the anterior part of the PFC (BA 10), an area particularly associated with control of internally-generated behaviours (Koechlin et al., 2000; Christoff & Gabrieli, 2000; Gusnard et al., 2001; Johnson et al., 2002; Christoff et al., 2003; Frith & Frith 2003; Pollmann, 2004). This organisational system then is consistent with a possible endogenous/exogenous dissociation of function,

and with the proposed function of the frontopolar (rostral) PFC. For instance, Christoff & Gabrieli (2000) state: *'dorsolateral cortex may be sufficient for the evaluation or manipulation of externally generated information, whereas frontopolar cortex is additionally required when evaluation and manipulation of internally generated information needs to be performed'* (p. 183).

Several researchers have proposed models of the function of rostral PFC in an attempt to account for the vast quantity of neuroimaging data that has accumulated regarding this brain region (for a review see Burgess et al., 2005). The difficulty appears to be the ubiquitous activation in this area during neuroimaging studies (e.g. see Ramnani & Owen 2004), thus making any single process account of its function limited. As such, the models have tended to propose broad functional accounts. As described, Christoff & Gabrieli (2000) ascribe the role of this area as crucial to the processing of self-generated information. This proposition is based on studies showing activation in rostral PFC in which task demands are very low (such as baseline or rest conditions), consequently the activation may be occurring because of 'stimulus-independent thoughts' (SIT), that is mental activity related to internally represented information (e.g. Gilbert et al., 2005). This is certainly consistent with the hierarchal organising principle described above, and fits with the lesion data from the ill-structured tasks. It is also consistent with the role of this area in prospective memory, in which the maintenance of the intentions could be described as SIT (e.g. Burgess et al., 2001).

At odds with their theory are imaging studies with episodic memory tasks that also reveal rostral PFC activation (Rugg et al., 1999). Several explanations have been offered for these data. For instance, one theory posits rostral PFC as responsible for the 'retrieval mode' (Tulving, 1983; Lepage et al., 2000). Fletcher and Henson (2001) describe this region as involved in 'metaprocesses' that coordinate optimal switching between working memory maintenance (DLPFC) and working memory manipulation (ventrolateral PFC). Burgess et al., (2005) however, criticise these theories as unable to account for all the activation data (e.g. motor learning). Christoff & Gabrieli (2000) analysed the role of rostral PFC within these episodic memory studies and reinterpreted the activation as ensuing from retrieval tasks in which there were fewer external constraints (e.g. recall vs recognition tasks). Damage to the frontal lobes certainly impedes performance on episodic tasks, especially



those that place high demands on internally-generated retrieval strategies (see Nolde et al., 1998; Simon & Spiers, 2003). Nevertheless, as Ramnani and Owen (2004) point out, these lesion studies have failed to localise the damage to the PFC – so impaired control processes arising from DLPFC may well play a part. Several of the imaging studies of self-generated episodic retrieval also found activation in DLPFC (Moscovitch & Winocur, 2002; Ramnani & Owen, 2004). Overall, Christoff and Gabrieli's theory suffers from underspecification at the functional level (how does BA10 evaluate internal information?). Moreover, as Ramnani and Owen (2004) perceptively note, it seems a difficult concept to falsify.

Nonetheless, the neuropsychological evidence remains that rostral PFC has a particular role in internally-guided behaviours. Other theories signify this, for example a role for rostral PFC is implicated in self-referential processes (Gusnard et al., 2001), the 'default mode' of brain function (Raichle et al., 2001) and theory of mind (Frith & Frith, 2003). To some extent though, these theories suffer from the same limitations as those mentioned above and are unable to account for some of the neuropsychological data, for instance theory of mind processes are not required for multitasking, although it is possible there is even finer fractionation of function (Gilbert et al., in press).

Burgess et al., (2005; see also Gilbert et al., 2005) used this neuropsychological data as a starting point for a new functional theory of BA10. Their hypothesis describes the rostral PFC as a gateway that acts as an attentional bias between stimulus-independent thoughts (SIT) and stimulus-orientated external cognitions (SOT) (Burgess et al., 2005; Gilbert et al., 2005; Burgess et al., in press). The region is further functionally divided with the proposal that lateral rostral PFC modulates attention towards internal thoughts and goals, including switches between internally- and externally-guided behaviours, whereas medial rostral PFC plays a role in the orientation of attention towards SOT cognitions (Burgess et al., 2005). The authors argue that the rostral PFC is acting as a 'router' for SIT and SOT information pathways, rather than being directly involved in the processing of the information. In this way, it resembles the SAS as well as the unitary cognitive control system devised by Miller & Cohen (2001) and described above. Perhaps this account and Cohen's are complementary; Faw (2003) for example, argues that the DLPFC is involved in decision-making in which there is a clear-cut answer, whereas more anterior regions are recruited during open-ended decisions for which there is no clear-cut answer and requires more

internal guidance. Certainly, Miller & Cohen (2001) accept that their proposed theory as it currently stands cannot easily incorporate planning and prospective memory processes.

Burgess et al., (2005) took the lesion data as the constraints on their theorising, but also secured evidence for their hypothesis from imaging data. Gilbert et al. (2005) describe a study that compared activation as participants performed three simple tasks (e.g. classifying letters of the alphabet as containing curved or straight lines). The key comparison was between participants performing these tasks using visual stimuli on the screen and conducting the same task 'in their head', that is by imagining the stimuli themselves. Differences in activation were analysed whilst participants carried out each task in each condition, and at the point of the switch. Medial rostral PFC was active whilst the participants performed all three tasks using the external information (which of course also required some internal information e.g. recalling task rules). Conversely, lateral rostral PFC demonstrated higher activation during switches between the two modes of performing the task. This provided evidence for the basic premise that rostral PFC is involved in mediating attention between SOT and SIT, in addition it speaks to the proposed medial/lateral dissociation. A follow-up imaging study (Burgess et al., in prep) manipulated the internal/external requirements of the tasks in four different conditions by changing task instructions (see Burgess et al., 2005). The authors report results that accord well with the Gateway hypothesis: medial rostral PFC was more active during the baseline condition in which basic attention to external stimuli is all that was required compared to when the same task also required SIT. Moreover, lateral rostral PFC showed higher activation during the condition that required increasing SIT. This hypothesis can also account well for the prospective memory imaging data, which also alludes to the involvement of this brain region (Okuda et al., 1998; Burgess et al., 2001). I will discuss this data further in Chapter 3, but that prospective memory requires modulation of attention between external stimuli or the current task, and internally represented intentions seems immediately apparent. Additionally, it is unsurprising that patients with damage to this area would show deficits in ill-structured tasks that require both SIT, SOT and switching between them (e.g. which task should I do next? And then engage with that task) if this area is acting as an attentional modulator between SIT and SOT. Nevertheless, it still difficult to understand why these patients might be able to produce normal performance on the Stroop or the WCST, as has been demonstrated, given they too require SIT and switches between them. Perhaps it is the

degree of reliance on SIT that is crucial. In this way, the neural mediation may reflect the continuum discussed by Pashler (2001, see above), thus perhaps only behaviours at the far end of the spectrum are dissociable. Certainly, the Gateway hypothesis has the potential to explain these cases after further research has elucidated the precise mechanisms.

Any evaluation of these theories must acknowledge the dependency on neuropsychological and neuroimaging studies for their evidence. These types of evidence are without doubt useful and have produced a wealth of data regarding structure-function relationships, but they naturally have their limitations (see for e.g. Willingham & Dunn, 2003 for discussion). Differences in lesion sizes and exact locations within patients of neuropsychological studies are of course a key limitation in attempting to dissociate cognitive processes (Fletcher & Henson, 2001; Humphreys and Price, 2001; Uttal, 2001). Whereas neuroimaging studies make assumptions about changes in task demands from one condition to another, presuming that the cognitive process being manipulated by the experimenter is the only change in processing demands across conditions (the 'pure insertion' difficulty as described by Friston et al., 1996). This latter point seems particularly relevant in a field of study comparing SIT and SOT in which there may be a whole host of differences in cognitive processing between conditions (e.g. perceptual processing). Behavioural studies therefore have some advantages in testing the dissociation between strongly internally-guided and externally-cued behaviours as posited by several of these theories, and this methodology is used in this thesis. I will now turn to a review of the experiments concerning prospective memory, a higher order skill requiring a good deal of internal guidance.

## Chapter 2

### ***A Review of Prospective Memory Research***

*'Every intention is essentially connected with making decisions, and is therefore a necessary component of volitional behaviour. Thus, intention should be studied in the context of volitional behaviour.'*

Kvavilashvili, 1992, p. 508.

#### **2.1. Summary**

I have discussed the role of prospective memory (PM) in the multitasking tests of Burgess and colleagues. Patients with rostral PFC damage seemed to show select deficits in the intentionality components of these tests and yet demonstrate intact performance on other executive and retrospective memory (RM) tests. Theories of rostral PFC function associate this area with cognitive control of internally-generated behaviours, including PM. Thus, PM is a useful tool for investigating cognitive control of these types of behaviours, possibly tapping a different cognitive control system, and neural area, to those tasks providing a good deal of external structure. The following review will explore this issue and focus on the cognitive components of PM, as well as discuss evidence for the neural basis of PM.

#### **2.2. Introduction to Prospective Memory**

As described, PM refers to *'the process and skills required to support the fulfilment of an intention to perform a specific action in the future'* (Ellis & Kvavilashvili, 2000, p. S1). It is a skill used frequently in everyday life, so much so that studies have suggested 50-80% of everyday memory problems are associated with PM difficulties (see Kliegel & Martin, 2003). Examples of everyday PM tasks include remembering to give colleagues a message, remembering to post a letter on passing a postbox or remembering to attend a meeting at 5pm. From these examples it is easy to understand how this memory differs from RM, in which an individual recalls an event or action from their past. In other words, PM is memory for the future. The reason why this type of task acquires the term 'memory' is because a delay ensues between creating the intention (e.g. to pass on a message) and

executing that intention (e.g. colleague does not return from lunch for another hour). As a result, there are several similarities between PM and RM in terms of the cognitive stages involved, for instance there is both the encoding and retrieval of intentions, terminologies that match the RM field (see Burgess & Shallice, 1997). The key functional difference, however, is that the cues for carrying out the delayed intention are often embedded in other ongoing tasks, or one is engaged in an ongoing task whilst maintaining the delayed intention (Ellis, 1996; Graf & Utzl, 2001; Burgess et al., 2003). For example, if one has to remember to give a colleague a message then one continues to work on other tasks as normal until she returns. If it were necessary to cease all other activities until the correct point of intention execution arrived, human progress would have been severely hampered! In contrast, RM is usually associated with a specific retrieval cue, at least in the laboratory setting, such as explicitly asking participants how many words they can remember from a previously presented list.

For clarity, I will list the key features of a PM task identified by Burgess et al., (2003):

- 1) There is an intention, or multiple intentions to act.
- 2) The act cannot be performed immediately.
- 3) The intention is to perform the act in a particular circumstance (the 'retrieval context').
- 4) The delay period between creating the intention and the occurrence of the appropriate time to act (the 'retention interval') is filled with activity known as the ongoing task.
- 5) Performance of the ongoing task prevents continuous, conscious rehearsal of the intention over the entire delay period.
- 6) The intention cue (or retrieval context) does not interfere with, or directly interrupt, performance of the foreground task. Intention enactment is therefore self-initiated.
- 7) In most situations involving PM no immediate feedback is given to the participant regarding errors.

The cognitive components of any PM task are thus commonly depicted as the formation and encoding of the intention, intention retention across the delay (the retention interval), retrieval of the intention at the correct point (the performance interval), execution of the reinstated intention and finally evaluation of the performed intention (Ellis, 1996; Kvavilashvili & Ellis, 1996; Martin et al., 2003). Ellis (1996) split these phases into retrospective and prospective components also. Indeed, Ellis argues for use of the term

'realizing delayed intentions' instead of PM because it captures the multiprocess demands of this type of task, above and beyond memory. The term PM is maintained here primarily for its brevity.

Shallice & Burgess (1991) describe PM as the SAS enabling the following steps: 1) plan formulation or modification, 2) marker creation or triggering, 3) evaluation or goal articulation. The marker represents a message to the system that *'some future behaviour should not be treated as routine, and instead, some particular aspect of the situation should be viewed as especially relevant for action'* (p. 737). The critical feature then is not just that the behaviour is non-routine but also the prompt to act is internally-generated, the system cannot rely on external aids to cue or to execute the intention. Indeed, there are several self-initiated aspects of these components – the planning (i.e. an aspect of encoding), the retrieval of the cue as well as the task-switch. PM is a multicomponential process then, drawing on processes from a variety of domains. Ellis (1996) described PM as *'an important means of exploring that interface between memory, attention, and action that the SAS/central executive is designed to address'* (p.18).

Much of the research in the PM field has actually narrowed to a debate concerning the extent to which one of these components, retrieval of the cue, requires self-initiated processing (Ellis & Kvavilashvili, 2000; McDaniel & Einstein, 2000), that is the attentional and memorial demands of retrieval. The question pertains to the conceptual distinction between retrieval which is externally-prompted and retrieval which is strategic (Moscovitch, 1997; Moscovitch & Winocur, 1995; 2002). This can also be conceptualised as a distinction between automatic and controlled processing, as described previously. The easiest route to the understanding of such a distinction is from the RM literature, epitomised in the distinction between recognition tasks (which of these words have you seen before?) and recall tasks (remember as many words as you can from the previously presented list). In the latter task, a group of processes not related to the memory traces themselves are required to perform the task successfully. These processes are responsible for the organisation, the search, the selection and the verification of the to-be retrieved information (see Moscovitch & Winocur, 2002). In contrast, recognition memory does not require such detailed searches, perhaps dependent on automatic association mechanisms (e.g. Moscovitch, 1994) such that familiarity with the exposed stimulus is enough to

retrieve the memory trace from long-term storage (Shimamura, 2002). The notion of automatic association mechanisms is described below, but for now a simple example makes the point quite successfully. Imagine, on hearing a song, that the woman's voice reminded you of another singer. Her voice immediately creates a sense of familiarity and if you are lucky the other singer's name will automatically 'pop' into your head as you listen to the song. This is automatic recollection, prompted by the stimulus itself. However, if the other singer's name does not pop into your mind then you might, to ease your frustration, initiate a detailed search of female singers you know in order to recall it. You might even work through music genres in order to aid your search. This organised search is strategic retrieval based on internally-generated cues and the processes are thought to be mediated by the PFC (Hirst & Volpe, 1988; Stuss et al., 1994; Daum et al., 1995; Gershberg & Shimamura, 1995; Moscovitch & Winocur, 2002; Shimamura, 2002). That RM tasks differentially recruit these self-initiated processes was suggested by Craik (1983; 1986) and has been used to explain deficits in ageing and frontal lobe patients (see Fletcher & Henson, 2001; Craik & Grady, 2002).

Einstein & McDaniel (1990) suggested that the role of self-initiated processes is likely to be particularly evident in PM tasks, since there is no explicit cue to retrieve the intention. Thus, controlled processing is required to strategically monitor the environment for the correct execution point and/or to periodically rehearse the intention (McDaniel & Einstein, 2000). Consequently, this is the basic characterisation of the role of the executive functions in PM and researchers have expounded theoretical accounts along these lines (e.g. McDaniel & Einstein, 2000; Smith, 2003). The reliance on self-initiated retrieval is accepted to be even greater with certain types of PM tasks (e.g. Einstein & McDaniel, 1995). For example, tasks that are intended to be performed at a particular time (e.g. call a colleague at a particular time) are deemed more highly demanding of executive resources because there is no cue within the environment to trigger prospective remembering; it relies entirely on self-initiated responses. These types of tasks have been termed time-based PM (Einstein et al., 1992). Another type of PM task distinguished is event-based, referring to intentions that are realised when a certain event in the environment occurs (e.g. call colleague when the telephone becomes available). Although these are not the only distinctions made in PM tasks (e.g. activity-based, see Kvavilashvili & Ellis, 1996), much of the theoretical discussions revolve around these two types. Furthermore, the cognitive

structure of event-based PM (EB PM from now on) has been investigated much more systematically than time-based PM (TB PM from now on). Before discussing these cognitive accounts of EB PM retrieval, I will briefly discuss the methodologies that have developed to research this crucial memory ability.

### **2.3. Methodologies**

As with the study of RM, both naturalistic and laboratory approaches are evoked to study PM. Early studies of PM tended to employ more naturalistic techniques, whereas recently the emphasis has been on laboratory-based studies. These methodologies have been thoroughly evaluated by Kvavilashvili (1992), but I will review some key points here.

Naturalistic studies clearly have the advantage of possessing more ecological validity. For instance, Wilkins & Baddeley (1978) asked participants to carry printed out clocks and press this button at pre-specified intervals, using the number of minutes late as a dependent measure. Similarly, participants in studies by Meacham and colleagues (1975; 1977) were required to post a card back to the experimenters on certain dates and deviations from this date were taken as a measure of PM forgetting. Alternatively, participants might be asked to make a phone call to a number at a specific time over a period of weeks or days (e.g. Poon & Schaffer, 1982; Maylor, 1990). Similar procedures but with more naturalistic tasks have been applied by other researchers. For instance, Levy and colleagues used real life opportunities to gain PM measures (Levy, 1977; Levy et al., 1979; Levy & Clark, 1980), such as asking individuals who had just received a flu jab to return a card after 24 hours on which they should detail any symptoms they may have suffered (Levy et al., 1979). Dobbs and Rule (1987) asked participants to remember to include the date and time on a questionnaire that they filled out at home. These latter tasks are all intentions that individuals may have in everyday life, and as such, can provide useful information about when and how people successfully perform them.

Nevertheless, there is a clear disadvantage to these tests from an experimental perspective; this is the lack of control of participants' behaviours during the retention interval. Some participants may use external aids, such as diaries, whereas others may try and rely on their own self-initiated rehearsals. As such, different cognitive processes may be involved.



Kvavilashvili also underlined the role of motivation in these studies, suggesting that intentions such as those in Levy and colleagues studies may be influenced by such factors as whether they felt the medical procedure had been effective. In other words, there may be many reasons why the participants did not carry out the PM task, which makes interpretation very difficult.

In terms of laboratory studies, Kvavilashvili again distinguishes between two types of studies, those employing artificial tasks and those employing more naturalistic tasks.

Artificial tasks in the laboratory have been administered by Harris and Wilkins (1982), Ceci & Bronfenbrenner (1985) and Loftus (1971). Based on these earlier studies Einstein & McDaniel (1990) developed an experimental paradigm now frequently used by many PM researchers because it successfully captures the key features of an everyday PM task. Participants are engaged in an ongoing task(s) (such as arithmetic, word pleasantness rating, memory tests) but are also instructed to press a certain key when they come across a target (i.e. cue) embedded in the task stimuli (e.g. a word, a particular number). This target(s) occurs after a set retention interval but is long enough such that the intention cannot be continuously rehearsed without affecting ongoing task performance. For instance, a participant may be asked to decide if words are real words or nonsense words as the ongoing task, but to press the 'f' key whenever an animal word appears. There are many aspects of the task parameters that can be manipulated by the experimenter in order to investigate the cognitive basis of PM. Examples of manipulations include: the type of target word used (e.g. McDaniel & Einstein, 1993; Brandimonte & Passolunghi, 1994; Einstein et al., 1995), the ongoing tasks (e.g. Hicks et al., 2000; Marsh et al., 2000, 2002), the length of the retention interval/ frequency of targets (e.g. Ellis et al., 1999; Hicks et al., 2000), the instructions regarding the importance of the PM task (e.g. Kliegel et al., 2001; Marsh et al., 2005). The researchers measure the effects that these manipulations have on the number of correctly identified, and acted on, PM targets. Other dependent measures can include the reaction times and accuracy to the ongoing task (e.g. Smith, 2003), but these are measures only recently included in PM studies (see section 2.4.4).

Kvavilashvili (1992) argued that naturalistic tasks within the laboratory setting is the most effective way of testing PM because, amongst other difficulties, the artificial tasks can lead to ceiling effects in PM performance (partly because they can guess this is the behaviour

under investigation). For instance, in an early experiment by this author (Kvavilashvili, 1987) participants were asked to hang up a phone after the 5 minute testing session, which had been left off the hook to ensure it did not ring during the session. Whether participants remembered to hang up the phone was taken as the dependent measure. This type of design has the advantages of the lab along with ecological validity, since the participants' behaviour is controlled during the retention intervals, motivation is presumably the same across individuals and ceiling effects are avoided. Finding suitable naturalistic tasks is the difficult design element, especially if a multiple-intention design is preferred.

In this thesis artificial tasks in the laboratory are employed as per the Einstein and McDaniel paradigm. This is primarily because it was important to control for any external cueing behaviour (since this thesis is investigating internally-guided behaviour) and it allowed for the development of theoretical positions based on empirical work utilising a similar design. Further methodological issues are discussed in the experimental Chapters following this review.

## **2.4. Cognitive accounts of Intention Retrieval**

As mentioned, a great deal of effort by PM theorists has been directed towards explaining the intention retrieval processes in EB PM. On the one hand is the notion that executive control is required to ensure the cue is retrieved (e.g. Burgess & Shallice, 1997; Smith, 2003), on the other is the notion that PM retrieval is essentially a memorial process which can occur quite automatically in the wake of encoding the intention (e.g. Einstein & McDaniel, 1996). There are also hybrid accounts that claim both attentional demanding control processes and automatic memory/attention processes participate in PM. These accounts will be sketched out in the following section since they differ in their conception of EB PM as an internally-guided task.

### **2.4.1. Automatic-association Accounts**

McDaniel, Robinson-Riegler and Einstein (1998) described an 'automatic-associative' memory system which mediates intention retrieval if '*the target event interacts sufficiently with the representation of the intended action so that the intended action is delivered to awareness*' (McDaniel et al., 2004, p. 606). Based on Moscovitch (1994) automatic-

associative mechanism of RM, it shares many of the proposed features. After creating an intention, there is an associative link established between the intention and the action. This cue-action pairing resides with a certain level of activation that may fall below conscious awareness during engaging ongoing tasks. This level of activation will gradually decay (making a PM failure more likely) unless rehearsal occurs or other activities to raise the activation levels (e.g. priming, reminders). If the environmentally encountered cue interacts sufficiently with the memory trace then the intention will come to mind (McDaniel et al., 1998; Guynn et al., 2001). On encountering the cue the retrieval process is rapid, obligatory and requires few cognitive resources (automatic), if the activation level is high enough. Certain encoding conditions increase the likelihood that increase the activation of the associative link of the cue-action pairing and thus that the cue will interact with the memory trace; these again parallel the RM literature. McDaniel et al., (1998, experiment 1) for instance showed that changing the semantic context at encoding and retrieval reduced PM performance (e.g. encoded cue word as 'traffic jam', retrieval context appeared as 'strawberry jam'). Similarly, cues processed at a deeper semantic level produced better PM performance than those processed at a shallower level (experiment 3). Guynn et al., (2001) also describe experiments that tested the effectiveness of reminders on PM performance. Reminders that increased the associative link between the cue and the action to be performed were effective at increasing PM performance. In contrast, the researchers report that reminders that only targeted the cue itself did not improve PM performance. Furthermore, distinctive or unfamiliar cues may aid the interaction between the cue and the memory trace (Einstein & McDaniel, 1990; McDaniel & Einstein, 1993; Einstein & McDaniel, 1996).

Drawing on another theoretical position relating to the architecture of cognition (Adaptive Control of Thought, ACT\*, Anderson, 1983), McDaniel & Einstein (2000) describe how these mechanisms might work. An unfamiliar or distinctive cue has fewer associative links therefore, according to ACT\*, when such a cue is perceived the likelihood of activation spreading from its node to the associated intended action is much higher. As McDaniel & Einstein (2000) acknowledge this automatic process account is intuitive with the phenomenological experience of an intention 'popping into mind' (e.g. see Einstein et al., 1990). It can also account for some of the ageing data (see section 2.6) and experiments which show no effect of dividing attention at retrieval on PM performance (e.g. Einstein et

al., 1997; Otani et al., 1997). However, as described below there is other evidence that is simply not consistent with this viewpoint.

#### **2.4.2. Noticing + Search Model**

Einstein & McDaniel (1996) also developed a notice + search model of prospective remembering. This identifies two strands within PM, an initial automatic notice of the cue and then a directed search for the associated intention action. The notice of the cue may occur in an automatic fashion as outlined above and is similar to recognition memory (e.g. Mandler, 1980), but the directed search component is a result of strategic retrieval. The success of both of these components will affect the efficiency of prospective remembering (see also Guynn et al., 2001). For instance, the noticing aspect of the cue must elicit a feeling of familiarity so that a directed search is necessitated. Cues that are specific and distinctive will lead to greater feelings of familiarity, as the empirical studies suggest (e.g. Einstein & McDaniel, 1990). Moreover, ongoing tasks that are more demanding will make the noticing of the cue less likely (Einstein & McDaniel, 1996; McDaniel et al., 2004). On noticing a cue as familiar, the directed search must then also be efficient for the intention to be acted upon. This model can account for much of the data that manipulates cue detection and can explain how intention retrieval can occur without an external prompt to initiate the search; an automatic familiarity with the cue can achieve this. The model also has useful predictions for research of older adults' PM abilities which are described in section 2.6. below. Nevertheless, the model is perhaps limited by its focus on PM's similarity with RM (see also Guynn et al., 2001) – Einstein & McDaniel (1996) draw several RM analogies in describing this theory which are useful to some degree (e.g. comparing to familiarity and recognition) but there is also neuropsychological evidence that RM and PM do not always use similar processes (e.g. Cockburn, 1995; see also Guynn et al., 2001). More recent theories describe the PM process in attentional terms as well as memory terms (see below) and this seems to be more useful in explaining other empirical data. For instance, Smith (2003) found a cost to the ongoing task across all trials when a PM instruction was added to the baseline task, an effect attributed to 'preparatory attentional processes' (again detailed below). The notice + search model would not predict such a distributed cost because the noticing of the cue is thought to be automatic, rather than require monitoring that seems to be the case here.

### 2.4.3. Multiprocess Framework

An updated account of the cognitive structure of EB PM from the same researchers is a detailed multiprocess framework of PM in which the processes mediating PM, or at least the retrieval component, are various and dynamic (McDaniel & Einstein, 2000). This theory maintains that PM retrieval can depend on both strategic (i.e. self-initiated and attention demanding) and automatic processes, according to various factors. Moreover, the strategic and automatic processes recruited can be of diverse types. For instance, McDaniel and Einstein describe two types of automatic processes: memory-driven and attention-driven. The first are described by the automatic associative system above, whereas the latter are related to an exogenous attentional system which involuntarily orients to salient stimuli (e.g. Berger et al., 2005).

In terms of self-initiated processing, strategic monitoring is identified as an internally-controlled approach to a PM task which makes demands on the executive cognitive control system (McDaniel et al., 2004). Strategic monitoring involves a conscious monitoring of the environment for the cue (see Guynn, 2003; Smith, 2003, although monitoring may require attention without necessarily being conscious). This is where the description by Shallice & Burgess (1991) of the key SAS processes required for PM tasks is adopted, for instance, the monitoring for the markers that indicate an intended action is appropriate and then the switch to the intended action.

The factors that affect the types of processes recruited for the PM task are elaborated upon at length in McDaniel & Einstein (2000), but include the perceived importance of the PM task (e.g. Kvavilashvili, 1987), the properties of the cue (e.g. McDaniel et al., 2004), the properties of the ongoing task (e.g. task appropriate processing; Maylor, 2000), planning (e.g. see Ellis & Milne, 1996) and the properties of the individual (e.g. Goshke & Kuhl, 1993). See Figure 2.1 for further details on these factors. Consider, for instance, the properties of the cue. McDaniel et al., (2004) report that the degree of association between the cue and the intended action will influence the processes recruited. Evidence for this stems from their study showing that increasing the demands of the ongoing task did not affect performance of the PM task when the cue and the intended action were highly associated (e.g. write the word spaghetti, cue word is sauce). They proposed that this

implicates relatively automatic retrieval processes, which were not compromised by increased attentional demands. The high PM success rate and the low number of participants who forgot the content of the intended action also supported this view. However, when the cue and the intended action were not clearly associated (e.g. steeple-sauce) - strategic, controlled processes – coordinated by the SAS – were utilised to identify and retrieve the cue and as revealed by reduced PM performance in the divided attention condition. The authors propose several cue-focussed mechanisms that might achieve this, for example, discrepancy + search model or strategic monitoring for the cue. Based on evidence from preexposing participants to the cue and non-cue words, McDaniel and colleagues argued that in this paradigm during low-association (between the cue and the intended action) conditions, discrepancy + search processes are implicated (see Whittlesee & Williams, 2001). The experiments thus manipulated several variables simultaneously and different outcomes were reported according to the properties of the cue; a convincing argument for the multiprocess framework. The authors did not however, measure RTs of the ongoing tasks, a dependent measure which may also index the degree of self-initiated processing occurring (see below and Smith, 2003). As such, the authors may not be able to conclude for certain that reflexive-associative processes were mediating PM in the low-association condition.

Other evidence for the multiprocess framework arises from two studies that manipulated the importance attached to the PM task. Kleigel et al., (2004) presented participants with a standard PM paradigm but also instructions that informed them that either the PM task was more important than the ongoing task, or vice versa. In the first experiment, the parameters of the task were set (according to McDaniel & Einstein, 2000) to increase the likelihood that cue detection would occur automatically, in the second experiment these parameters were altered to make strategic processing more likely. Perceived PM task importance only improved PM performance in the second experiment. Analyses showed that this was due to a self-initiated change in allocation of attention between the ongoing and PM tasks. This study nicely demonstrates that the multiprocess framework can act as a useful heuristic in predicting the types of parameters that will affect PM performance.

A number of studies have investigated the role of strategic processes in PM by conducting studies in which an extra cognitive load is added to the basic ongoing task to determine the effects on PM performance. Presumably, if attention is divided or the cognitive load increased during the retrieval context and strategic processing is required for cue detection then PM performance should be worse (e.g. Marsh & Hicks, 1998, Marsh et al., 2002). Studies of this type have reported mixed evidence for this effect, arguably providing support for the multiprocess framework.

For instance, Einstein et al., (1996) report that their participants who were presented with an ongoing task plus a background digit task (to monitor for 3 consecutive odd numbers) performed worse at the PM task than participants who just had the ongoing task alone. Stone et al., (2001) also established a negative effect of cognitive workload on PM performance, although they found no effect of increasing the length of the retention interval. Otani et al., (1997) however reported no effect on PM performance when a group of their participants had an extra articulatory suppression task. Subsequently, Marsh & Hicks (1998) argued that the character of the concurrent task affects the degree of interference. Using Baddeley's central executive model of working memory (Baddeley, 1996; Baddeley & Della Sala, 1996) they found that only a concurrent task which was presumed to rely on central executive resources (random number generation) rather than added tasks that tapped purely the slave systems of the visuo-spatial sketchpad and the phonological loop, impoverished PM performance. The concurrent tasks that did seem to interfere with PM performance showed a similarity in requiring planning and monitoring. Similarly, measures from the WCST and verbal fluency tests correlated with participants' PM performances. The authors argue this is consistent with EB PM requiring strategic monitoring. They also suggest the central executive may be essential in allocating attention between the different tasks (e.g. performing the ongoing task versus monitoring for the PM cue). In a later study, Marsh et al., (2002) manipulated the ongoing task by creating conditions in which participants must either perform just one type of judgement task or switch between two judgement tasks, whilst the PM cues were embedded in the ongoing task stimuli. This task-switching negatively affected PM performance and was attributed to increased cognitive demands that forced participants to shift their attention away from the PM task towards the ongoing task (see Chapter 3, section 3 for fuller discussion on this

study). In contrast, D’Ydewalle et al., (1999) demonstrated that the nature of an ongoing task did not affect PM performance in young or elderly participants.

These cognitive load studies provide evidence that a more cognitively demanding ongoing task can affect PM performance, but this is not always the case; supporting McDaniel & Einstein’s theoretical viewpoint. However, these studies presume that PM performance is only indexing the success of cue detection (i.e. successful retrieval). It is quite possible that cue detection does occur but the extra cognitive load actually affects the other processes required to switch to the PM task (e.g. holding online both the tasks, interrupting ongoing task, see Guynn et al., 2001 and section 2.7 below). Studies that break down the components of the PM process may inform theory further, as also discussed below in section 2.7.1.

*Figure 2.1. Factors affecting degree of self-initiated processing in PM*

<b>Factor</b>	<b>Detail</b>	<b>Example References</b>
<b>Encoding of Intention</b>		
	Transfer appropriate processing	E.g. McGann et al., 2002, 2003
	Planning	E.g. Mantyla, 1996 E.g. Guynn et al., 1998
<b>Properties of the Retrieval Cue</b>		
	Distinctive/salient cue	E.g. Einstein et al., 2000
	Categorical/specific cue	E.g. Ellis & Milne, 1996
	Cue and intended action highly associated or not	E.g. McDaniel et al., 2004
<b>Properties of the Ongoing Task</b>		
	Easy or demanding tasks	E.g. Marsh et al., 2002
<b>Metacognitive Factors</b>	Importance of PM task	E.g. Kvavilashvili, 1987 Kleigel et al., 2001, 2004
<b>Properties of the Retention Interval</b>		
	Length/nature of retention interval	E.g. Hicks et al., 2000
	Reminders/Priming	E.g. Guynn et al., 1998
<b>Properties of the Individual</b>	Individual differences in personality	E.g. Goshke & Kuhl, 1993
	Working memory capacity	E.g. Cherry & LeCompte, 1999
	Attention allocation/effort policy	E.g. Marsh et al., 2005



#### 2.4.4. PAM Theory

An alternative cognitive model of EB PM is the preparatory attentional and memory (PAM) processes theory, which contests the notion that prospective memory cue retrieval can be accomplished automatically (Smith, 2003; Smith & Bayen, 2004). The PAM theory deems that executively controlled preparatory processes are a prerequisite for successful performance of a PM task. In a series of experiments to test PAM theory, Smith (2003) demonstrated that an EB PM task had costs to the ongoing task – in the form of longer reaction times (RTs) - and that these latency costs represent the extra processing requirements. These longer RTs were found in trials that were non-PM cue trials, suggesting processes requiring conscious capacity were being recruited in preparation for the PM task. More specifically, Smith proposed these processes might include sustained monitoring for the PM cue and that they will increase the likelihood of successful PM performance. Thus, Smith & Bayen (2004) conclude that *'resource-demanding preparatory attentional processes are always required for successful PM performance.'* (p. 757). This is in contrast to McDaniel & Einstein's multiprocess theory then, which claims some PM tasks can be achieved automatically. A problem in evaluating this claim is that much of the previous PM research did not include RTs to the ongoing tasks, which Smith has demonstrated can be a useful index of self-initiated processing<sup>1</sup>. Furthermore, Smith & Bayen (2004) proposed a multinomial model of EB PM which provided further support for the PAM theory, and found that setting the model's parameters according to the multiprocess theory did not fit their data.

A shortcoming of many PM studies then is the lack of data of ongoing task RTs or accuracy, to assess the degree of strategic processing. In addition, the ongoing task RTs can provide some temporal information with regards to the degree of strategic processing across retention intervals (hence the 'preparatory' processes), and indeed can show dynamic changes in processing requirements. This cannot be achieved with simply correct PM performance (i.e. the number of correct PM responses generated) as the key dependent

---

<sup>1</sup> An abstract from a very recent study suggests no costs to ongoing task RTs were found under presumed automatic retrieval conditions (Einstein & McDaniel, 2005).

measure. This is a point not yet acknowledged in the literature, but that I make full use of in experiments 1-6 of this thesis, with some useful outcomes.

There are limitations that are common to several of these theories. Firstly, they are only relevant to EB PM, rather than all types of PM (e.g. TB). There is no reason to assume that all types of PM tasks recruit the same cognitive processes, indeed, the evidence suggests this is not the case, at least not with TB and EB PM (e.g. Sellen et al., 1997; Cicogna et al., 2005; also see the ageing section below). Nevertheless, there are certain processes required that are unlikely to use different mechanisms, for instance the switch from the ongoing task to the PM task. TB PM tasks are assumed to be entirely self-initiated, and thus similarities between TB PM and EB PM could offer another source of evidence regarding the self-initiated processing required in EB PM. This is an argument elaborated in Chapter 4. A further limitation of these theories is that they primarily describe the encoding/retrieval aspect, for example cue detection, of the PM process (e.g. see Dobbs & Reeves, 1996; Ellis, 1996). Naturally, they do not claim to be anything but theories for this end, but a fuller account of the entire PM process may aid our understanding of the retrieval component. The executive and attentional demands of the other components of the PM process remain underspecified. For instance, the interruption of the ongoing task to switch to the PM task and their coordination, which, although discussed as a core process (e.g. Marsh et al., 2002), are not well detailed. Before discussing the role of executive processes in PM in more depth, I will review the theories concerning TB PM, a review which is necessarily short due to the comparative dearth in empirical and theoretical information.

## ***2.5. Cognitive accounts of TB PM***

TB PM is remembering to perform an intended action at a particular time (e.g. attend a meeting at 5pm). Kvavilashvili & Ellis (1996) distinguish between 'step' and 'pulse' TB intentions. The former refer to intentions that must be realised within a certain time window (e.g. meet a friend tomorrow morning) whereas the latter refers to intentions that must be realised at a specific time (e.g. meet a friend at 10 tomorrow morning). Despite this intuitive distinction, few studies have investigated potential cognitive differences between these types, instead focusing on pulse type TB intentions, which will therefore be the focus of this review (e.g. Harris & Wilkins, 1982; Ceci & Bronfenbrenner, 1985; Cicogna et al.,

2005). This is unsurprising given how few studies investigating TB PM there are generally. Most studies that are reported generally compare older adults' performances on TB and EB PM tasks (e.g. Einstein et al., 1995; Park et al., 1997; D'Ydewalle et al., 1996; 1999). Manipulations of the parameters of TB PM tasks are rarer with only two recent major studies providing any new empirical data (Cicogna et al., 2005; Cook, Marsh & Hicks, 2005), these two studies are discussed in detail in Chapter 4.

A fundamental premise of TB prospective remembering, which makes TB PM particularly relevant for this thesis is that since there is no external cue to prompt the intention (as is possible in EB PM) TB PM is thought to load even more highly on self-initiated or internally-guided processes (Craik, 1986; Einstein & McDaniel, 1995). Consequently, cognitive accounts of TB PM do not evoke memory-based processes (such as automatic-association) and focus on attentional control. Consequently, the two theories from the EB PM literature likely to be applicable to TB PM are the multiprocess account of McDaniel & Einstein (2000) and the PAM theory of Smith (2003). The application of these theories to TB PM is considered in detail in Chapter 4 but certainly a strategic (time) monitoring mechanism is a critical feature of theories of realising TB intentions.

Harris & Wilkins (1982) proposed that successful TB prospective remembering involves a Test-Wait-Test-Exit cycle of time monitoring. This is a very intuitive model of time monitoring in which participants will initially test the time, and then wait for an appropriate amount of time to pass before checking the clock again. Eventually they will 'test' the time during the critical period of realising the intention and the test-wait cycle is exited and the intended action performed. This time monitoring is a self-initiated process (Einstein et al., 1995) which is executed in addition to the ongoing task(s) (Cicogna et al., 2005) and thus makes demands on strategic processes. Einstein et al., (1995), Park et al., (1997) and Logie et al., (2004) all found evidence for the Test-Wait time monitoring strategy as measured by their participants' clock checking behaviour. However, there is little theoretical work addressing the cognitive processes that allow for time estimation in TB PM tasks. This is despite a large body of literature investigating the cognitive and neural basis of time estimation (e.g. Pouthas & Perbal, 2004; Zakay & Block, 2004). The relevance of time estimation processes to TB PM is again discussed in Chapter 4.

Ceci & Bronfenbrenner (1985) conducted a study with children and TB PM to investigate time monitoring further. They asked male and female children to either 'remember to take the cup cakes out of the oven in 30 minutes time' or 'remember to disconnect a charging motorcycle battery in 30 minutes time'. During these 30 minutes the children were engaged in a 'Pac Man' game. The researchers also manipulated both the environmental context (at home or in a lab) and the age of the children. They established a strategic monitoring pattern that comprised three different phases of time-monitoring: 1) an early calibration phase during which participants 'calibrate' their psychological clock with the passage of real clock time by frequent clock checking; 2) an intermediate phase during which participants reduce their clock checking behaviour and focus on other tasks; and 3) a 'scalloping' phase during which participants greatly increase their clock checking as the correct moment draws near. Thus, the children developed a strategic U-shaped pattern of clock checking, but this was mediated by the environmental setting (increased clock checking in the lab, termed anxious time monitoring), age (older children were more strategic monitorers), and task type (girls clock checked more during the cupcake task and boys during the battery task). Overall, the researchers concluded that a strategic U-shaped pattern of clock checking is most efficient and can be found in children as young as 10.

The key idea in both these models of time monitoring is that TB prospective remembering allows for some attentional disengagement during 'Wait' periods (Einstein et al., 1995; Park et al., 1997). Park and colleagues describe the reason why this dissociates TB PM from EB:

'An important dimension on which TB & EB may differ is the amount of continuous sustained attention required for adequate PM. EB PM requires relatively more continuous attention, whereas TB memory requires the central executive to redirect short bursts of attention to the process of time-monitoring (as reflected in clock-checking behaviour)' (p.325).

In Chapter 4, section 4.2.2. I discuss the implications of this proposed difference in more detail. Suffice it to say for now that the apparent differences in required sustained attention or strategic monitoring across the retention interval in EB and TB tasks implies different

cognitive processing requirements across the delay. As such, there are no studies, to my knowledge, that address this issue head on.

Sellen et al., (1997) and Kvavilashvili (2005) also report differences between EB and TB cognition in their studies that are comparatively more naturalistic. In the former study, participants were asked to press a button they were supplied with at specific times or at specific places during their everyday activities. They also instructed participants to press the button whenever they thought about performing these tasks whenever and wherever they did so. An analysis of how thoughts regarding the PM tasks were distributed across the retention interval could then be considered. The 'place' task was conducted more successfully than the TB PM task and there seemed less need to think about the EB task during the retention interval. The place task allowed for contextual cueing, whereas the TB task did not (except for in one participant who tied the TB intention to a particular routine activity). The TB task, in contrast, required participants to internally control ruminations regarding its performance. However, these ruminations did not appear to increase immediately preceding intention performance, as demonstrated by Harris & Wilkins. The authors explained this discrepancy as a consequence of the lengthier retention intervals and coarser-grained measuring. Sellen and colleagues discuss two mechanisms for these two task types; TB PM required more 'inside-out' control, that is internally-generated promptings whereas the place task required 'outside-in' control, in which external cues triggered the intentions. In contrast, Kvavilashvili (2005) report that in one naturalistic study with diary reports only 9% to 14% of participants' TB intention rehearsals were self-initiated, and that most were also prompted by an external cue, albeit incidentally. The author thus remarks that TB tasks may also rely on automatic retrieval processing. Indeed, the retrieval demands of TB PM have been discussed in relation to clock monitoring and internal reminders, but there have been few studies investigating how the parameters of the ongoing task, or the type of TB intention, or the cue (which is essentially the clock in experimental studies) might affect this monitoring and retrieval process. It is certainly clear that further research is required to understand the factors affecting processing demands in TB PM.

## **2.6. Ageing studies and PM**

An area of study that has revealed some empirical data regarding the cognitive processes of TB PM is with ageing populations. The fundamental assumption of the PM and ageing research is that an age-related decline in PM should occur since self-initiated processing is disrupted by ageing (Craik, 1986; Einstein & McDaniel, 1995; West, 1996). PM tasks particularly void of environmental support will suffer the greatest, such as TB PM tasks. Research in the retrospective memory (RM) field has demonstrated differing patterns of age-related impairments on RM tasks that vary according to their dependence on self-initiated retrieval processes (e.g. free recall vs recognition tasks, Craik, 1986; Craik & McDowd, 1987). As such, researchers have compared older adults' performances on TB and EB Pm tasks (for a review see Henry et al., 2004). Evidence for the predicted hypotheses has been somewhat equivocal in the PM literature. Einstein et al., (1995) did find age-related decrements in TB PM compared to EB PM tasks. Their younger participants performed the TB PM task (press a particular key every 10 minutes) more accurately than the older adults, and monitored the clock more strategically (i.e. increased monitoring leading up to the correct time). They found no age differences in PM performance in a matched EB task. Park et al., (1997) found older adults manifested poorer performance on a TB PM task compared to younger adults and this impairment was exacerbated by adding a concurrent working memory task. However, they also report a deficit in EB PM in their older population, suggesting that ageing deficits are not simply confined to TB PM. In contrast, D'Ydewalle et al. (1996; 1999) found no age impairment on TB PM tasks. Similarly, naturalistic studies appear to produce equivalent PM performance between older and younger adults, or even better performance by the older population (e.g. Moscovitch, 1982; Martin, 1986). Maylor (1990) describe her elderly participants as turning the TB PM task into an EB PM task by anchoring the intention to the end of watching a TV show. By using this strategy, the older participants reduced demands on internally-guided processes. These types of strategies may be common ways of dealing with TB intentions in this population (Henry et al., 2004). Although, as Huppert et al., (2000) portray in their very large sample of elderly and early dementia participants, performance of the elderly can also be impaired in lab-based EB tasks.

Researchers have also reported ageing studies that manipulate the level of self-initiated processes required within just EB tasks. For example, Mantyla (1994) presented, to both young and older adults, typical and atypical exemplars of categories of words that acted as

the PM cue. Although there was an overall age-impairment in performing the PM tasks – older adults were particularly poorer at this EB PM task when the cues were atypical words from a category. This was attributed to the larger demand on self-initiated processing required to recognise the atypical example as the PM cue. Consistent with this, Cherry et al., (2001) also provided evidence that age effects of PM performance depend on properties of the PM cue. These different findings associated with age and EB PM performance can be related to the multiprocess theory (McDaniel & Einstein, 2000). Variables, such as the properties of the PM cue, determine the magnitude of the age effects (Vogels et al., 2002; Henry et al., 2004). The modulation of age-related effects in TB PM remains poorly understood, except to say that older adults perform better in naturalistic scenarios rather than lab-based tasks, but this may be because they use compensatory strategies so they do not need to rely on internal control processes. Furthermore, whether ageing participants demonstrate a disadvantage on PM tasks because of failing executive functions remains an open debate. The next section will discuss the potential role of executive processes in PM.

## ***2.7. The Role of Executive Processes in PM***

Contemporary theories of PM accept that PM is ‘more than memory’ (Dobbs & Reeve, 1996). The role of executive processes in PM has been discussed so far mainly in terms of the demands of self-initiated retrieval, such as those that are recruited in episodic memory retrieval (e.g. see Burgess & Shallice, 1997 and Stuss & Levine, 2002). Executive resources are involved in other stages of PM in both EB and TB PM (see Van de Berg et al., 2004). Although few studies have attempted to specify the exact executive functions involved in PM, apart from assumptions based on the task demands. As described, it is certainly expected that the SAS plays a role given the need to inhibit a prepotent response to stimuli, and also the novelty of executing the intended action instead of the routine action (Shallice & Burgess, 1991). Demands in PM associated with mediation by executive processes include planning, monitoring the environment for the cue or the time (as described above), inhibiting the ongoing task response, switching to the intended action and error monitoring (e.g. Martin & Schumann-Hengsteler, 2001; Kliegel et al., 2004). That PM is a combination of these processes and RM processes is partly evidenced by the SAD patients described in Chapter 1. These patients show intact RM performance and yet impaired PM (Burgess & Shallice, 1997). Other neuropsychological and neuroimaging studies provide evidence for

executive control in PM, these will be discussed below, but first I will mention some behavioural studies that implicate executive processes in PM.

### **2.7.1. Complex PM Paradigm**

Kliegel and colleagues have developed a complex PM test, which resembles the multitasking tests described in Chapter 1, section 1.3.1, to study the recruitment of executive processes (e.g. Kliegel et al., 2000; Kliegel et al., 2002; Kliegel et al., 2004). They have argued that the standard Einstein & McDaniel paradigm, in which only a single or few intentions are initiated, is not sophisticated enough to differentiate between processes over the course of the PM task, including planning. In Kliegel et al., (2000) participants performed a task very similar to the Six Elements Test and are scored on their plan, their plan-following and their execution of a series of multiple intentions (i.e. switching between the subtasks). Older and younger adults performed this test plus a series of other neuropsychological tasks including the Stroop, a working memory test, the digit-symbol subtask of the Wechsler Adult Intelligence Scale and finally an RM test. Regression analyses established that inhibition (Stroop) and working memory were related to plan initiation and Stroop performance was associated with the number of subtasks attempted. These same PM and neuropsychological test scores were impaired in the older adults, leading the authors to argue that age-related impairments are due to deficits in more basic cognitive skills. The study also suggested only complex, multiple intention PM tasks were associated with working memory, rather than the single intention PM task (i.e. in which participants just had to initiate one intention at the correct time). They proposed that automatic retrieval processes, which made no demands on working memory, mediated the single intention task, whilst the planning required in the complex task encouraged participants to use strategic processing. Although this may be true, other elements of the PM process require executive processes (not just the retrieval of the cue), for instance the inhibition of the ongoing task to generate the PM intended action or the required task-switch (which also occurs in the single intention task e.g. Rogers & Monsell, 1995; Ellis, 1996). Why at least then did inhibition not correlate with the single intention performance? No doubt because a single isolated switch is not powerful enough to generate a correlation.



In a follow-up study, Kliegel et al., (2002) reported finding differential patterns of executive test correlations with separable components of the PM process. Again, they operationalised PM with a complex multitasking test rather than the standard paradigm and scored several components of the test e.g. planning, plan-following, number of subtasks attempted to represent their proposed 4 stages of PM: intention formation, retention, intention initiation and execution. They then analysed the relationship of these scores with the participants' performances on other executive tests. Planning ('Plan a Day' task) was associated with the intention formation phase of the PM task, which was essentially operationalised as planning too. Problem-solving ('Tower of London' task, which is actually often conceptualised as a planning task e.g. Shallice, 1982; Dagher et al., 1999) was associated with initiation of the complex PM task and 'cognitive flexibility' (WCST) was associated with execution of the delayed intentions. They thus argue much of the executive demand of a PM task appears in the intention formation and execution phases. Different executive tests were also differentially associated with different PM task types (a single intention task, a standard EB and TB PM task and a complex multitasking PM task) in a later study by Martin et al., (2003). Variance on the complex multitasking PM task could be predicted by differences in performance of the executive functioning tasks (WCST, Stroop and Tower of London), even after age had also been added to the regression analyses. This suggests an overlap of processes in these three tasks and in the multitasking test – and in this sense this is different to the neuropsychological findings of Burgess et al., (2000) and Shallice & Burgess (1991). Executive functioning also predicted performance on the EB and TB PM tasks even after controlling for health, education and RM, but it did not predict performance on the single intention task, presumably because this latter task is much less demanding.

Finally, another study by Kliegel and colleagues (2004) supports the notion of executive functions as crucially involved in PM. They showed that a group of young participants with traumatic brain injury and a group of neurologically normal older participants were impaired on their complex multitasking PM test compared to a control group, despite intact RM. These same groups performed at a deficient level on the WCST also. The authors propose that this once more highlights the importance of executive functions and moreover that age-related deficits in PM are associated with their decline in executive functioning. They again emphasised the multi-phasic nature of PM, with executive functioning seeming

to be particularly related to the intention formation and execution phases. They discuss the limitations of their study, which include the lack of information regarding speed of processing (which also declines in older age, e.g. Salthouse, 1996, and may affect PM processing, e.g. West & Craik, 2001) and their small group sizes. Nevertheless, this group of researchers is making headway in separating the component PM processes and their relation to executive measures. The ecological validity of these multitasking PM tests also gives them advantages in the applied domain.

Unfortunately, difficulties remain in dissociating the executive functions involved in PM. In the correlational/regression studies described above the executive tasks correlated with PM performance are also multicomponential (as described in Chapter 1, section 1.2.2). For example, the WCST and TOL in Kliegel et al., 2002 are defined as ‘cognitive flexibility’ and ‘problem-solving’, which are very broad terms and not necessarily any more helpful in describing the executive role. Indeed, Rogers et al., (1998) deliberate over the psychological character of frontal patients’ deficits on the WCST, they question whether it is related to an inability to inhibit attention to previous stimuli, failure to keep task relevant info online in working memory or a general difficulty in complex problem-solving. Stuss & Levine (2002) discuss how separate scores from the WCST may be measuring different frontal areas, and thus potentially different processes, for instance DLPFC is associated with set-shifting whereas ventral PFC lesions cause set loss errors. One way of tackling this issue might be to use more componential measures of executive functioning – such as working memory tests (e.g. n-back), inhibition (e.g. flanker) and task-switching. In addition, Kliegel et al. (2004) report the performance of their TBI patients on the PM tasks but there is little data as to the specific location of the lesion or the extent of the lesion. To the extent that dissociable executive functions are associated with different PFC regions (see Chapter 1) we have gleaned very little about the potentially different PFC areas involved in PM. For example, the review of Burgess et al. (2000) indicates that rostral PFC (particularly BA 10) may have a crucial role in PM and in Chapter 1, section 1.3.2. the potential functions of this area were described, with the suggestion that rostral PFC is involved in cognitive control of internally-generated behaviours. Neuropsychological studies of PM have not tended to discuss particular areas of the PFC however, and instead effort has been directed at assessing the role of RM impairment in PM ability. Executive functions have been included at a more general level, as with the studies of Kliegel and

colleagues (e.g. McDaniel et al., 1999; Kopp & Thorne, 2003; Mathias & Mansfield, 2005). I shall now turn to these other neuropsychological studies of PM in order to assess their conclusions about the role of executive processes in PM.

### **2.7.2. PM and Neuropsychological Studies**

Several studies have demonstrated impaired PM performance in patients with traumatic brain injury (TBI), which is commonly associated with temporal and frontal damage (e.g. Hannon et al., 1995; Cockburn, 1996; Kinsella et al., 1996; Shum et al., 1999; Fortin et al., 2002; Carlesimo et al., 2004; Schmitter-Edgecombe & Wright, 2004; Mathias & Mansfield, 2005). Shum et al., (1999) demonstrated that a group of severe TBI patients performed worse on three types of PM tasks: TB, EB and activity-based (see Kvavilashvili & Ellis, 1996), and their performance on the TB PM task was the most deficient, presumably because of the increased demands made on self-initiated processing. Schmitter-Edgecombe & Wright (2004) correlated performance on EB PM task with the patients' neuropsychological profiles and found strong relationships between PM performance, RM and attention/speed of processing scores. The authors thus emphasised the attentional requirements for PM tasks, specifically the lapses of attention that may be the cause of age-related and TBI decline (Craig & Kerr, 1996; West et al., 2000) and may be attributable to poor frontal functioning.

McDaniel et al., (1999) report a neuropsychological study that also suggests a frontal contribution to PM tasks. Older adults were assessed on two batteries of tests, the first assumed to test hippocampal (RM) processes and the latter to test frontal (executive) processes. From these composite scores the participants were split into high and low hippocampal and frontal functioning groups and an EB PM task was administered with salient and non-salient cues. Older adults with low scores associated with frontal functioning were impaired on the PM task compared to older adults with higher scores on these measures. There were no significant differences on the PM task between the high and low scorers on the tasks associated with hippocampus functioning. Acknowledging the indirect nature of the evidence, the authors nevertheless discuss the potential role of the frontal lobes in PM. Firstly, they suggest the role could be the monitoring for the SAS 'marker', as previously discussed. However, if monitoring processes were deficient then

PM performance of the low frontal functioning group should be even worse in the non-salient cue condition compared to the salient cue condition. This was not the case. They also discuss the frontal/executive contribution as providing strategic encoding processes in order to raise activation thresholds of the intended actions (e.g. Burgess & Shallice, 1997). Furthermore, they discuss the requirement to interrupt the ongoing task and initiate the PM task, a process the authors relate to working memory and PFC, but this is clearly also associated with task-switching (Rogers & Monsell, 1995, see Chapter 3), which remains an area unexplored with regards to PM. Their experimental design was unable to differentiate between these alternative roles.

Kopp and Thorne (2003) used a similar experimental design to test brain-injured patients with high and low executive functioning scores and with high and low RM scores. Once more, those patients with low executive functioning scores showed diminished scores on a PM task, whereas the low RM scorers could still perform at control levels on the PM task, perhaps because the RM element of the PM task was minimal (entailing remembering three cue letters). It is perhaps unsurprising, however, that the high scoring executive group performed better since they were assigned to the groups according to their scores on the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996). This is an executive battery that includes measures of PM, or tests that require PM related processes (such as the Zoo Map test and the Six Elements). In this sense, there is a degree of circularity to their study. Groot et al., (2002) found that patients with brain injury exhibited deficits in EB and TB tasks, with worse performance on the latter. Correlations with both RM and executive function tasks (including the Stroop, a version of the WCST, verbal fluency) and PM performance appeared in both the control group and the brain-injury group. Groot and colleagues found poorer TB performance in the brain-injury group because of deficits in inhibitory control mechanisms (see also Cockburn, 1995), but this was based on rather indirect evidence. Carlesimo et al., (2004) conducted a TB and EB PM study with patients with closed-head injury (CHI) in a design which separated the PM (remembering the intention) and the RM (remembering what the intention is) components of the task. CHI patients manifest both RM and PM deficits leading to impaired PM performance. However, overall they argue that the CHI participants showed insufficient utilization of strategic time monitoring and/or self-reminders, as a consequence of a disturbed attentional control system, since RM could be intact and clock checking was

reduced in the TB conditions. Several proposals regarding the role of the attentional system in PM were offered by the authors, including planning the strategic behaviour, such as clock checking, and shifting attention to the PM task away from the ongoing task (see Chapter 3 for further discussion on this and also Guynn et al., 2001).

Mathias & Mansfield (2005) found no correlations between performances on RM measures and several PM tasks in participants who had sustained TBI. This is despite reporting impaired performance of these participants on the PM and RM tasks. Executive functioning, as assessed by a verbal fluency task and WCST, did not correlate with PM ability, although the TBI participants performed significantly worse at the verbal fluency task. Measures of attention (trail-making tests) also produced poorer performance in the TBI participants, but both this result and the fluency impairment could reflect reduced information processing speed as they are both timed tests. These researchers could find no relationship between PM and traditional executive functioning tests, which is consistent with the neuropsychological findings of Burgess and colleagues.

Several explanations can be submitted to explain these discrepant findings; the usual difficulties with neuropsychological studies of course apply, such as small sample sizes and heterogeneous aetiologies (Mathias & Mansfield, 2005). In the studies described in this section there was little precise anatomical information about lesion sites, so several PFC areas may have been damaged. Moreover, there are inconsistencies with both the PM tasks used, for instance changes in retention interval lengths and PM cues, and the executive tasks administered. The same limitation applies to these studies as mentioned above in relation to the complex tasks: the executive tasks used to assess performance are multicomponential and tap a variety of processes. In some cases, composite executive scores have been utilised from several executive tests or battery of tests (e.g. McDaniel et al., 1999; Kopp & Thorne, 2003), making interpretation difficult in terms of the exact processes contributing to PM. Theoretically, it would be useful to compare performance on executive tasks associated with specific regions of the PFC, such as task-switching (DLPFC;) or purer working memory tasks (such as complex span tasks), and tasks associated with other PFC regions. This would test the hypothesis that there is fractionation of the executive processes and PFC, and tasks with different degrees of internal and external cueing may involve different PFC regions (see Chapter 1, section 1.3.2). Thus,

generally these studies are consistent with frontal contributions to PM but there is little understanding of the relationship between the control processes employed in PM with other executive processes. Imaging research can shed some light on this issue.

### **2.7.3. PM and Neuroimaging Studies**

Support for the role of the PFC in PM has also been obtained from neuroimaging studies. Okuda et al., (1998) conducted PM studies in which participants' blood flows were compared on blocks of ongoing task with and without an added PM demand (to tap their hand on identifying a certain word cue). Several sets of activations were unique to the PM blocks. These appeared in the anterior cingulate gyrus (BA 24), superior frontal gyrus (BA 10) and parahippocampal gyrus (BA 28) in the left hemisphere and inferior frontal gyri (BA 8, 9 and 47) and medial PFC (BA 8). These activations were similar (but not identical) to those found in a previous study by Yamadori et al., (1997), which also confirmed a role for BA 8-10 and the anterior cingulate gyrus plus some DLPFC involvement in the right hemisphere. The activations were related to the following functions by Okuda and colleagues: Right VPFC and the left frontal pole to maintaining the intention, left parahippocampal region to novelty detection and the medial PFC area to dividing the attention between performing the intended action and the ongoing task.

Burgess et al., (2001) also demonstrated BA 10 activation in the maintenance of intentions, along with increased activation in the right lateral PFC, the inferior parietal cortex and the precuneus and decreased activation in the insula of the left hemisphere. The realisation of the delayed intentions activated a different region, the thalamus and deactivated the right DLPFC. The maintenance versus realisation of intentions was differentiated by contrasting baseline with an expected intention condition (in which participants were given PM instructions but the cue never occurred) and baseline with an execution condition (in which the same PM instructions were given and the PM cue did occur). A role for BA 10 in PM and other PFC areas then is once more substantiated. Burgess and colleagues contend that the activation patterns in the 'expectation' condition represents 'anticipatory' processes. Although the nature of these anticipatory processes could not be described definitively from their experiment, the authors suggested that *'there is no reason to assume that this state of*

*anticipation or readiness occurs in situations which do not require self-generated action'* (p. 553). As such, the internal guidance required in PM tasks is once more highlighted.

Finally, another imaging study was conducted to investigate the neural basis of PM, but this time with the motivation to rule out the task difficulty hypothesis (Burgess, Scott & Frith, 2003). Potentially the activations found in PFC in the PM conditions could be attributed to extra attentional demands, that is, task difficulty, challenging the maintenance of the intentions hypothesis. Burgess et al., found no support for this hypothesis because they demonstrated that BA 10 activation could be lower in more behaviourally effortful ongoing task conditions. The authors proffered a dissociation between the medial and lateral regions of BA 10 based on the activation patterns, suggesting medial regions suppress internally-generated thought and the latter maintain it (see Chapter 1, section 1.3.2. and another PM imaging study is described in Chapter 3, section 4.2.1. supporting this argument). Thus, Burgess and colleagues (2005) have made a convincing case for the role of these regions supporting the biasing of attentional modes between SOT (for ongoing task performance) and SIT (for maintenance of intention), with medial regions supporting the former, and lateral regions supporting the latter.

## **2.8. Summary**

So what has this review of the PM literature established regarding the cognitive mediation of this ubiquitous behaviour? Firstly, that there are several components to successful PM. These are intention formation, retention, intention instantiation, intention execution and evaluation. Some of these components require, or behave like, RM processes. However, several of these components, including retrieval and intention execution, require strategic, self-initiated processing which place demands on the executive control system. The degree of executive control required for retrieval is dependent on several parameters of the task; these parameters are well researched in the EB literature, but relatively unexplored in the TB domain. Moreover, the characterisations of the executive processes in PM tasks remain somewhat focussed on these retrieval demands. Broadly, the neuropsychological studies support a role for PFC and executive functioning in PM, although our understanding of the precise executive contribution to this behaviour remains weak, and this is particularly true of TB tasks. Behavioural and neuropsychological studies are still required to disentangle

the precise executive control processes and neural regions involved in PM. This thesis hopes to fill some of the gaps in our understanding.

## **2.9. Focus of Thesis Research**

There is no doubt that behaviours are both internally-generated and driven by the stimuli in the environment, with most lying somewhere in the middle. Nonetheless, PM and multitasking are voluntary, uniquely human behaviours that require a great deal of top down, self-initiated organisation. Thus, studying these behaviours can give us an insight into how executive control manifests itself. For instance, one line of evidence in the cognitive control literature described above suggests that tasks relying heavily on endogenous control, such as PM, may recruit different neural areas and cognitive processes to executive tasks that are more externally constrained. Theories of the functions of rostral PFC associate this area with these types of tasks, whereas the role of DLPFC seems apparent in other executive, more externally-constrained, tasks. This thesis explores this possible dissociation of function behaviourally by investigating the cognitive processing requirements of performing internally and externally-cued tasks.

### **2.9.1. Broad Overview of Experiments**

To achieve this aim, I describe four experiments in Chapter 3 that assess common processing in two tasks possessing a fundamentally similar demand (task-switch) but differ in whether this is internally- or externally-cued. By integrating the externally-cued task switching paradigm with a PM task, I hope to demonstrate an effective means of operationalising the distinction between internal and external cueing. The four experiments utilise slightly different PM instructions in order to manipulate the degree of external cueing in the PM tasks and uncover processing differences or similarities between these PM task types.

Next, in Chapter 4, I describe two experiments investigating the cognitive processes implicated in PM tasks that vary along an internally- and externally- cued continuum. This involved exploring the nature of TB PM tasks, specifically questioning the assumption that these types of PM tasks always depend heavily on self-initiated processing because of lack of external cues.



Finally, in Chapter 5, I take a slightly different approach to the study of internally-guided behaviours, by turning to multitasking tests. In two experiments, I investigate individual differences in multitasking in the healthy population, and explore the relationship of performance on these tests to externally-cued tests and real life outcomes. In the second of these experiments, some external cues were imposed on the multitasking test in order to determine their effects on performance.

## **Chapter 3**

### ***Cognitive Control of Internally-generated and Externally-cued Task-switches***

#### **3.1. Introduction**

The aim of this first empirical Chapter is to investigate the cognitive control of PM by combining a lab-based PM paradigm with another paradigm used to study executive control, task-switching. Task-switching is simply the switching between two task sets, such as from addition to subtraction and is a widely used paradigm for studying cognitive control (e.g. Jersild, 1927; Allport et al., 1994; Rogers & Monsell, 1995; Meiran, 1996; De Jong, 2000; Rubenstein et al., 2001; Koch, 2003). By combining these two paradigms, the intention was to uncover the common processing of two similar procedures that differ, primarily, in the degree of endogenous and exogenous cueing. Thus, this provides a behavioural test of the functional dissociation of cognitive control along the endogenous/exogenous continuum, as proposed in the preceding Chapters. Before detailing the background and rationale for these experiments, I will first briefly review the task-switching literature.

#### **3.2. Task-switching and the Study of Cognitive Control**

Task-switching experiments comprise of participants switching, according to cues provided by the procedure (such as + or – if participants are performing addition and subtraction), between two or more simple cognitive tasks. Several procedural variations have emerged (e.g. alternating runs: Rogers & Monsell, 1995 versus alternating tasks: Miyake & Emerson, 2003) but a robust effect found in the reaction time (RT) data reveals that participants are significantly slower when alternating between tasks compared to when repeating the same tasks. Similarly, error rates can also be higher during task-switching (for review see Monsell, 2003). This switch-cost is largest when the tasks share the same stimuli. For instance, numbers can both be added or subtracted; indeed a whole range of responses can be produced in response to numerical stimuli (e.g. parity or magnitude judgements). Internal goals thus dictate the ‘task-set’ (in this context, a task-set is the

appropriate configuration of mental resources to execute the task) employed on a particular group of external stimuli and as such the paradigm is accessing executive top-down control (Monsell, 1996; 2003; Allport et al., 2000; Ruge et al., 2005).

Different theoretical accounts of the source of the switch costs generally evoke top-down processes or bottom-up processes. In top-down accounts, executive control processes are required to 'reconfigure the task-set'; such that the lower-level cognitive processes required to perform the upcoming task are prepared (e.g. Rogers & Monsell, 1995; Monsell, 1996; Monsell et al., 2000). The 'task-set-reconfiguration' accounts then, explain the switch cost as though it reflected 'mental gear changing', with extra processes performing a variety of potential preparatory functions, such as *'shifting attention between stimulus attributes or elements, or between conceptual criteria, retrieving goal states (what to do) and condition-action rules (how to do it) into procedural memory working memory (or deleting them), enabling a different response set and adjusting response criteria'* (Monsell, 2003, p. 135). The lengthier RTs to trials in which an individual has switched task, compared to repeating a task, reflect the duration of one or more of these processes (e.g. Rubinstein et al., 2001; Sohn & Anderson, 2001; Mayr & Kleigl, 2000, 2003).

Evidence for these accounts essentially derives from experiments showing reduced switch costs with increased preparation time (response-stimulus interval: RSI). Providing information in advance about the upcoming task and more time between the trials, allowing for increased preparation time and reduced switch costs (e.g. Rogers & Monsell, 1995, experiment 3; Meiran, 1996). Generating random RSIs on a trial-by-trial basis did not produce this reduced switch cost (e.g. Rogers & Monsell, 1995, experiment 2; although see Meiran, 1996). Consequently, the successful reduction of the switch costs was attributed to endogenous, SAS-driven control processes that can be initiated prior to the presentation of the stimuli (Rogers & Monsell, 1995). Rogers & Monsell also posited another component to the switch cost. Although increasing the preparation interval reduces the switch cost it did not eradicate it altogether, a 'residual switch cost' still remains (e.g. Rogers & Monsell, 1995; Kimberg et al., 2000; Sohn et al., 2000). The authors therefore assumed that this reflects an exogenous, stimulus-driven control process that can only be triggered once the stimuli are available. Other models of task-set-reconfiguration models argue for control processes occurring at different stages of the switching operation. For instance, Rubenstein

et al. (2001), present a model that includes an active process after stimulus identification, whereas Meiran (2000) suggests the active process appears before stimulus identification. However, Koch (2005) has argued the active control process is not specific to switch trials. He demonstrated that predictable task sequences (as opposed to random sequences) benefited RTs of both switch and repetition trials (see also Sohn & Carlson, 2000; Koch, 2001; Dreisbach et al., 2002; Gotler et al., 2003). A specific task-set-reconfiguration process for task switches cannot explain this pattern of data. Instead, the authors argue that a control process (e.g. goal updating) must be occurring before task repetitions and task switches, but for some reason this process(es) takes longer in switch trials.

In contrast, bottom-up accounts of task-switching argue that the switch cost is not a result of active control processes, but arise from passive, involuntary interference carried over from the previous task-set. According to Allport and colleagues, (1994) and their task-set-inertia hypothesis, residual activation from the previously used task-set interferes with producing the required task-set following the switch. Moreover, there is a carry-over of inhibition from the trial previously, in which the response to the 'switched-to' task-set was prevented from being executed. These priming effects generate the switch costs because of increased competition between the task-sets. Allport and colleagues thus argue that the extra processes posited by the authors above are unnecessary to explain the switch costs (e.g. Waszak, Hommel & Allport, 2003).

Evidence for this position stems from a series of task-switching experiments showing that the magnitude of the switch cost was sensitive to whether the participant had previously performed a different task-set afforded by the same stimuli. This resulted in 'pro-active interference', which dissipates only after performing the new task-set for some time (Allport et al., 1994). Moreover, larger switch costs appear when participants switch from a non-dominant task (e.g. colour-naming in Stroop task) to a well-learned, dominant task (e.g. word-reading in Stroop task) than from a switch into a non-dominant task. The task-set reconfiguration models provide no reason why there should be different size switch costs in these cases. These data can be reconciled by suggesting that the dominant, well-learned task requires extra inhibition to prevent the usual response and this inhibition is carried over into the next trial. During this trial the dominant task-set is required and longer RTs are therefore produced to counteract this residual interference (although see Monsell et

al., 2000 who report no asymmetric switch costs). Allport & Wylie (2000) also present evidence that interference may occur from the target stimuli themselves, since they automatically retrieve the previous task-set from memory (i.e. priming). This leads to competition between the two response-sets and longer RTs.

A difficulty in this field is that often evidence can be accounted for by both sets of theories (see e.g. Arrington & Logan, 2005; Hsieh & Liu, 2005). Thus, theorists now argue that several component processes could be responsible for the switch costs, including carry over interference and active control processes (e.g. Meiran 2000; Meiran et al., 2001; Sohn et al., 2001; Monsell, 2003; Rushworth et al., 2005;). Evidence for these multiprocess accounts comes from ERP data collected by Rushworth et al., (2005) and empirical dissociations of the subcomponents (e.g. Meiran 2001). Rushworth and associates measured ERPs as participants first initiated a task-switch (i.e. shown the task-set cue) and as they then implemented that task-set with a response (i.e. when the stimuli appeared). The authors concluded that ERP modulations suggested both active task reconfiguration processes and passive task interference processes exist.

### **3.3. PM and Task-switching**

As Chapter 2 has illustrated, several explanations have been advanced to characterise the role of executive processes in PM, and especially EB PM. However, researchers are only just beginning to note the similarities between PM tests and task-switching experiments. PM tasks, whether TB or EB, involve a self-initiated task switch from the ongoing task to the PM task during the correct performance interval (Ellis, 1996). PM tasks also require internal switches between the ongoing task and retrieval of the intention. Kvavilashvili (1998) also describes the process of interruption of the ongoing task to switch to the unrelated prospective task. However, a qualitative difference is apparent between the nature of the task switches in the PM type tests and the tests of the task-switching literature. In the former, the task switch is self-initiated; during PM tests there is a switch of task because of internally represented goals. The participant is responsible for ignoring the current task-set (the ongoing task) and producing the PM task-set, and there is little direct environmental cueing to initiate this switch (a discussion of how EB PM fits into this picture occurs below). In the task-switching literature, task switches are externally-cued; the participant is

instructed of a task switch because of a specific, associated cue (e.g. + or – indicate which task to perform in addition and subtraction tests). Consequently, these cues set into motion the switching of the task-set. Indeed, it can be argued that the key element within PM tasks that is indisputably under endogenous control is the task-switch (retrieval for example can be automatic, see Chapter 2, section 2.4). Thus, the comparison of externally-cued task-switches and internally-driven task-switches can speak to the independence of the cognitive control of these two sources of behaviour (see also Weidner et al., 2002).

Marsh et al., (2002) produced two experiments that combined task-switching and PM as part of their investigation into the effects of the ongoing task on PM performance. During their first experiment participants were engaged in two different types of ongoing task – word-pleasantness rating and syllable counting - whilst also maintaining an intention to make a particular response whenever they saw an animal word in the ongoing task stimuli. Two versions of the experiment were administered in which only one aspect was different. In experiment 1a participants randomly switched between performing the two types of ongoing task (i.e. they task switched), whilst in experiment 1b participants performed only one of the ongoing tasks throughout (i.e. with no task-switching.) The authors noted reduced performance of the PM task in experiment 1a compared to 1b, they also noted longer RTs of the ongoing task in experiment 1a (as would be expected from the task-switching literature.) They interpreted this as the PM component of the task drawing on resources from the central executive (Marsh & Hicks, 1998), resources which, they argue, are also required in task-switching.

However, this is an incomplete analysis of the relationship between task-switching and PM. Firstly, the purpose of the Marsh et al. studies was to manipulate the executive demands of the ongoing task in order to assess the impact on EB PM performance. The task-switching paradigm offers a convenient and well-researched methodology with which to manipulate the level of executive resources used in the ongoing task. However, beyond concluding that EB PM tasks do require some executive resources, demonstrated by the reduced PM performance in the task-switching conditions, these studies were unable to elaborate further on the specific or overlapping processes involved in either task-switching or PM. Secondly, the authors did not recognise the PM task as a task switch in itself (as described above) and thus failed to have a matching externally-cued condition to assess the voluntary task switch

cost (this is outlined in more detail below). Finally, the experiment only considered EB PM; no study has investigated the relationship of time-based PM and task-switching.

### ***3.4. Internally- and Externally-cued Task-switching***

Despite little research directly comparing PM and task-switching, studies have begun to manipulate the degree of environmental cueing within the task-switching paradigm. Kray and Lindenberger (2000) conducted a study in which they presented no external cues to prompt the task switch. Adult groups of different ages were presented with two tasks that were afforded by the same stimuli (colour-naming or shape-naming) and response keys. Participants were told to switch between these tasks in a predictable AABB procedure. They found that switch costs behaved similarly as with the external cueing procedure, such that increased preparation time reduced the switch cost. This was interpreted as evidence for an endogenous control process to reconfigure the task set. Koch (2003) highlighted that this study did not provide an additional control condition in which external cues were provided. Such a control condition would have allowed for a comparison between internally-cued and externally-cued switches. Hence, Koch (2003) carried out such a study, asking participants to switch tasks according to the AABB procedure. One group were provided with an external cue (the shape of the stimulus presentation frame), whereas another group were not presented with a cue and thus relied on internal (i.e. memory based) retrieval to know when to switch. Participants for whom an external cue was provided exhibited reduced switch costs with longer preparation time, whereas the internal cue group did not. In other words, there were differential effects of internal and external cues. Several processes are discussed as potentially producing these differential effects, for example, task selection by goal updating (Rubenstein et al., 2001) or retrieval of task-specific stimulus-response rules (Mayr & Kliegl, 2000). Koch argues that task selection could occur faster with external cues or retrieval of task rules could be more effective because external cues are more salient (this issue of saliency/cue strength is addressed in Chapter 6, section 6.5.1. Whatever the explanation, Koch argued that internal and external cues have differential effects on task-switching costs and thus recruit different cognitive processes.

Koch's internal cueing condition resembles a PM paradigm, participants had to retrieve from memory the correct task to execute, except the RIs were very short (switch every two

trials, a matter of seconds) and thus the PM task (essentially to remember to switch) is very frequent and may be considered more similar to vigilance tasks (see Brandimonte et al., 2001) . In addition, the participants also know in advance when the intention must be carried out. This is somewhat like TB PM, in which participants know exactly when the task switch should occur, but different to EB PM in which the participants must monitor for the cue (although it is not like TB PM in that the cue in TB PM is external to the ongoing task). The important point here is that there is a difference in task switch predictability between the two paradigms of EB and TB PM. The predictability of the cue affects the switch costs (and the neural mediation of the task switch, see Dreher et al., 2002 below). For instance, Monsell and associates (2003) investigated runs of task repetitions after predictable and unpredictable task switches. They identified a differential effect on the subsequent trials. After predictable task switches participants' RTs 'recovered' after just one trial, whereas after unpredictable trials participants RTs were slowed for several trials post switch, perhaps because of incomplete reconfiguration. Hence, task switch predictability may be of relevance in comparing TB and EB PM, this is discussed below.

### ***3.5. Voluntary Task-switching Paradigm***

Recently a new approach has developed to investigate task-switching, which has examined the cognitive control of a voluntary, self-initiated task switch (e.g. Arrington & Logan, 2004, 2005). Within this voluntary task-switching paradigm, participants are simply instructed to switch between performing two easy digit tasks whenever they wished. Arrington & Logan (2004) contend that this is measuring endogenous control processes, because clearly, there are no external cues and the participant is making an active decision about whether to repeat or switch tasks. Consequently, this type of task-switching procedure is more directly comparable to PM. Analyses revealed that these voluntary task switch trials also generated longer RTs compared to voluntary task-repetition trials. Moreover, these switch costs were comparable to those found in externally-cued task-switching studies and behaved the same, in that they decreased (though did not completely disappear) with a longer RSI. Increasing the RSI is thought to allow increasing active preparation for the task switch (Rogers & Monsell, 1995). In addition, the authors found a pre-switch slowing when they analysed the trials before and after a voluntary switch. As the authors acknowledge, this study was not designed to tease apart the type of processes these



voluntary task switch costs represent, whether top-down reconfiguration processes or bottom-up interference. It simply established that a residual switch cost still exists even when participants have voluntary control over task-switching.

The second voluntary task switch study by the same authors replicated the initial results that there is a switch cost in endogenous controlled task switching (Arrington & Logan, 2005). Participants consistently showed voluntary switch costs that decreased with increased preparation time, again suggesting top down control processes. In addition, they showed this time that the switch costs were different to that of the explicit cueing (i.e. externally-cued) procedure, actually showing comparatively lower differences in RTs between the switch and repetition trials. Thus, Arrington & Logan concluded that the explicit task cueing procedure generates switch costs for different reasons to the voluntary task switching procedure, with the former arising predominately (but not entirely) from bottom up processes and the latter from predominately top down processes. They attribute this difference to the degree of environmental support provided by the tasks, with the explicit cueing procedure constraining and directing behaviour with external cues and the voluntary task procedure leaving the task open for internal control.

With this evidence in mind, it is reasonable to suppose that any cost to the ongoing task in the PM paradigm could be partly a consequence of task switch processes, as demonstrated in the Arrington & Logan voluntary task switch studies. Arguably, the slower RTs in the ongoing task may be a result of the cost of task-switching, rather than completing just the 'pure' ongoing task. In EB PM the switch is unpredictable and thus there may be a longer cost to the ongoing task after the PM response (Monsell et al., 2003). In contrast, TB PM could produce slower RTs prior to the self-initiated task switch because of preparatory processes involved in predictive task-switching (Monsell et al., 2003). Equally, slower RTs could be a result of bottom up processes, such as task-set-inertia from the PM task-switch, interfering with the ongoing task (this is discussed further in Chapter 6, section 2). Since PM tasks have previously not been conceptualised as self-initiated task switches this possibility has not been taken in account within the theoretical models. For instance, Smith (2003) included a control group that kept the maintenance of intentions equal but manipulated the monitoring aspect of the PM task, that is, the control group maintained the PM intentions but did not perform the PM task until after the ongoing task. However, there

was no control group included that did not have the PM intentions but did have the equivalent task switch, that is, a control group who were externally-cued to make the same PM response at the same time points. By including such a control group, it would have been possible to dissociate the slowing due to PM task switch task set reconfiguration processes from that due to monitoring and/or maintaining the intention. The experiments reported here included such a control group in order to investigate this possibility.

### **3.6. Further Evidence for a Dissociation between Internally- and Externally-cued Task-switching**

Of relevance here is the evidence indicating that cognitive control over externally-cued tasks may engage the lateral areas of the PFC, particularly BA 9 and 46 (Christoff & Gabrieli, 2000; Stuss & Levine, 2002), whereas control of internally-cued tasks may engage more rostral areas (see Chapter 1, section 1.3). This supplies a neural basis for the dissociation proffered by Arrington & Logan above. For example, imaging studies using the task-switching paradigm are providing evidence for a role of lateral PFC in cognitive control (e.g. Meyer et al., 1997; Dreher et al., 2002; also ventrolateral PFC (BA 47) e.g. Dove et al., 2000; Sohn et al., 2000), as does neuropsychological evidence (e.g. Rogers et al., 1998; Mecklinger et al., 1999). The exact contribution that lateral PFC provides for externally-cued task-switching is uncertain but several theories have been posited, for example, to inhibit the irrelevant task sets in working memory (Arbuthnott & Frank, 2000; Mayr & Keele, 2000) or load the task-set into working memory (Dreher et al., 2002).

In one neuroimaging study, performed by Dreher et al. (2002), the authors manipulated both the timing and the predictability of a task switch. In certain blocks, participants could predict the upcoming tasks, which allowed for endogenous preparation, whilst in other blocks the tasks were determined randomly. Anterior medial (BA 10) activation was demonstrated when the concurrent task was predictable, but lateral PFC activation when the task was unpredictable. They describe a '*functional organisation of the PFC along a mediolateral axis on the basis of task order predictability*' (p.104). Since participants in the predictable condition are aware of the next task and are not awaiting a cue to prompt them to perform a certain task, this activation is consistent with this area's involvement in the control of internally generated information (see Chapter 1, section 1.3.). Dreher et al, argue that the role of BA 10 may involve monitoring the expected outcome (from internal

knowledge) and comparing with the actual outcome, thus is more involved in internally-cued task-switching. Dreher et al's results are also consistent with Burgess et al, (2001) proffered role of this area in PM. The activation of BA10 may represent the internal knowledge of the correct time and rule that are appropriate for the next task while performing the current task. Similarly, Forstmann et al. (2005) found a specific BA 8 activation for internally-generated task-sets compared to directly cued task-sets. Although they demonstrated a different neural area, which can perhaps be explained by the different methodology that they used to manipulate the endogenous/exogenous continuum, the findings are still consistent with a possible dissociation between externally-cued and voluntary task control.

On account of the evidence described above, that different neural bases and executive processes are implicated in the cognitive control of self-initiated and externally-cued tasks, it may well be possible that the processes involved in PM (self-initiated task switches) and task-switching are distinct. If this were the case, we would expect no interaction between task-switching and PM performance. The present study therefore has three aims. Firstly, to investigate the possible dissociation between self-initiated cognitive control and externally-cued cognitive control by adding PM demands to a well-established task-switching procedure. As part of this, the second objective is to conceptualise PM as a self-initiated task switch and include a novel, externally-cued task switch control condition that matches the PM task switches in every way, except for the volition. By doing so, it is possible to draw conclusions about the nature of the RT cost to the ongoing task in PM conditions. Finally, these experiments aimed to contribute to the theoretical debate of the executive processes involved in TB and EB PM and task-switching.

### ***3.7. The Experimental Paradigm***

In order to investigate the issues described above a new experimental paradigm was developed utilising additive factors logic (Sternberg, 1969). According to this logic, two given variables affect the same cognitive processes or stages if they interact, whereas if their effects combine additively it is taken to indicate that they affect discrete processes. Thus, a factorial design was employed which crossed the factors of task-switching and PM.

Participants performed either task-switching or pure task arithmetic verification as the ongoing task. In the task-switching conditions participants switched from addition to subtraction on every trial (ABAB procedure), whereas in pure task conditions participants performed only addition or subtraction (AAA or BBB). This factor was crossed with the prospective memory factor in which PM task demands (either TB, experiments 1-3 or EB, experiment 4) were also required or not. To complement the usual PM paradigm, an externally-cued condition was added, in which the PM task switch demands were carried out automatically by the computer during the non-PM conditions.

During the PM conditions, participants were asked at specific time intervals and for specific cues to carry out a particular action: press the Space Bar on the keyboard and continue the ongoing task on similar stimuli in a new spatial location. The externally-cued conditions (i.e. non-PM conditions) automatically moved participants to the new spatial location after similar intervals. With such a procedure, it was possible to investigate the nature of the preparatory processes that may occur in self-initiated task switches.

Within these experiments, the PM task was also manipulated with the purpose of varying the demands made on self-regulatory processes (i.e. reliance on internal cues). For example, TB PM tasks have previously been argued to make more demands on self-initiated processing (e.g. Einstein et al., 1995) than EB tasks (though see Park et al., 1997) and thus a different pattern of results was expected between these two types of PM task.

### **3.8. Experiment 1**

The aim of experiment 1 was to explore the relationship between TB PM and task-switching and investigate the costs of the PM task switches on the ongoing task. The experiments started with a TB PM procedure for three reasons. Firstly, because there has been little research into the effects of TB PM demands on the ongoing task generally. Secondly, because the multitasking tests of Burgess et al., (2000), which show a particular deficit of PM in medial PFC patients, and therefore are the basis of the proposed cognitive control dissociation, produce TB PM demands. Thirdly, the increased reliance on self-initiated processes would be more likely to demonstrate the predicted dissociation of executive processes used in task-switching and PM, if such a dissociation exists. The

hypothesis for this study was therefore that the PM task demands would not differentially affect performance in the task-switching conditions compared to the pure task conditions (i.e. will have additive rather than interactive effects) because of the reliance on different executive resources.

### **3.8.1 Method**

#### **Participants & Design**

Twenty-four volunteers recruited from a participant database ran by the UCL Psychology department participated in the experiment in return for monetary compensation. Participants were aged between 18 and 26, 13 were female and 11 were male. Participants completed a health screen questionnaire to establish any history of neurological or psychiatric disorders, but no participants were excluded on this basis. All participants reported a similar level of educational background, with the majority being current UCL undergraduates. Testing was administered on an individual basis in a session lasting approximately 55 minutes. All participants performed all eight conditions of the experiment in this repeated measures factorial design (see Figure 3.2. below for list of conditions).

#### **Materials & Equipment**

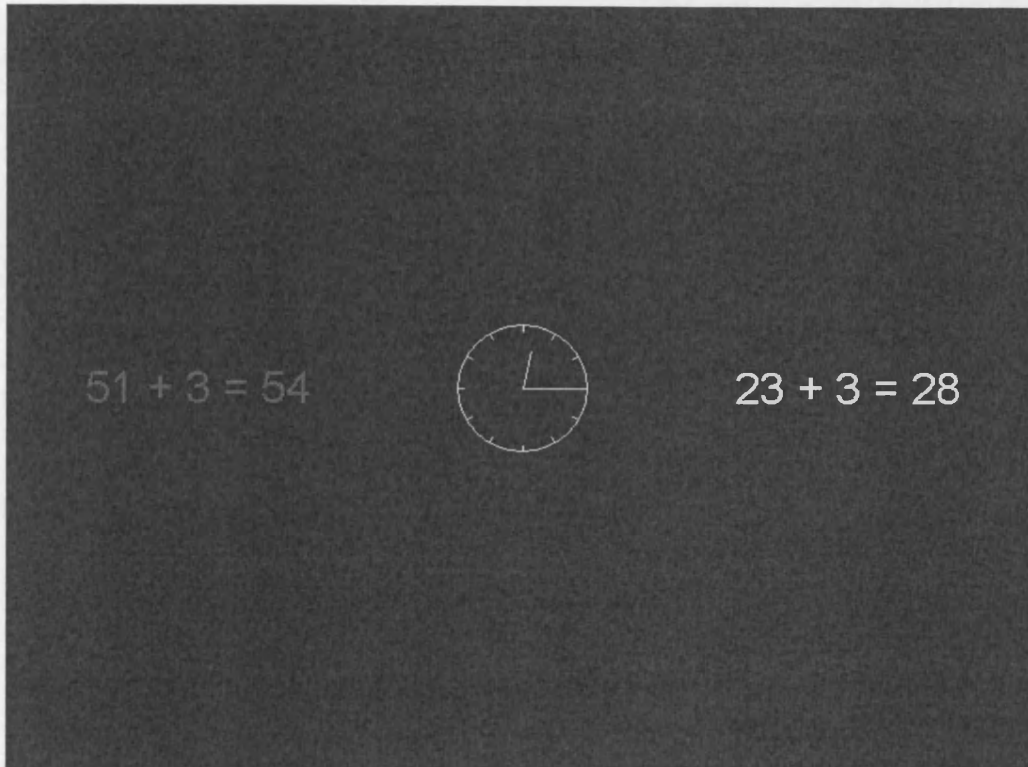
The task was presented on an IBM compatible Dell notebook with a 14 inch monitor and controlled by software written in Cogent (UCL, Institute of Cognitive Neuroscience). The viewing distance was approximately 60cm. Two sums, including the solution (e.g.  $56 + 3 = 59$ ), appeared on the screen simultaneously. The first aligned in the centre vertically and approximately 2 cm from the left edge of the screen. The second also centrally aligned and approximately 2cm from the right edge of the screen. Digits were displayed in white Arial font size 40 on a black background screen. The program randomly generated the addition or subtraction sums from the integers 10 through to 99, however, the second addend and the subtrahend were always 3. The sums were set to be correct on 50% of the trials and incorrect on 50% of the trials. Sums on the left and the right of the display were generated, and changed, simultaneously.

The participant only attended to one sum at a time; this was indicated by which sum appeared in white text. The sum not being attended to appeared in dark grey and was barely

visible. The side to attend to at the beginning of the block was decided randomly by the program. When the active sum (i.e. that being responded to) switched side (i.e. participants switched from responding to sums on the left to the sums on the right because of the PM task or because the computer switched them – see below) the colour of the sums changed accordingly. The participants' task was arithmetic verification, such that if the solution to the sum was correct they pressed the right arrow key (on a QWERTY keyboard) marked with a green sticker and if the solution was incorrect they pressed the left arrow key marked with a red sticker. After a correct or incorrect response had been made, new sums were immediately generated; thus, responding to the trials was self-paced. In the pure task blocks (i.e. non task-switching) the sums were either all addition or all subtraction. In the task-switching conditions the sum changed from an addition sum to a subtraction sum on each trial.

A clock face, 2cm in diameter, with a minute and second hand (but no digits) was also on display in the centre of the screen between the sums (see Figure 3.1). In the PM conditions, the clock was functioning correctly so participants could use it as an indicator of seconds passed. The hands of the clock always began at the 12 o'clock position at the start of any block. In the equivalent externally-cued conditions the clock hands were not functioning in a manner useful to the participants. Instead, the second hand flipped between the 'quarter-to' position and the 'quarter-past' condition, once a second. The minute hand stayed at the '12.30' position. Consequently, the visual image was very similar in the two contrasting conditions but the clock in the externally-cued conditions could not interfere with the participants' performance.

Figure 3.1. The screen design for experiment 1. In the PM conditions the clock was functioning, in the externally-cued side switch conditions the clock hands flipped between quarter-to and quarter-past.



#### Procedure

Firstly, participants were asked to remove any watches or other time-keeping devices and hide these out of sight for the entire experiment. Participants read instructions for the arithmetic verification task on a sheet of paper. They were instructed that their task was to identify sums as correct or incorrect as accurately and quickly as possible. They were informed that the experiment was split into sections and that each section would change in the type of sums they were verifying, i.e. addition, subtraction or alternating between addition and subtraction. They then completed 3 short practice blocks. This practice consisted of just the arithmetic verification ongoing task, specifically 30 seconds of addition, 30 seconds of subtraction and finally 30 seconds of switching between addition and subtraction. Participants' attention was directed to the sum in white text and they were required to place their left index finger on the left arrow key and their right index finger on the right arrow key to make their responses. Participants were told that the non-functioning

clock in the middle of the screen should be ignored for these practice sections. Following this practice, participants were given a second set of instructions on paper regarding the PM element of the task. They were instructed that during some sections of the experiment they would also be required to do an extra task. This extra task was to remember to switch to verifying the sum on the other side of the display every 30 seconds (i.e. the TB PM task). Thus, if they were attending to sums on the left hand side of the screen then at the 30-second point they should begin on the right-hand side, or vice-versa. To switch to sums on the other side of the screen they were told that they would need to press the Space Bar on the keyboard and this would then change the text on the new side into white text and darken the current side. They were also instructed that there would be no cue to help them remember to make this side switch but that there would be a functioning onscreen clock displaying the time. Short retention intervals (RIs) of 30 seconds were employed in these experiments to keep the PM task switches frequent, such that they were more similar to the task-switching demands. Furthermore, only short RIs could generate sufficient data to analyse RTs in time bands across the RIs, as will be explained below.

Participants were also informed that during sections where they did not need to remember to switch sides, the computer would do it automatically for them. They were told therefore that they could forget all about the intention to switch sides (i.e. the extra task) during these sections. Thus, during the externally-cued side switch conditions the computer was programmed to switch the text colours of the sums on each side at every 30-second point; to indicate a side switch. Participants then completed a practice block of 70 seconds with the extra PM demands and with alternating addition/subtraction sums as the ongoing task, in order to familiarize themselves with the display and procedure. A verbal prompt to switch sides was given ten seconds after the correct timepoint if they did not switch correctly at the 30-second point. Any other instructions were clarified by the experimenter as necessary.

Participants then began the experiment, which was split into the 8 different block types (see Figure 3.2.) each 5 minutes and 10 seconds long. Note that two task-switching blocks were presented in each PM condition to compensate for the two types of pure task blocks (addition and subtraction). A total number of 10 side switches occurred in each block (or should occur in the PM conditions). Before each block began a screen informed the



participants about the type of block they would be undertaking - whether adding, subtracting (pure task condition) or alternating between the two (task-switching condition) - and whether they had to remember to switch sides (PM side switch condition) or if the computer would be doing it automatically for them (externally-cued side switch condition.) Participants were informed that they could take breaks whenever these information screens appeared, for as long as they required, before beginning the next section. Block order was counterbalanced across participants with the constraint that the PM side switch blocks and externally-cued side switch blocks alternated.

*Figure 3.2. Factorial design – list of block types each participant performed*

<b>BLOCK TYPES</b>	
<b>Task-switching Factor</b>	<b>Prospective Memory Factor</b>
Pure task – Addition	PM
Pure task – Subtraction	PM
2* Task-switching	PM
Pure task – Addition	No PM – Externally-cued Side Switches
Pure task – Subtraction	No PM – Externally-cued Side Switches
2* Task-switching	No PM – Externally-cued Side Switches

### **3.8.2. Results**

The chosen alpha level for statistical significance is set at .05 for all the analyses reported in the following experiments, unless a specific p value is noted. Furthermore, for all the experiments reported, the results include analyses of the error rates of the ongoing task, the RT data of the ongoing task and accuracy of the PM performance. Multivariate statistics are reported from the analysis of variance (MANOVA) throughout this thesis for two reasons. Firstly, in some instances, this was because the sphericity assumption was not met and secondly because they are more conservative tests, which ensures against making Type 1 errors.

#### *3.8.2.1. Ongoing Task Results*

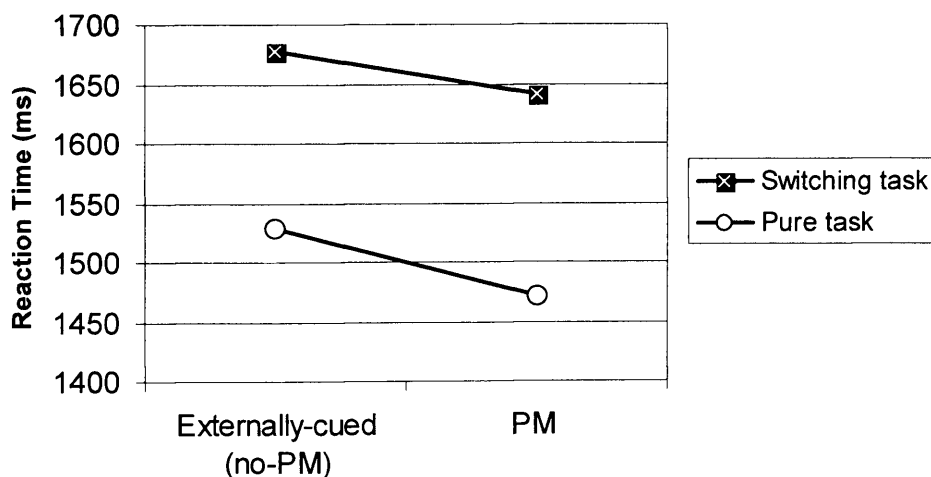
### *Accuracy of Ongoing Task*

Participants completed a mean of 1574 (SD = 395.15) trials (sums) across all 8 blocks (self-paced). The first trial of each block was excluded from the following analyses. Accuracy was high with a mean error rate of only 5.44% (SD=4.7). A 2 (PM: PM side switch, externally-cued side switch) x 2 (Task Switching: pure, task-switching) repeated measures multivariate analysis of variance (MANOVA) on the error rates showed no significant main effects of task-switching or PM and no significant interaction.

### *Reaction Time Data of Ongoing Task*

Participants' mean RTs to the ongoing task were included in the following analyses. However, in this experiment and in the following experiments within this Chapter, error trials, post error trials, outliers of below and above 3 standard deviations from the mean (in each condition) and one trial before and after a side switch (in order to remove variance from eye movements) and the first trial of each block were excluded from all analyses. The resulting RT data were subjected to a 2 (PM: PM side switch, externally-cued side switch) x 2 (Task Switching: pure, task-switching) repeated measure MANOVA. There were main effects of both PM,  $F(1,23) = 6.2, p < .05$ , and task-switching  $F(1,23) = 23.82, p < .001$  on RTs, but the interaction of PM and task-switching was not significant ( $F < 1$ ). This pattern of data is considered further below.

*Figure 3.3. Overall mean RTs as a function of task-switching and PM trial type.*



### *Task Switch RTs*

Mean RTs were slower for the task-switching blocks than the pure task blocks (see Figure 3.3). Thus, using a simple measure of switch costs (comparing mean RTs for pure trials and mean RTs for alternating trials) the robust effect of task-switching on RTs was replicated in this study.

### *Prospective Memory RTs*

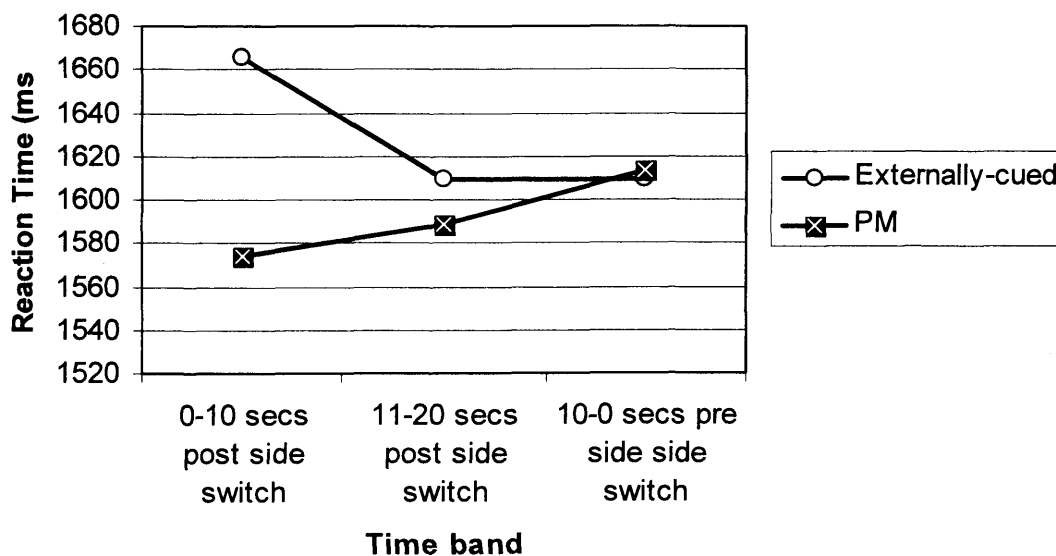
Rather surprisingly, the means of the RTs in the conditions with the added PM demands were faster, than in the equivalent externally-cued side switch conditions (see Figure 3.3). This is the first study to show an RT advantage in the ongoing task when PM demands are added. Because this result contradicts other studies that show an RT disadvantage to the ongoing task when PM demands are added (e.g. Smith, 2003), and an aim of the experiment was to understand the effects of the PM task switches, further analyses were carried out on these RT data. Mean RT's of trials in time periods between a side switch (i.e. PM target) were calculated and used in the analyses as a method of investigating the effect of the extra PM demand on RTs across the RIs at a more fine-grained level. Periods of 30 seconds within blocks were divided into three time bands – 0-10 seconds (i.e. representing the trials just after the completion of a side switch), 11-20 seconds and 21-30 seconds (i.e. representing the 10 seconds leading up to a side switch.) A repeated measures MANOVA with PM (PM side switch, externally-cued side switch) and task-switching (task-switching, pure task) and time (0-10 secs after a switch, 11-20 secs after switch and 10-0 secs before switch) as the factors. The results again showed a main effect of task-switching, with the task-switching conditions producing significantly slower RTs,  $F(1,23) = 27.67$ ,  $p < .001$  and a main effect of PM that approached significance,  $F(1,23) = 4.04$ ,  $p = .056$ , with faster trials in the PM conditions. In addition, the analysis revealed a significant interaction between PM condition and time,  $F(2,22) = 8.08$ ,  $p = .002$ . No other main effects or significant interactions reached significance ( $F < 1$  for 3 way interaction).

Posthoc t test analyses of this interaction revealed several significant findings. Firstly, trials from within the same time bands, collapsed across the task-switching variable, but in the different PM conditions were compared. Thus, the trials just *after* a PM response (i.e. time band 1 - 0-10 secs after a side switch) were associated with significantly faster RTs than the same trials in the externally-cued conditions,  $t(23) = 4.1$ ,  $SE = .022$ ,  $p < .0001$ .

Secondly, trials from the same conditions but in different time bands were compared. Thus, in the PM conditions, trials were significantly slower before a PM response (i.e. time band 3 – 0-10 secs before a side switch) than after a PM response (i.e. time band 1 – 0-10 secs after a switch),  $t(23) = 2.33$ ,  $SE = .017$ ,  $p < .05$ . Finally, in the externally-cued task conditions, trials were significantly slower after an automatic side switch (i.e. time band 1 – 0-10 secs after a side switch) than before an automatic side switch (i.e. time band 3 – 0-10 secs before a side switch),  $t(23) = 3.72$ ,  $SE = .017$ ,  $p < .01$ .

This contrasting pattern of data in the PM and externally-cued conditions is clearly illustrated in Figure 3.4. Participants RTs gradually slowed down over the course of the 30 seconds in the PM conditions but in the matched externally-cued side switch blocks they showed the opposite pattern, speeding up as they progressed through the 30 seconds.

Figure 3.4. Overall mean RTs as a function of PM and time band trial type.



### 3.8.2.2. PM Task Accuracy

For all the experiments reported here (and the following experiments within this Chapter), the correct number of side switches in the PM conditions across each experiment was 40 (4 blocks of PM side switches each block lasting 5 mins 10 secs and switch every 30 secs = 10

per block.) In this experiment, there was very high PM accuracy. The mean number of PM side switches was 39.83 (SD=2.68). The mean RI between PM side switches was 30.20 secs (SD=2.72).

### **3.8.3. Discussion**

Consistent with the task-switching literature (Jersild, 1927; Rogers & Monsell, 1995), the present results indicated a significant cost to RTs when participants had to switch between verifying addition and subtraction as the ongoing task. In contrast to the PM literature, however, the results indicated the somewhat surprising finding that there was a facilitation of ongoing task RTs during the PM conditions, compared to the matched externally-cued side switch conditions. This finding is discussed in detail below. The main finding remains that there was no interaction between PM and task-switching; indeed they had opposite effects on performance. This supports the suggestion that there is little common processing between PM and externally-cued task-switching.

At first glance, the finding that an added PM task facilitates RTs of the ongoing task is difficult to reconcile with past research. However, the post-hoc follow-up analyses can aid explanation: these data showed that when participants initiate the PM task switches their performance of the ongoing task slows as the point of the switch arrives. After the PM task switch (and they return to the ongoing task on the new side) the participants are much faster to recover compared to the externally-cued side switch condition. This faster recovery from the side switch in the PM task switch conditions compared to the externally-cued condition may partly explain the apparent RT improvement in these conditions. Moreover, studies that have analysed the effects of interruptions on the ongoing task performance have demonstrated faster RTs as a consequence of interruptions (e.g. Speier et al., 1999; Zijlstra et al., 1999); which these data are consistent with if the PM response is considered an interruption (see Chapter 5, section 5.3.2.).

The patterns of the RT data provide important insights into the cognitive processes of PM. The pre-switch slowing is consistent with Arrington & Logan's (2004, 2005) studies that also showed a slowing of RTs prior to a self-initiated task switch. They attributed this slowing to the recruitment of active reconfiguration processes and these data indicate that some active preparation may be occurring before carrying out the PM task switch also (i.e.

PM response), as this would explain both the pre-switch slowing and the faster recovery post-switch. However, it seems possible that this preparation for a PM task switch employs different processes from those involved in the externally-cued rapid task-switching that is occurring in the ongoing task.

An obvious limitation to this experiment, however, is that it is not possible to eliminate the possibility that the slowing prior to the PM task switch is a result of eye movements related to checking the clock as the time for the PM response approaches. Logie et al. (2004), for instance, have shown an increase in clock checks as participants approach the time to initiate the PM task switch. Accordingly, a further experiment was designed to examine this possibility.

### **3.9. Experiment 2**

The aim of experiment 2 was to replicate the results of experiment 1 whilst additionally controlling for participants' eye movements to the clock. New participants were presented with almost identical instructions and procedure as in experiment 1. The key difference was that during the PM conditions the hands of the clock were no longer on permanent display; instead, if participants wanted to check the time they were required to press a button to reveal the clock (see Cicogna et al., 2005 for similar methodology). This allowed us to exclude trials pre and post clock checks and thus remove trials relating to eye movements to the clock. It also allowed us to monitor the number of clock checks participants made, as previous studies in this field (e.g. Ceci & Bronerfener, 1985; Einstein et al., 1995; Maylor et al., 2002; Cook et al., 2005). As in experiment 1, the hypothesis remained that there would be no interaction between the effects of PM and task-switching, with the further prediction that PM performance would be slightly poorer than in experiment 1, because there was a further reduction in external cues (omission of the clock hands.)

#### **3.9.1. Method**

##### **Participants and Design**

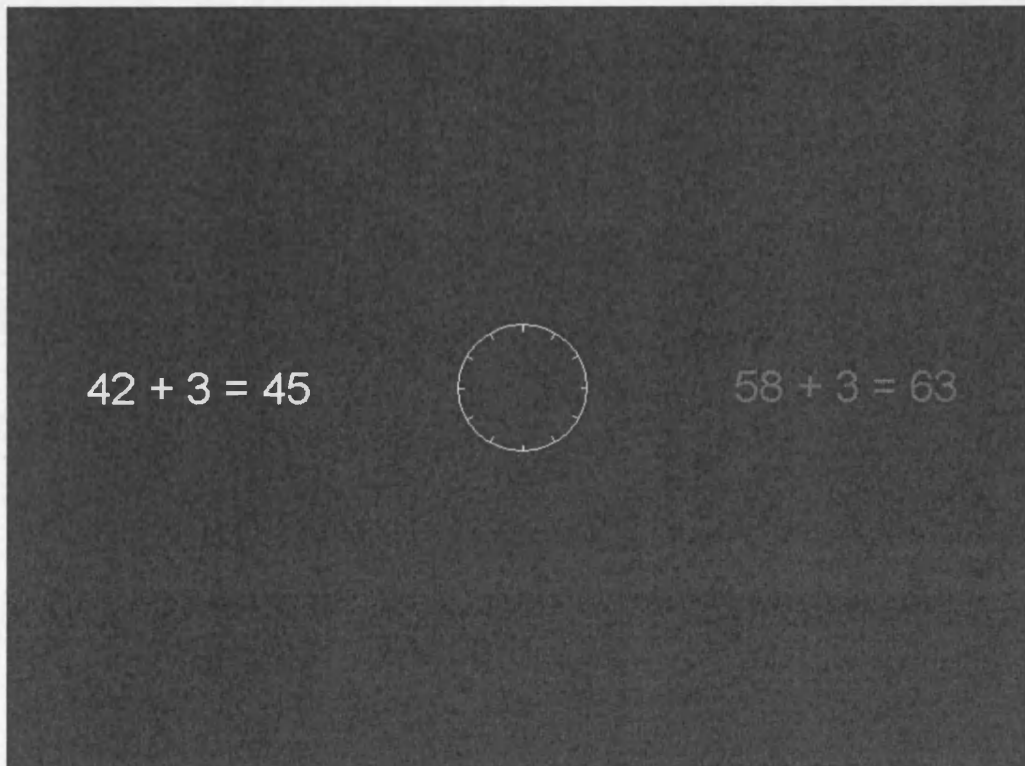
Thirty-two healthy volunteers recruited from the psychology database, the majority of whom were undergraduates of UCL, participated in experiment 2. Twelve of these participants were male and 20 female, with an age range of 18 to 36. No volunteer who had

participated in experiment 1 was included in this experiment – indeed novel participants were used in all the experiments reported in this thesis. Participants were screened for any neurological or psychiatric history, and again none were excluded on this basis. Testing of participants was completed individually in a session lasting approximately 55 minutes. All participants completed all 8 blocks of this experiment.

#### Materials and Equipment

As described, this experiment used identical materials and method of generating stimuli, as in experiment 1. The clock face remained on screen throughout all blocks of the experiment (see Figure 3.5.). However, during the PM conditions, pressing the Control button on the keyboard revealed the hands of the clock. Once pressed, the hands of the clock were remained for 1.5 seconds, after which they disappeared again. In the externally-cued side switch conditions the hands of the clock could not be revealed, and the clock face remained blank throughout.

*Figure 3.5. The screen design for experiment 2. The clock face remained empty in all conditions, but in the PM conditions the clock hands could be revealed for 1.5 secs.*



## Procedure

The procedure for experiment 2 was almost identical to experiment 1. Participants were given the same instructions and practice, with the exception that they were instructed that in the PM conditions they could check the time, as often as they wished, by pressing the Control button to reveal the clock hands. The same 8 block types, each lasting 5 minutes and 10 seconds long, were presented in counterbalanced order across all participants with the identical constraint that PM and externally-cued blocks alternated.

## 3.9.2. Results

One participant was excluded from the analyses because they checked the clock an exceptional number of times (e.g. 228 in one block) leaving few ongoing task trials for analysis. Another participant was excluded for exceptionally long RTs (mean: 3033 ms).

### 3.9.2.1. Ongoing Task Results

#### *Accuracy of Ongoing Task*

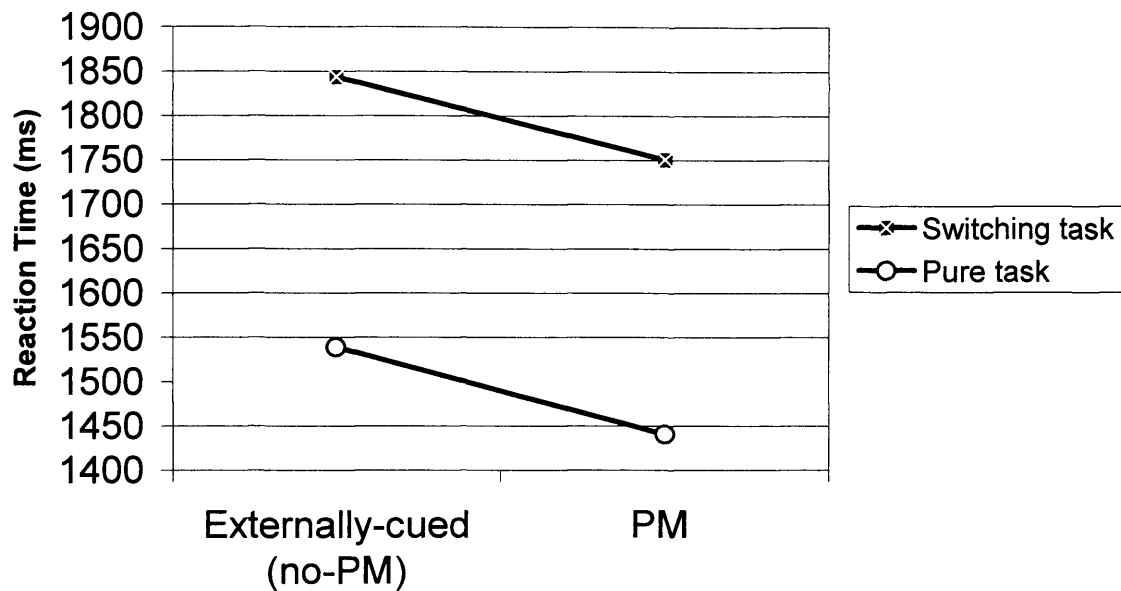
Participants made an average of 6.2% (SD=2.78) errors and performed an average of 1351 trials (SD=346.23). A repeated measures MANOVA was conducted on error rates with PM (PM side switch, externally-cued side switch) and task-switching (task-switching, pure task) as the factors. There was a main effect of task-switching,  $F(1,30)=14.12$ ,  $p<.01$ , with participants making significantly fewer errors in the pure task conditions (mean: in pure task blocks and collapsed across PM condition = 5.64% versus 6.89% in task-switching conditions). There was no main effect of PM and no significant interaction ( $F < 1$ ).

#### *Reaction Time Data of Ongoing Task*

The same types of trials were excluded from the RT analyses as described above, plus pre and post clock checks, and the same analyses executed. Thus, firstly a 2 (PM: PM side switch, externally-cued side switch) x 2 (Task Switching: pure, task-switching) repeated measure MANOVA was conducted on the data. The results revealed main effects of both task-switching,  $F(1,29) = 41.38$ ,  $p<.001$ , and PM,  $F(1,29)=17.95$ ,  $p < .001$ , but the interaction of PM and task-switching was not significant ( $F < 1$ ).



Figure 3.6. Overall mean RTs as a function of task-switching and PM trial type



#### *Task Switch RTs*

As in experiment 1 mean RTs were slower for the task-switching blocks than the pure task blocks (see Figure 3.6.). The task-switching conditions thus did produce the expected switch costs to the ongoing task.

#### *Prospective Memory RTs*

Participants in experiment 2 replicated the behaviour of those in experiment 1. Participants responded to the sums significantly faster during the PM conditions than during the externally-cued side switch conditions (see Figure 3.6.). To investigate if the pattern of RTs was the same as in experiment 1, trials were again split into 10-second time bands between the side switches in both the PM and the externally-cued conditions. A second repeated measures MANOVA was conducted with these data and PM (PM side switch, externally-cued side switch), task-switching (task-switching, pure task) and time (0-10 secs after a side switch, 11-20 secs after side switch and 10 secs leading up to a side switch) as the factors. There were highly significant main effects of task-switching,  $F(1,29)=41.13$ ,  $p<.001$ , and time  $F(2,28)=10.21$ ,  $p<.001$ . The main effect of PM was no longer significant.

There was also the same significant interaction as in experiment 1 between PM condition and time,  $F(2,28)=17.19$ ,  $p<.001$ . However, a new interaction also became significant in this experiment between task-switching and time,  $F(2,28)=6.94$ ,  $p=.004$ . No other main effects or interactions reached significance.

Follow-up t-tests revealed significantly faster ongoing task RTs in the 10 secs leading up to an externally-cued side switch (time band 3) than in the 10 secs following a side switch (time band 1) collapsed across the task-switching variable,  $t(29)=5.91$ ,  $SE=.015$ ,  $p<.0001$ . In contrast, RTs were faster after a PM response side switch (time band 1) than the trials before a PM response (time band 3), although this did not reach significance collapsed across the task-switching variable. This pattern did reach significance in the task-switching PM conditions,  $t(29)=2.66$ ,  $SE=.041$ ,  $p<.05$ , suggesting this slowing pattern was somewhat stronger in the task-switching conditions. However, trials after the side switch were significantly faster in the PM conditions than in the externally-cued conditions,  $t(29)=3.53$ ,  $SE=.025$ ,  $p<.01$ . These different patterns of RTs across the RIs are illustrated in Figure 3.7.

Follow-up t-tests regarding the task-switching and time interaction revealed significantly faster ongoing task RTs in the 10 secs leading up to a side switch (time band 3) than in the 10 secs following a side switch (time band 1) in the pure task conditions and collapsed across the PM variable,  $t(29)=3.91$ ,  $SE=.018$ ,  $p<.001$ . This same comparison was not significant in the task-switching condition. These patterns of RTs across the RIs are illustrated in Figure 3.8.

Figure 3.7. Overall mean RTs as a function of PM and time band trial type

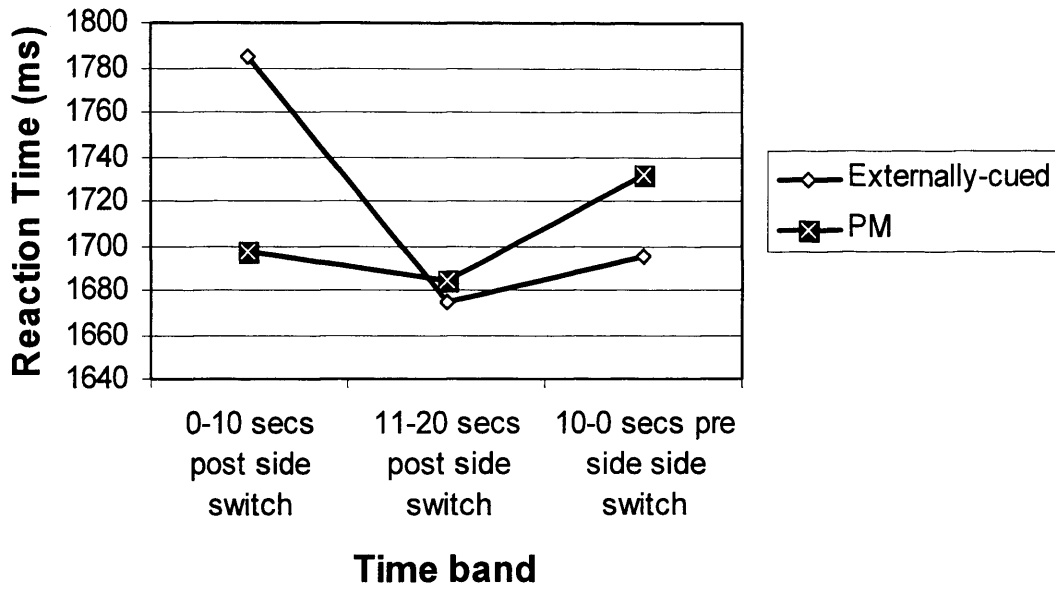
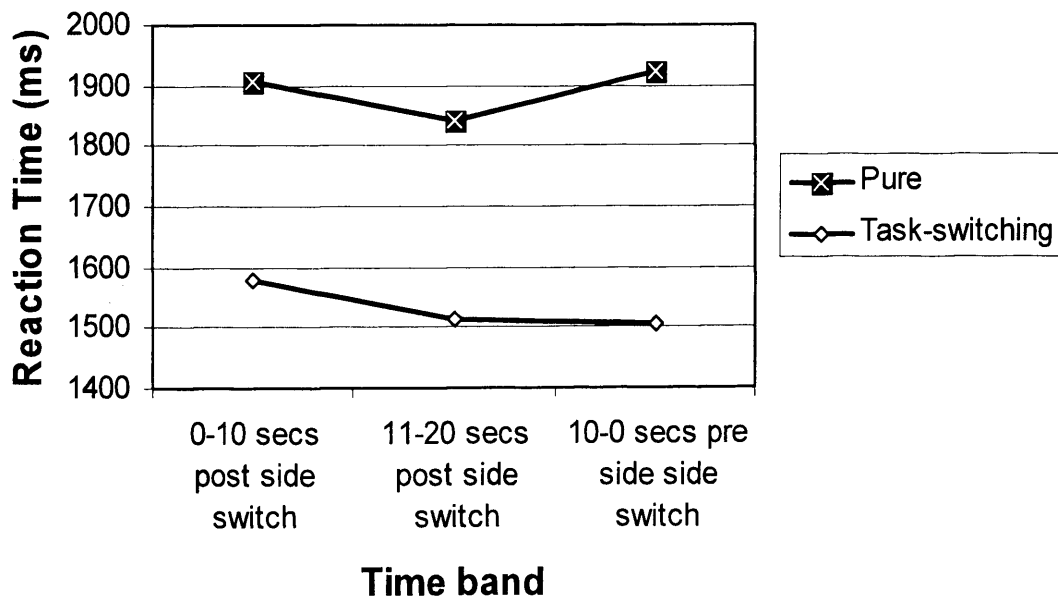


Figure 3.8. Overall mean RTs as a function of task-switching and time band trial type



### 3.9.2.2. PM Task Accuracy

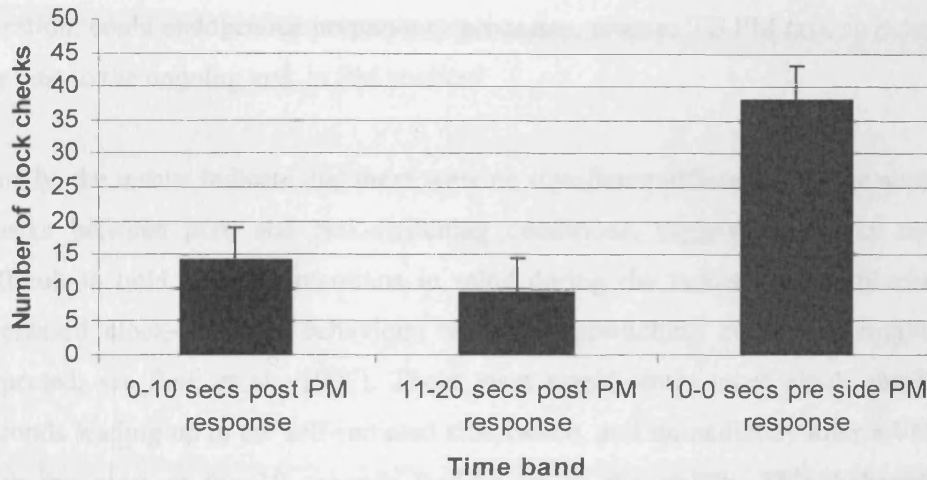
Participants completed a mean of 38.87 (SD=3.82) side switches (PM responses) in the PM conditions again indicating high PM task accuracy. The mean retention interval between

PM side switches was 30.88 secs (SD=2.44). A repeated measures MANOVA with the total number of PM side switches in each PM block as the factor, revealed no significant differences between number of prospective switches in task-switching and pure task conditions ( $p > .05$ ).

### 3.9.2.3. *PM Clock-Checking*

Figure 3.9. shows the details of the participants' clock checking behaviours. Firstly, a 2 (Task-switching: pure, task-switching)  $\times$  3 (Time: 0-10 secs after a side switch, 11-20 secs after side switch and 10 secs leading up to a side switch) repeated measure MANOVA on the number of clock checks showed a main effect of time,  $F(2,28) = 64.34$ ,  $p < .001$ , but no main effect of task-switching or interaction ( $p > .05$ ). To understand the effect of time on clock-checking behaviour, the number of clock checks were collapsed across pure and task-switching conditions and paired sample t-tests performed on these data. This revealed significantly different numbers of clock checking between each time band. There were significantly more clock checks in time band 1 (0-10 secs after PM response) than in time band 2 (11-20 secs after PM response),  $t(29) = 2.69$ ,  $SE = 1.74$ ,  $p < .05$ . There was also significantly more clock checks in time band 3 (10 seconds before PM response) than in either other time band, (time band 3 compared to time band 1 =  $t(29) = 6.93$ ,  $SE = 3.47$ ,  $p < .001$ , and time band 3 compared to time band 2 =  $t(29) = 10.58$ ,  $SE = 2.72$ ,  $p < .001$ ).

Figure 3.9. Number of clock checks in the PM conditions (collapsed across task-switching conditions) as a function of time band



\* $p < .05$

\*\* $p < .01$

### 3.9.3. Discussion

To some extent, the data from this experiment replicate that of experiment 1 and support the primary hypothesis. A robust task-switching effect was demonstrated as well as the more surprising facilitation of RTs in the PM conditions. There was no interference between these two effects, which supports the hypothesis that PM and externally-cued task-switching have little common processing. There was also a task-switching effect on accuracy of the ongoing task, which is line with previous experiments (e.g. Sohn & Anderson, 2000), however, there was no interaction within the ongoing task accuracy data and no effect of task-switching on PM performance (which was almost at ceiling).

The two significant interactions between the variables of PM and time and task-switching and time demonstrate that recovery from the side switch was quicker in PM conditions than in the externally-cued conditions, but that the trials before the side switch were slower in the PM conditions. However, these effects did not always reach significance in the pure task conditions (this is discussed further in the General Discussion below and in Chapter 6, section 6.2.3.). This slower recovery in externally-cued side switch condition may partly

explain the faster RTs in the PM conditions. Additionally, with the removal of trials before and after clock checks we have strengthened support for the hypothesis that active preparatory processes may be employed to prepare for PM task switches, rather than simply variance from eye movements explaining the data. Thus, these findings entail the same question: could endogenous preparatory processes, prior to TB PM task switches, be part of the cost to the ongoing task in PM studies?

Finally, the results indicate that there were no significant differences in the number of clock checks between pure and task-switching conditions, suggesting it was not any more difficult to hold the PM intentions in mind during the task-switching blocks (otherwise decreased clock-checking behaviour in the task-switching conditions might have been expected, see Park et al., 1997). There were significantly more clock checks in the 10 seconds leading up to the self-initiated side switch, and immediately after a PM response – with the most in the 10 seconds leading up to the switch. This J-shaped pattern of responding is consistent with past studies Ceci & Bronfenbrenner (1985) and supports Park et al.'s (1997) hypothesis that during TB tasks there may be 'attentional disengagement' from PM demands. Park et al. (1997) argue that this disengagement from the PM task entails that the need to remember to switch back to the time-monitoring aspect of the PM task is increased. They hypothesised that this switching may be more difficult if the ongoing task makes demands on executive resources (e.g. a working memory ongoing task.) However, here these results do not agree with Park and colleagues' (1997) speculations. In this experiment, participants were equally accurate at PM responding in both pure and the executively-demanding task-switching conditions, and made equivalent numbers of clock checks. These findings again suggest therefore that self-initiated, internal switching - between the ongoing task and the PM task - does not require the same executive resources as the background task-switching.

A criticism may be directed at experiment 1 and 2 that potentially limit these conclusions. The on screen clock (or simply the clock face in experiment 2) could be acting as an external cue for the PM demands, and reducing demands on self-initiated processes. By doing so, the reliance on executive processes may be reduced and this could explain the non-interaction with task-switching. Indeed, the facilitation of RTs in the PM conditions could be cited as evidence for this argument, and the almost ceiling level of PM

performance. A further experiment was thus conducted to increase the demands on self-initiated processes.

### **3.10. Experiment 3**

As described above, the TB PM tasks used thus far have provided some external cues to switch for the participants in the form of the onscreen clock. To increase the demands on internal guidance in experiment 3 the clock was removed, and participants were therefore forced to remember the PM demands with no aid. The same hypothesis underlies this experiment: task-switching and PM will not interact, but that also PM performance would decrease compared to experiments 1 and 2 because of the extra self-initiation demands. In addition, if the same pattern of RTs is found across the RIs in the PM conditions then the explanation that the pre PM response slowing is simply due to increased clock monitoring can be ruled out by this experiment.

#### **3.10.1. Method**

##### Participants & Design

Thirty-two healthy volunteers recruited from the psychology database, the majority of whom were undergraduates of UCL, participated in experiment 3. Sixteen of these participants were male and 24 female, with an age range of 18 to 27. Participants were screened for any neurological or psychiatric history, and again there were no exclusions on this basis. Testing of participants was completed individually in a session lasting approximately 55 minutes. All participants completed all 8 blocks of the experiment. However, as will be explained below, only 24 of these participants were included in the final statistical analyses.

##### Materials & Equipment

The set-up and stimuli for the arithmetic verification task was identical to experiment 1 except in this experiment the level of self-initiation required in the PM element of the task was manipulated by providing no external PM cue at all. Thus, participants were shown the two sums, but they did not have any indicator of time available to them on screen (there was neither a clock, nor an empty clock face presented, otherwise the screen was identical to experiment 2). Instead, participants were instructed to switch sides “*whenever they*

*thought 30 seconds had passed.*” The screen thus looked identical in both PM and externally-cued side switch conditions.

To ensure complete matching of the externally-cued side switch condition and the PM side switch condition (because now the time of the PM side switches would be idiosyncratic), the task was designed such that the exact times at which the participants switched sides in the PM conditions were extracted. These timings were then used as the exact times that the participants were automatically switched in the externally-cued side switch condition. However, because of counterbalancing constraints half of the participants began with an externally-cued side switch condition first. Thus, to provide the times of these first blocks of externally-cued side switches, 12 of the participants were tested with the PM conditions first. Their side switch times from the first PM block were extracted and set as the side switch times for matched participants who began with the externally-cued conditions. The 12 participants from whose first block of PM times were extracted, were not included in any of the analyses, they had simply performed the test for their switching times. Thus, 24 participants were included in the analyses.

#### Procedure

The procedure used in this experiment was identical to experiment 1 except there was no mention of a clock in the instructions. Instead, participants were instructed that in the blocks with the ‘extra task’ they should remember to switch sides whenever they thought 30 seconds had passed. They were informed that there would be no cue to help them remember to do this. They were asked to pay special attention to the information screens before the beginning of each section in order to be certain of whether they would be required to do the extra task or not (since the screen looked the same in both PM and non-PM blocks).

### **3.10.2. Results**

#### *3.10.2.1. Ongoing Task Results*

##### *Accuracy of Ongoing Task*

The mean number of trials performed by participants was 1304 (SD=406.64). The mean total percentage of errors in the ongoing task = 7.03% (SD=3.65). A repeated measures

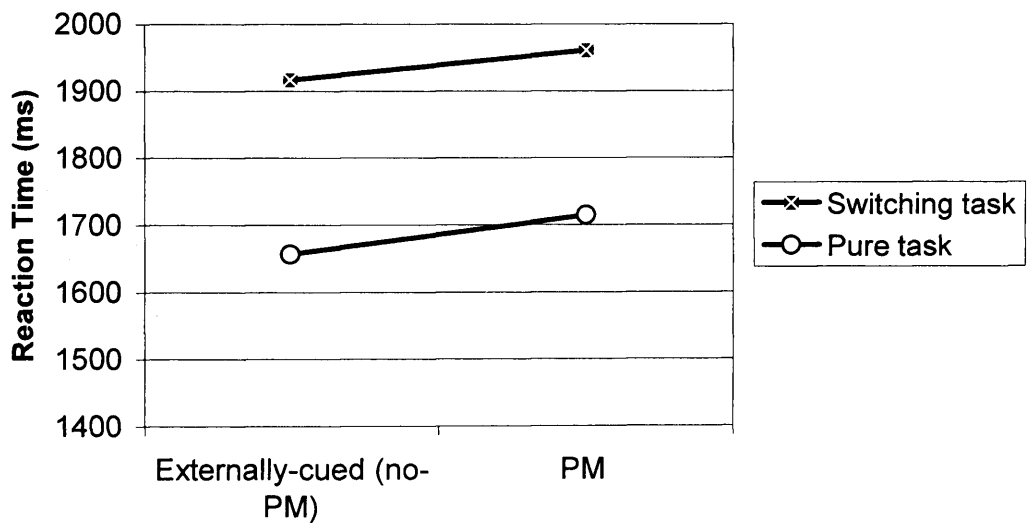


MANOVA with percentage of errors with the factors PM (PM side switch, externally-cued side switch) and task-switching (task-switching, pure task) showed a significant drop in accuracy in the task-switching conditions,  $F(1,23)=9.75$ ,  $p<.01$ , (mean: 7.71% in task-switching blocks collapsed across PM condition and 6.44% in pure task blocks). There was no main effect of PM or a significant interaction ( $F < 1$ ).

*Reaction Time Data of Ongoing Task*

As before the relevant RTs were excluded before submitting participants' mean RTs to a repeated measures MANOVA with PM (PM side switch, externally-cued side switch) and task-switching (task-switching, pure task) as the factors. This produced main effects of task-switching,  $F(1,23)=22.32$ ,  $p<.001$ , and PM,  $F(1,23)=8.25$ ,  $p<.01$ , but with no significant interaction ( $F < 1$ ).

*Figure 3.10. Overall mean RTs as a function of task-switching and PM trial type.*



*Task Switch Reaction Times*

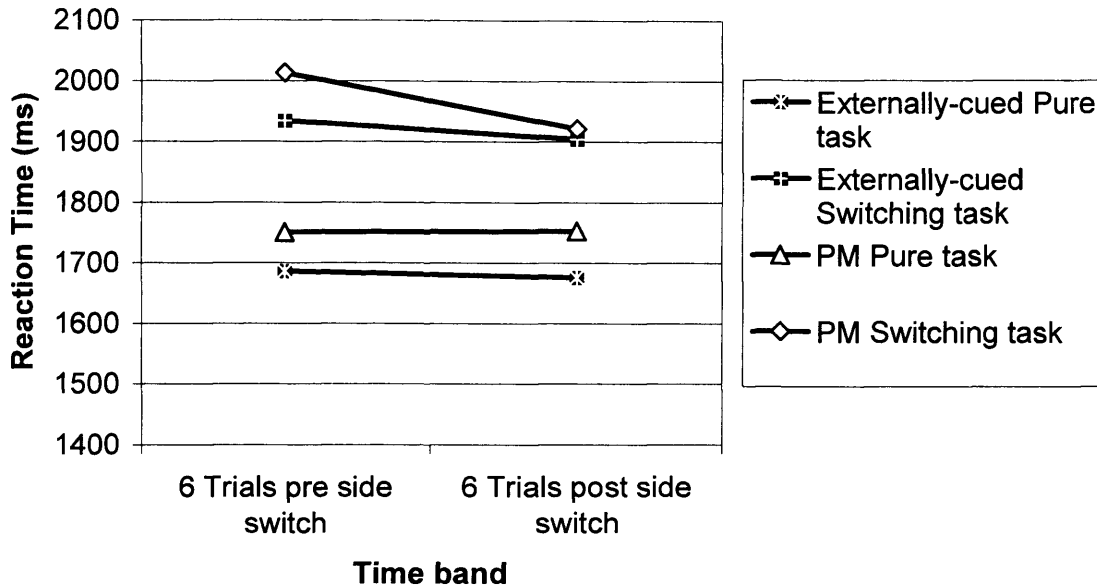
Participants were significantly slower identifying the sums as correct or incorrect in the task-switching blocks compared to the pure task blocks, as can be seen in Figure 3.10.

*Prospective Memory Reaction Times*

As can be seen in Figure 3.10., participants in this experiment performed significantly slower during PM blocks than the equivalent externally-cued side switch blocks. This is in contrast to experiments 1 and 2 in which participants performed faster on the ongoing task in the PM blocks. In the previous experiments, the change in RTs in the 30 seconds between side switches was analysed. In this experiment, the number of side switches (and thus the length of the RIs) was idiosyncratic to each participant; thus, to examine the pattern of RTs across the RIs the mean RTs for the 6 trials before (pre) and 6 trials after (post) a side switch were analysed. Six trials were analysed on the basis that 6 trials averaged corresponded to approximately 10 secs, which matches the time bands used in the previous experiments (participants' overall mean RT collapsed across all conditions was 1.81 secs). These RT data were subjected to a 2 X 2 X 2 repeated measures MANOVA which included PM (PM side switch, externally-cued side switch) and task-switching (task-switching, pure task) and pre and post switches (6 trials pre side switch and 6 trials post side switch) as the variables. This analysis revealed significant main effects of task-switching,  $F(1,23)=36.72$ ,  $p<.001$ , and PM,  $F(1,23)=5.74$ ,  $p<.05$ , such that participants were slower to respond to the sums in the task-switching blocks and the PM blocks. The main effect of the prepost factor also reached significance,  $F(1,23)=4.26$ ,  $p=.05$ , with the 6 trials pre side switch being slower overall than those post side switch (see Figure 3.11.). There were no significant interactions.

However, for consistency with the previous experiments, paired sample t-tests were conducted to examine further the differences between pre and post side switch trials of the same conditions. Analyses revealed only one significant difference between the 6 pre side switch trials and 6 post side switch trials. This significant difference was found in the PM task-switching condition,  $t(23)=3.04$ ,  $p<.01$ , such that the 6 post side switch trials were significantly faster than the 6 pre switch trials. No significant differences between pre and post switch trials in other conditions approached significance ( $p>.05$ ).

Figure 3.11. Overall mean RTs as a function of task-switching, PM pre and post trial type



### 3.10.2.2. PM Task Accuracy

The mean total number of PM side switches = 27.17 (SD=11.15). The mean time between switches = 47.22 secs (SD=15.71). A repeated measures MANOVA with the total number of PM side switches in each PM block as the factor, revealed no significant differences between the number of PM responses in the task-switching and pure task conditions ( $p > .05$ ).

### 3.10.3. Discussion

This experiment produced similar results to experiments 1 and 2 in that two main effects of the variables in question – task-switching and PM – were observed, but with no interaction. Robust switch costs were demonstrated when switching between two tasks than compared to repeating either of the two tasks alone. There was also an increase in RTs in the PM conditions compared to the externally-cued side switch conditions in this experiment; which is, notably, the opposite effect of PM in experiments 1 and 2. Nevertheless, the same conclusion can be derived; task-switching and PM demands produced separate effects on performance of the ongoing task and therefore require difference processes. This remains in line with the original hypothesis. Indeed, the manipulation of the clock variable shows

dissociable effects on the two factors of task-switching and PM, which strengthens the argument that they share little overlap in processing.

Slower responding to the ongoing task during PM blocks is a finding also reported by Smith (2003) within an EB PM task, but is the reverse of the data observed in experiments 1 and 2. This experiment increased demands on self-initiation processes (e.g. self-initiated retrieval and time estimation) accounting for the overall slower RTs. However, inspecting the pre and post side switch data does reveal a similar pattern of RTs as in experiments 1 and 2, albeit slightly weaker. The 6 trials before a PM response were significantly slower than the trials after the PM response in the PM task-switching conditions, as was also apparent in experiments 1 and 2 (in which the pure task conditions also showed this pattern). Again, then the interpretation of these findings is that preparatory processes for the PM task switch are being recruited, since the opposite pattern appears in the externally-cued task-switching conditions (i.e. slower responses after the switch and gradually speeding up). Arguably, this brings into question the theory (Smith, 2003) that denotes monitoring processes as the basis for the slower responding to the ongoing task during PM conditions (instead it may be preparatory processing). This theory has not been directly applied to TB PM tasks as the empirical basis for the theory has been developed using EB PM. Indeed, these are amongst the first experiments, to have examined ongoing task RTs during a TB PM task. Combining Smith's PAM theory and the speculations of Park et al. (1997) the equivalent TB theory would predict increased slowing as participants approached the correct PM target time, because of increased time-monitoring. Latencies after a PM switch might be faster because of temporary 'attentional disengagement' from the PM task, that is, reduced prospective time monitoring. However, the theory would not necessarily predict the difference between the ongoing task latencies in the externally-cued side switch conditions and PM conditions immediately after a side switch. The former are slower in all three experiments, presumably because there can be less preparation. These data therefore need incorporating into a cognitive model of TB PM.

If preparatory processes are occurring in TB PM it is because they are predictable and under complete endogenous control (e.g. Rogers & Monsell, 1995; Arrington & Logan, 2004, 2005). Conversely, EB PM task switches are unpredictable (or at least less predictable) because participants wait for the external cue to signal that the intention must

be acted upon (the process of identifying the cue is still self-initiated of course). Unpredictable task-switching may not always generate the same degree of preparation (Monsell et al., 2003). Thus, to understand if any preparatory processes are occurring in EB PM conditions (and therefore question Smith's PAM theory as the explanation for the ongoing task slowing) another experiment is required with EB PM task demands.

### **3.11. Experiment 4**

The aim of this experiment was to test the same hypothesis that task-switching and PM recruit separable processes, but now using an EB PM task. Much of PM research has focussed on EB PM and thus the theoretical picture regarding the effect of PM demands on the ongoing task is clearer. McDaniel and Einstein (2000) for example, produced a multi-process theory claiming that identification of EB PM targets, under certain task conditions, can be automatic (see Chapter 2, section 2.4.3.). In contrast, Smith's (2003) PAM theory, as discussed in claims that there will always be self-initiated monitoring for the PM target. If the former is the case in this experimental paradigm then there may be little cost to the ongoing task and no interaction with task-switching on this basis. The PAM theory predicts there will be a cost to the ongoing task, but the prediction is that this cost will be unaltered by the task-switching conditions.

As previously discussed, an EB PM task switch is more similar to an unpredictable task switch in the task-switching paradigm. Indeed, the nature of the external cueing in EB PM means it resembles task-switching more closely. For this reason, the data may reveal a different pattern of behaviour than the previous experiments, for instance there may be slowing immediately after the PM response. The difference in the degree of endogenous control required however, still leads to the same prediction: that task-switching and PM will not interact.

#### **3.11.1. Method**

##### **Participants and Design**

Twenty-four healthy volunteers of similar educational background, the majority of whom were UCL undergraduates, recruited from the same UCL database and ranging in age from 18 to 26 participated in experiment 4. 10 were males and 14 were females. Again a health

screening ensured participants had no history of neurological or psychiatric disorders. Participants attended one session of testing lasting approximately 55 minutes and completed all 8 conditions.

### Materials and Equipment

This experiment used the same materials, and method of generating the sums, as in experiment 1. The task screen looked identical as experiment 3, without the clock. In this EB PM study however the targets for a side switch were embedded in the trial stimuli as in previous EB PM studies (e.g. Einstein and McDaniel, 1990). Thus, the targets for side-switching were no longer associated with a time point, instead the event cue became a repeated digit within the first addend, minued or solution of the sum. Participants were told to switch on detecting any term with a repeating digit. Thus, if sums such as  $33 + 3 = 39$  or  $58 - 3 = 55$  appeared – the participant should press the space bar to switch sides.

Each participant received a novel and pseudorandom schedule of PM targets and externally-cued side switches in each block. The program generated the PM targets and automatic switch schedule from the following constraints: the target/automatic switch occurred 10, 20, 40 or 50 seconds after the last switch with 15% probability and after 30 seconds with 40% probability. This irregularity of targets was intentional in order to avoid ceiling effects. However, since a large proportion of targets had a RI of 30 seconds, the experiment is comparable with the previous TB experiments. If the participant missed a PM target, the program continued presenting targets every second trial until the participant switched. No repeating digits were presented in the stimuli of the externally-cued side switch condition.

### Procedure

The procedure for experiment 4 was the same as for experiment 1. Participants were provided with the same instructions and practice, with the exception that they were instructed that in the PM conditions they must switch sides whenever they saw repeating digits. One example of a repeating digits target (00) was supplied in the instructions, although the target 00 never appeared in the actual stimuli. The experimenter ensured that the participants understood all instructions correctly before beginning testing. The same 8 block types as in experiments 1-3, each lasting 5 minutes and 10 seconds long, were

presented in counterbalanced order across all participants, with the same constraint that PM and externally-cued blocks alternated.

### **3.11.2. Results**

One participant was excluded from the analyses because of an exceptionally high error rate (mean: 17.53%). The results below are therefore based on 23 participants.

#### *3.11.2.1. Ongoing Task Results*

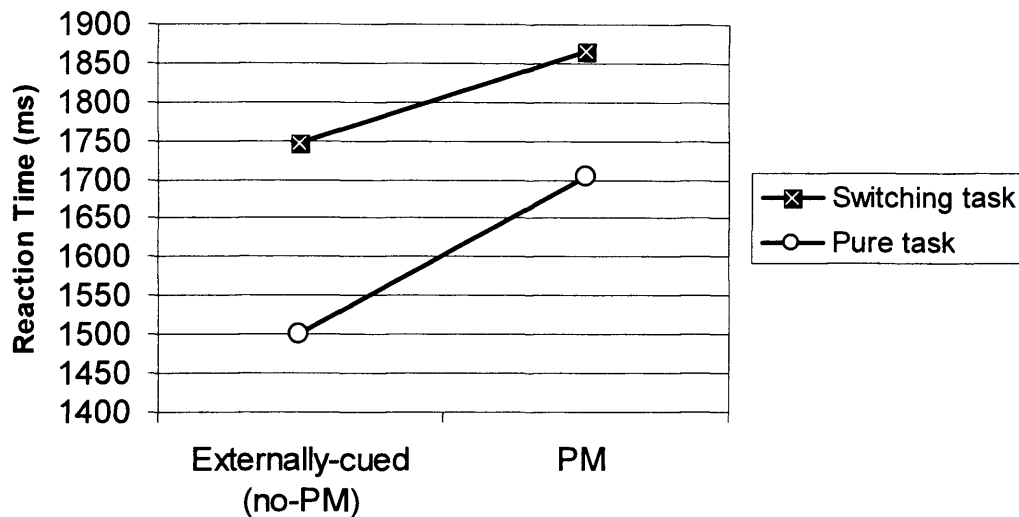
##### *Accuracy of Ongoing Task*

The mean error rate for the arithmetic verification task was 5.71% (SD=2.23) with an average of 1422 trials performed (SD=287.42). A repeated measures MANOVA using the accuracy data (percentage of errors) and with PM (PM side switch, externally-cued side switch) and task-switching (task-switching, pure task) as the factors. This revealed only a significant effect of PM,  $F(1,22) = 7.56$ ,  $p < .05$ , with participants making fewer errors in the externally-cued side switch conditions (mean: 4.99% in externally-cued conditions collapsed across task-switching conditions and 6.56% in PM conditions).

##### *Reaction Time Data of Ongoing Task*

The same trial types were excluded as in the previous experiments, participants' mean RT's were then subjected to a 2 X 2 repeated measures MANOVA with PM (PM side switch, externally-cued side switch) and task-switching (task-switching, pure task) as the factors confirmed main effects of PM,  $F(1,22)=56.28$ ,  $p < .0001$ , and task-switching,  $F(1,22)=19.73$ ,  $p < .0001$ . Participants were faster to respond to the ongoing task in the pure task and externally-cued side switch conditions (see Figure 3.12.). There was no significant interaction between these two effects ( $F < 1$ ).

Figure 3.12. Overall mean RTs as a function of task-switching and PM trial type.



#### *Task Switch Reaction Times*

Participants were significantly slower identifying the sums as correct or incorrect in the task-switching blocks compared to the pure task blocks, as can be seen in Figure 3.12.

#### *Prospective Memory Reaction Times*

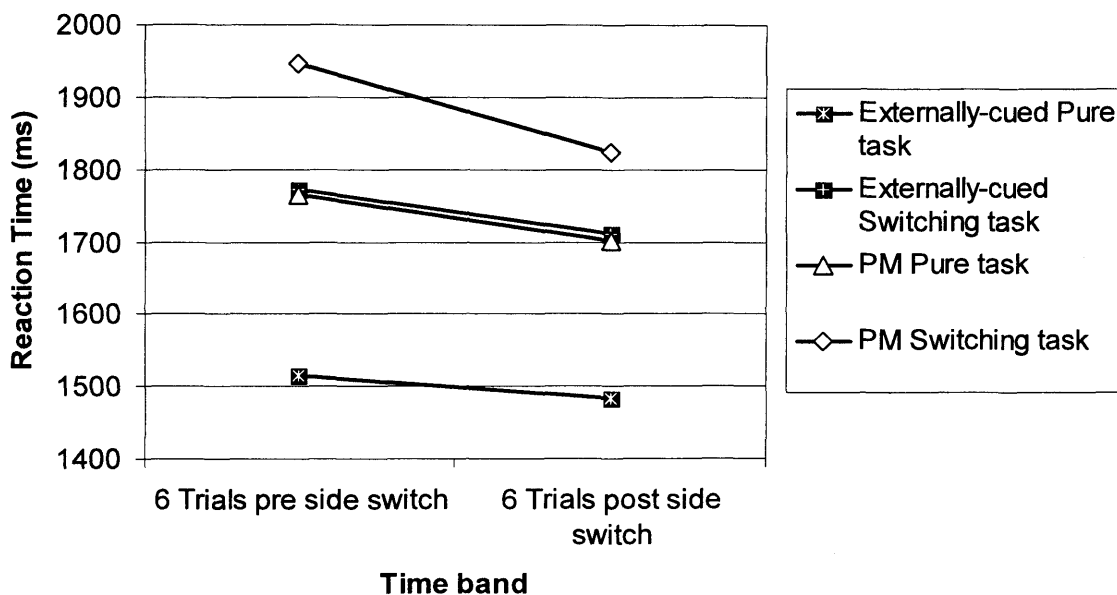
As can be seen in Figure 3.12., participants in this experiment performed significantly slower during PM blocks than the equivalent externally-cued side switch blocks. A further MANOVA on RTs with 6 trials before (pre) and after (post) PM response and the matched externally-cued side switches, task-switching (task-switching, pure task) and PM (PM side switch, externally-cued side switch) as the factors revealed main effects of task-switching,  $F(1,22)=16.61$ ,  $p=.001$ , PM,  $F(1,22)=74.95$ ,  $p<.001$ , and prepost,  $F(1,22)=26.73$ ,  $p<.001$ . Participants were slower to respond to the sums in the task-switching, PM and pre side switch blocks (see Figure 3.13.). The interaction of the prepost and task-switching variables approached significance,  $F(1,22)=4.0$ ,  $p=.058$ , but no other interactions approached significance (and the 3 way interaction showed  $F < 1$ ).

Again for consistency with the previous experiments, paired sample t tests were performed and revealed the following significant differences: in the PM blocks, trials were significantly faster after a PM response than before a PM response in both the pure task,



$t(22)=2.71$ ,  $SE=.023$ ,  $p<.05$ , and the task-switching,  $t(22)=3.56$ ,  $SE=.034$ ,  $p<.01$ , conditions. In the externally-cued (non-PM) blocks, trials were significantly faster after a side switch than before a side switch in the task-switching condition only,  $t(22)=2.79$ ,  $SE=.02$ ,  $p<.01$ .

Figure 3.13. Overall mean RTs as a function of task-switching, PM pre and post trial type.



### 3.11.2.2. PM Task Accuracy

The accuracy of the PM task was measured by assessing the proportion of correct targets each participant detected (this included trials where participants switched sides after mistakenly completing the arithmetic verification task first i.e. late detection of target). The mean number of targets presented to participants across all the PM blocks was 72.70 ( $SD=36.84$ ). The mean percentage of correct PM targets detected was 61.49% ( $SD=20.08$ ). A paired samples t-test found no significant difference between the mean correct PM targets detected in the task-switching blocks (mean=63.11%,  $SD=20.08$ ), and the mean correct PM targets detected in the pure task blocks (mean=63.13%,  $SD=23.95$ ). This suggests it was no more difficult to detect PM targets in task-switching conditions than in pure task conditions,  $t(22)=.004$ ,  $p>.05$ .

### **3.11.3. Discussion**

The major finding of this experiment is consistent with that of experiments 1-3. The results suggest that the rapid switching between two simple tasks has little common processing with EB PM. Participants showed slower performance on the ongoing task during the task-switching conditions and slower RTs, along with significantly poorer ongoing task accuracy, during PM conditions. There was also relatively poor PM task accuracy such that participants were only identifying approximately 60% of the targets, although there were no differences in PM performance between the task-switching conditions. These data suggest that this EB PM task may be more cognitively demanding than the previous TB PM tasks. It is thus unlikely that there was automatic noticing of the targets. The slowing of RTs during the ongoing task is instead consistent with Smith (2003); who maintains that EB PM tasks require some executive resources, in the form of monitoring for the target.

Pre and post PM responses showed the same pattern over the RIs as the externally-cued non-PM conditions (within this experiment), with slower pre side switch trials than post switch trials. This is consistent with the idea of EB PM task switches being more similar to unpredictable task switches because the RTs match the externally cued side switch conditions, which are also essentially unpredictable task switches. The implications of these data are discussed in more detail in the next section.

### **3.12. General Discussion**

The four experiments presented here explored the relationship between PM and task-switching, with the prediction that they would show little interference because of the difference in the degree of internal guidance required. Across all four experiments, task-switching and PM produced separate effects on the RTs of the ongoing task and did not interact; these data addressed this initial hypothesis. Accuracy data of the ongoing task also failed to indicate any interaction between these two variables. This lack of interference was attained using four variations of the PM task: TB with a clock, TB with a 'revealable' clock, TB without a clock and EB PM. In the first two experiments, RTs to the ongoing task were found to be faster in the PM and pure task conditions. In the third and fourth experiments however, participants were still faster in the pure task conditions but were now slower in the PM conditions, which demonstrates another dissociation of PM and task-

switching because of the differential impact of the clock variable. The accuracy of PM responding was high and was unaffected by the task-switching manipulation across all four experiments. These findings are consistent with the hypothesis that self-initiated, PM switches and rapid, externally-cued task-switches employ potentially separable cognitive processes.

These data are inconsistent with a previous experiment that has combined task-switching and EB PM (Marsh et al., 2002) which did show interference to PM performance in the task-switching conditions, but this can be explained by theoretical and methodological differences. Firstly, Marsh et al., (2002) only measured PM performance and not the ongoing task itself. Secondly, the experiments presented here were the first to recognise that any PM response involves a self-initiated task switch, and consequently provide a suitable externally-cued PM response control condition. Interesting data have emerged from this methodological procedure, primarily, from analyses comparing ongoing task RTs before and after PM responses with the equivalent RTs of the externally-cued condition. The findings have provoked the consideration that task switch preparation processes, and other task switch costs, may be partly responsible for the negative effects of the PM conditions on the ongoing task (e.g. Smith, 2003). These processes cannot explain all of the cost to the ongoing task (because experiment 3 and 4 showed an increased cost), nevertheless the results do have some important implications which are discussed further below.

Initially, the discussion will focus on the apparent independence of processing between PM and task-switching. There are three theoretical possibilities to explain the results from these experiments. Firstly, there is the explanation that fits the original hypothesis: that rapid, externally-cued task-switching involves independent cognitive control processes to those involved in PM (internally-generated) task switches. Secondly, there is the possibility that rapid, externally-cued task-switching actually requires few executive control processes than previously conceived, and for this reason does not interact with PM. Finally, the opposite is also possible: that PM tasks actually require few executive control processes and thus does not interact with task-switching. I will now consider these three theoretical possibilities.

*Potential Explanation 1: Task-switching and PM rely on independent executive control processes*

The theoretical basis of this interpretation rests on the concept of multiple executive processes, and the functional fractionation of the prefrontal cortex, as discussed in Chapter 1, section 1.2.2. There is gathering support for this concept of multiple executive processes and for fractionation (Burgess & Shallice, 1996; Burgess et al., 1998; Shallice, 2002; Stuss & Levine, 2002; Burgess & Simons, 2005). More importantly, there is also evidence that this self-initiated/externally-cued dissociation exists. For example, lesion data has demonstrated that frontal patients may selectively suffer in tasks that are ill structured and unconstrained (Shallice & Burgess, 1991; Goel et al., 1997; Levine et al., 1998, Levine et al., 2000; Burgess et al., 2000), whilst performing within normal limits on IQ tests, memory tests and other executive function tests. Multitasking tests have been particularly successful at drawing attention to these selective deficits and mimicking the patients' everyday task difficulties. From a large lesion study, Burgess and colleagues (2000) argued that the cognitive components of multi-tasking appeared to involve retrospective memory, planning and 'intentionality'; any of which could be selectively disrupted. The latter component was associated with the medial areas of PFC (BA 10 and some parts of 8 and 9) because damage to these areas resulted in poor self-initiated task-switching and plan and rule following. The other cognitive components were also tentatively linked to different neural bases (left anterior and posterior cingulates, DLPFC respectively.) Recent imaging studies also support a role for BA10 in PM (Yamadori et al., 1998; Burgess et al., 2001, 2003). Thus, evidence from these multitasking tests shows a possible selective self-initiated task control deficit (self-regulatory disorder). This implies the dissociation of the cognitive and, possibly, neural mediation of self-initiated and externally-cued tasks (refer to Chapter 1, section 1.3.2. for further discussion on this).

With respect to internally-guided and externally-cued task-switching there is evidence for different processes and neural mediation which corroborates the results of these experiments. Firstly, Koch (2003) compared externally-cued and internally-generated (i.e. task sequence retrieved from memory) task-switching and argued that non-identical processes appear to be responsible for the switch cost given the differential effects of RSI on each condition. For instance, he contends that the external cues may aid in the process of

inhibiting competing tasks because of their association with the respective task, a process that would reduce switch costs. Secondly, Arrington & Logan (2004, 2005) deemed voluntary task-switching as operating differently to task-switching performed using the explicit-cueing procedure. This too was based on the differential effect of RSI on switch costs in these two task types, but this time voluntary task-switching with longer preparation time was shown to reduce switch costs compared to the explicit-cueing procedure. Thus, it was postulated that the source of switch costs in voluntary task-switching was disparate to the source within the explicit-cueing procedure. The authors argue that voluntary task switch costs must reflect endogenous control processes (because it requires entirely top-down control), whereas externally-cued task switch costs may represent the processes required to overcome priming (e.g. Mayr & Keele, 2000). Thirdly, neuroimaging evidence pinpoints involvement of the DLPFC in externally-cued task switching (Meyer et al., 1997; Dove et al., 2000). Dreher et al., (2002) report involvement of the medial areas of PFC in predictable task switches (which can thus be internally-generated) and lateral areas in unpredictable task-switching. These different processing demands can convincingly explain the non-interference between PM and task-switching (see also Koechlin et al., 2000; Weidner et al., 2002).

*Potential Explanation 2: Externally-cued task-switching makes few demands on executive processes.*

It is possible to argue that self-initiated task-switching and externally-cued task-switching produce no interaction because actually externally-cued task-switching does not make demands on executive control processes at all. This is consistent with the task-set inertia hypothesis of Allport and colleagues' (1994). This theory claims that performance in task-switching conditions is slower because of task-set interference from the different response to the task-set on the previous trial. In other words, response selection is slowed because of previous task-set priming. This model emphasises the bottom-up processes involved in task-switching (e.g. priming) and thus has little emphasis on the role of top-down executive processes. Switch costs are viewed as a result of passive, involuntary processes, which are therefore unlikely to interact with the executive processes involved in self-initiated task-switching. Data from these experiments might be considered to support this model, although there is no direct support from the methodology or data to explain the source of

the switch costs. Although possible, this conclusion is at odds with the ‘active process’ model of switch costs proffered by Rogers and Monsell (1995) amongst others (e.g. Rubenstein et al., 2001; Sohn & Anderson, 2001; Mayr & Keele, 2000; Mayr & Kliegl, 2003), which states that endogenously controlled task-set reconfiguration processes (that is, executive control processes) generate the switch costs.

A recent review of the task-switching literature (Monsell, 2003), suggests that the empirical evidence endorses a view that combines these two models. Experiments (e.g. Meiran et al., 1996) demonstrating that increasing the time available for preparation reduces the switch cost shows Allport et al.s’ task-set inertia theory to be lacking in explanatory power. Similarly, experiments showing an asymmetrical switch cost between strong and weak task-sets cannot easily be accounted for by the task-set reconfiguration model. Monsell argues that a combination of different processes produce the switch cost (and the residual switch cost) and are likely to include some top-down preparatory processes. With this review in mind, and also considering the evidence that task-set priming may lead to the recruitment of active processes (namely inhibition, e.g. Mayr & Keele, 2000; Mayr, 2002) – it is unlikely that rapid, externally-cued task-switching as used in this experiment is not mediated by some executive control processes.

It is worth noting that much of this theory regarding the source of switch costs is based on experimental manipulations of the alternating-runs procedure (AABBAA) of Rogers and Monsell (1995), rather than the ABAB procedure. However, Rogers and Monsell (1995) have argued that performing the task-switching blocks in this ABAB procedure, as used in these experiments, places greater demand on executive control since two task sets have to be maintained in a state of readiness. The use of this methodology then should increase the likelihood of interference with PM if they do share executive resources.

### *Potential Explanation 3: PM makes few demands on executive processes.*

The finding of facilitation of RTs in PM conditions is unique to these experiments. The reason for this speeding-up is discussed in more detail below – but one could contend that this provides evidence that few executive resources were being used. It might suggest participants had little difficulty in performing the PM task, and indeed accuracy of PM was

high. Arguably, the external cue, in the form of the clock, was enough to reduce self-regulatory executive (retrieval) processes to such an extent that there was no conflict with the background task-switching. Indeed, Einstein & McDaniel's (2000) multi-process theory suggests that PM cue recognition can be automatic, depending on the ongoing task properties and PM cue properties (e.g. Cherry & LeCompte, 1999; McDaniel et al., 2004), in which case it is unsurprising there was no interaction with task-switching.

There are several ripostes to this argument. Firstly, on closer inspection of the pattern of RTs, the facilitation can be (at least partly) attributed to the slower task-resumption after a side switch in the matched externally-cued conditions. This was presumably because participants were unable to prepare for this unpredictable side switch. For this reason, it seems some endogenous preparation processes are occurring in the PM conditions, again this is discussed more fully below. Secondly, latency data from experiments 3 and 4 did show a slowing of RTs to the ongoing task during PM conditions. Experiment 3 removed any external cues and thus placed further demands on self-initiated processing and the EB PM task in experiment 4, according to PAM theory, creates monitoring demands. Thus, experiments 3 and 4 did make demands on executive processes, and again these processes did not seem to interfere with the background task-switching. Further to this, Einstein et al., (2003) found evidence that maintaining intentions for even 5 second delays used moderate amounts of executive resources because participants periodically activated the intentions over the delay period. Finally, Arrington and Logan (2004) also established that there were switch costs to voluntary, self-initiated task switches, and although somewhat speculative, they ascribed this to active reconfiguration processes. From the evidence above, it is reasonable to believe that the PM tasks employed in these experiments did utilise executive processes, and that these were thus different to those employed in externally-cued task-switching.

### **3.12.1. Time-Based and Event-Based PM**

At the broadest level, the results from these experiments confirm what is becoming more obvious as PM research progresses, that there are different cognitive mechanisms at play within TB and EB PM (e.g. Einstein et al., 1990, 1995). These are the amongst the first experiments to show the effects of TB PM demands on the ongoing tasks. Experiments 1

and 2 (TB with clocks) showed a different pattern of performance, in both RTs and accuracy, than experiment 4 (EB). In the former, participants were actually faster to respond to the ongoing task during PM conditions than in the externally-cued conditions – whereas the opposite is true in experiment 4. Interestingly, experiment 3 (TB with no clock) also showed a different pattern of performance to experiments 1 and 2. Without any external cues, and therefore increased reliance on self-initiated processes, TB PM in experiment 3 induced longer ongoing task RTs. The results of experiment 3 are as would be expected from the TB PM literature, which has argued that TB PM has high dependence on self-initiated processes (Craik, 1986; Einstein et al., 1995; see Chapter 2, section 2.5.) and thus will have a cost on the ongoing task. There are also of course extra demands made in the form of time-estimation and time-monitoring processes in this experiment (Ceci & Bronferbrenner, 1985; Cicogna et al., 2005).

As discussed in Chapter 2, there are fewer theoretical models of TB PM than EB PM, but any model must now be extended to account for these data illustrating a novel distinction between types of TB PM tasks. Firstly, a type in which the time is obvious and externally-signified by an environmental cue, that is a clock, and secondly a type in which the cue is internally-signified by one's own time estimation, which places greater demands on self-initiated processing, as evidenced by longer RTs. Thus, the former type might actually be conceptually related to an EB task, but clearly from the difference in RT patterns there is something unique about it. This 'unique' aspect may be that the clock acts as a threatening deadline on performance; consequently producing faster RTs. Plainly, there is a continuity and predictability about time, which is simply not present in an unpredictable EB paradigm, which provokes this 'deadline' hypothesis. This 'deadline effect' will certainly require replication and further research, and indeed, I address this in experiment 5 of this thesis.

With respect to experiment 4, involving the EB PM task, participants demonstrated slower RTs and greater inaccuracy in the PM conditions. The detrimental effect of EB PM demands on ongoing task performance replicates Smith (2003). According to Smith's PAM theory endogenously controlled monitoring for the cue produces the slowed ongoing task performance in PM conditions. Other evidence supports this viewpoint. Marsh and Hicks (1998) in a series of experiments that manipulated the ongoing task found that only ongoing tasks which made demands on planning and monitoring affected PM performance.



Similarly, Burgess and Shallice (1997) also emphasised the links between planning, monitoring and PM. Although monitoring for the cue can sufficiently explain the ongoing task slowing, another hypothesis is also proposed in the section below that can also account for this effect.

The lower accuracy to the ongoing task during the EB PM conditions suggests that EB PM actually may be more demanding than TB PM (at least with the parameters in this experiment), despite hypotheses that the opposite will be the case (e.g. Craik, 1986). As Park et al. (1997) have previously argued, this may be because TB allows for some attentional disengagement from the PM task immediately after a PM response that enables participants to focus more successfully on the ongoing task during these periods. Conversely, as described above, EB PM requires constant preparatory attentional processes to monitor for the cue. This potential difference is also explored further in the subsequent Chapter, but it seems a reasonable explanation for this finding.

### *3.12.1.1. Explaining the Pattern of RTs Across the Retention Intervals*

That PM requires a self-initiated task switch is axiomatic and yet these are the first experiments, to my knowledge, to incorporate an externally-cued version of the PM task switch to understand the effects, if any, of this voluntary task switch on ongoing task performance. This also motivated the methodologically novel approach of analysing RTs across the RIs in TB PM, by splitting the trials into equal time periods between PM responses and looking for significant changes. The data from experiments 1 to 3 revealed significant effects of time band (i.e. position of trial within the RIs) on ongoing task performance between the PM task switch and its equivalent externally-cued switch. As Ruge et al., (2005) comment, *'the involvement of a task preparation process can be inferred only indirectly from the beneficial impact it has during the subsequent task implementation.'* (p. 341). The interpretation of these data is that task preparation processes can be inferred from the beneficial impact of task implementation, in this case indicated by the comparatively faster recovery from the side switch in the PM conditions (i.e. after the PM task switch) compared to the externally-cued conditions. It seems difficult to reconcile another explanation for these data. For instance, increased time monitoring or increasing retrieval processes, although able to account for the pre-PM response slowing, cannot

explain the faster recovery after the side switch compared to the control condition (this is discussed further in Chapter 6, section 6.2.3.). This is consistent with Burgess (2001) et al., who described neural activation associated with ‘anticipatory processes’, which could be associated with these task-switching preparation processes, although they used an EB paradigm.

Theoretically, this argument is also consistent with Monsell and colleagues (2003) argument that predictable task switches allow for task-set reconfiguration (or ‘task-readiness’) before the task switch, which then reduces the switch cost and produce one-trial recovery from the task switch (again this argument is developed further in Chapter 6). The findings of the TB PM experiments also corroborates Arrington & Logan’s (2004, 2005) studies with voluntary task-switching, which as described above, demonstrated that the switch costs decreased with preparation time, presumably reflecting endogenous control processes. Both internally- and externally-signified TB tasks (i.e. with and without the clock) showed this cost to the ongoing task ‘pre switch’; in contrast to the cost to the ongoing task during the externally-cued side switch, which was ‘post switch’. However, these effects did seem to be stronger in the task-switching rather than in the pure task conditions (although the interactions were not significant). This is discussed further in Chapter 6, section 6.2.3., but it is possible that the self-paced alternating trials procedure used here (i.e. ABAB) with its short RSIs only allows for some preparation for these task switches, and this explains the lack of interference in these pre-switch time bands.

In the EB PM experiment the trials prior to the side switches were slower than the trials post side switch in both the PM and the externally-cued conditions. In other words, there was no difference in the RT pre and post side switch patterns between the PM and no-PM conditions. This is in contrast to the TB PM experiments in which participants showed a differential RT pattern in the PM and externally-cued (non-PM) conditions. Firstly, this provides extends the evidence that EB PM is qualitatively different to TB PM. Moreover, this qualitative difference may again be partly attributable to the predictability of the PM task-switches in each paradigm. Whereas a TB PM task-switch is comparable to the predictable, highly endogenously controlled task-switching, an EB PM task-switch is more similar to those generated in the random, unpredictable task-switching paradigm (e.g. Meiran, 1996; Tornay & Milan, 2001; Monsell et al., 2003; Milan et al., 2005).

Accordingly, as is the case, these EB switches should produce a similar RT pattern (pre and post side switch) as the externally-cued conditions, which are also unpredictable.

However, although the EB PM conditions and the externally-cued conditions produce the same pattern of RTs, as expected, this pattern is inconsistent with previous unpredictable task-switching studies. Monsell et al., (2003) showed that several trials were required to recover from an unpredictable task switch, whereas these data show faster trials after an unpredictable side switch, at least compared to the trials preceding the side switch. Why do these data show a fast recovery rate in an unpredictable task-switching condition compared to previous studies showing a slow rate of recovery? Firstly, the post side switch RTs are only faster compared to the pre side switch RTs, RT data from the entire RI is not considered. The decrease in the need to monitor for the cue immediately after the PM response can perhaps explain the faster RTs here and mask the effects of the unpredictable task switch cost. (Although this cannot explain why the same pattern occurred in the externally-cued conditions, given there is no need to monitor for a cue). Moreover, Tornay & Milan (2001) have argued that unpredictable task-switching allows for fuller task-set reconfiguration (i.e. preparation) since they found faster trials after the switch. These findings seem consistent with their data.

The EB PM switch, although unpredictable, is still self-initiated, thus, the processes of cue monitoring and cue interpretation are different to those in unpredictable task-switching in which a specific cue immediately signals which task to perform (e.g. Monsell et al., 2003). Forstmann et al., (2005) describe distinct PFC regional activation for tasks directly cued compared to tasks in which the participant must internally-generate the task because of indirect task-cue associations. Behaviourally, their data revealed higher switch costs for the internally-generated task-switches compared to the directly-cued task-switches, but they did not report RTs of any trials following this switch trial, which would be the trials equivalent to the post trials here.

Some qualifications must be considered to the interpretations discussed so far. Firstly, in the task-switching literature, it is clear that preparation processes are inferred from the beneficial impact of task implementation judged by the RTs to the 'switched-to' task (i.e. not the RTs to the trials after the task-switch). This data is unavailable in this experiment;

the PM task itself is computationally different to the ongoing task (i.e. the PM task just involves pressing a different key to initiate the side switch, there is no arithmetic) and a PM task repeat trial is not included (i.e. the RTs of two consecutive PM responses). The first trials immediately following a side switch were also not included because of the noise created by eye movements from switching from one side of the screen to another. However, the trials after the switch trial are also considered in the task-switching literature and used in the method of inferring preparatory processes (e.g. Arrington & Logan, 2004, 2005; Milan et al., 2005).

Secondly, it could be argued that the PM response was not really a task switch, because the same task was carried out on the other side, it was rather more like a 'location' switch. The definition of a 'task-switch' and a 'task-set' is certainly a negotiable feature of experiments in the executive functions field (and arguably the question of what does constitute a task-set remains uncomfortably open, note Tornay & Milan's (2001) attempt to define this concept as '*a particular set of processes, linked together in a certain way*', p. 786). For some researchers a 'task-switch' is as simple as a change in dimension, for instance, Ruge et al., (2005) considered the requirement to switch between judging if a filled white square appeared up or down or if the square appeared left or right was indeed task-switching. On the other hand, Weidner et al (2002) have argued that a visual search task that required participants to switch between searching different dimensions such as motion and colour (e.g. which stimulus is moving compared to following trials of which stimulus is red) is not a task-switching paradigm. In the current experiments, I would argue that the PM response is a task switch on several levels – the internal switches to remembering the intention, then the actual task-switch of pressing a different key followed by the side switch itself. Moreover, a key characteristic of task-switching experiments, that the same stimuli can afford both task-sets, was met.

Thirdly, the interpretation that PM may also involve task preparation processes, and that this may partly explain the detrimental effect on ongoing task RTs, is based on data from very short RIs used within the present experiment. RIs of thirty seconds are short compared to other studies in the PM literature (e.g. Cicogna et al., 2005). In real life, intentions are held for much longer delays such that switches to acting out intentions are less frequent (e.g. post birthday card at lunch time, which is four hours away). Thus, the extent to which

these preparation processes occur prior to less frequent PM task switches remains an area of uncertainty. Certainly, if these preparation processes are occurring and detracting from the ongoing task then the implication would be that any procrastination of tasks reduces current task performance (somewhat worryingly!). Seeking evidence from the task-switching literature does not help fill this void, as real life task-switching appears to be an area completely neglected, (apart from the multitasking studies which measure general perseveration), no doubt because of the difficulties inherent in measuring real life switch costs. Although it may be difficult to look for preparatory processes in longer RIs it would be a useful avenue for future research.

In addition, it could also be argued that because of the short RIs involved in these experiments processes more associated with vigilance tests may be implicated (e.g. see Burgess et al., 2003 for discussion of RIs). The similarity between vigilance and PM tests is that they both require participants to make a different response upon noticing specific stimuli (see Brandimonte et al., 2001). The key difference is that in vigilance tests this requirement to make a different response is very much at the forefront of the test, whereas in the PM tests the intentions become a background dual-task and must be retrieved from memory and initiated at the correct time. Accordingly, these two paradigms make different cognitive demands (Brandimonte et al., 2001). A good source of evidence that the experiments presented here are not comparable to the vigilance paradigm, and are more appropriately considered as PM, is the finding of faster RTs in experiments 1 and 2. According to the literature, vigilance tests should slow participants down as they await the specific stimuli; participants are required to monitor 'online'. In experiments 1 and 2 participants actually showed faster RTs in the PM conditions, suggesting that the intentions are not being maintained 'online' or it is unlikely (although granted not impossible) this effect could occur.

### **3.13. Summary**

The aim of this Chapter was to examine the relationship between self-initiated PM and externally-cued task-switching. The results revealed that task-switching and PM recruit potentially separable processes and this was attributed to the difference in endogenous control required. Performance of the ongoing task changed across the RIs in a pattern that

suggests PM may involve preparatory task-switching processes. However, analyses also demonstrated distinct differences in ongoing task performance between TB PM with and without a clock present; this interesting finding is considered further in experiment 5.

## Chapter 4

### *Internal Control in Prospective Memory*

#### **4.1. Introduction**

The novel pattern of results from the first set of experiments was that participants produced faster RTs to the ongoing task during the PM conditions in experiments 1 and 2. In contrast, during the third TB PM experiment participants were slower at the ongoing task during the PM conditions. The design and procedure of the three experiments were identical except for the clock, which was either present, 'revealable' or absent. This variable appears to have altered the processes recruited for the task and this was attributed to different demands made on self-initiated retrieval processes and time estimation. This is consistent with previous PM research that emphasises self-initiated retrieval processes as a key variable in PM performance (Craik, 1986; Einstein et al., 1995).

Einstein and colleagues (1995) originally split PM into TB and EB PM tasks on the basis that the latter provides external cues for performing the intentions, whereas the former does not. From the outcome of experiment 1-3, I propose that TB PM can be split further along this internal/external cueing dimension according to the nature of the presentation of the clock. The presence of a clock on screen acts as an external cue and reduces both demands on self-initiated retrieval processes and on time estimation/time monitoring. However, when there is no clock available, or one must remember to check it because it is out of sight, these processes are necessary for successful completion of the PM task.

In everyday life, the presence of a clock is quite common and this might reduce its efficiency as a cue because it is not salient (e.g. Cohen et al., 2003 for discussion on cue saliency). For example, in the workplace the clock on a computer screen is constantly displayed and may not be adequately associated with each TB intention (for example, attending a seminar at 5pm) such that it acts as an effective cue. Nevertheless, in a laboratory TB PM task, when there is a clock present - the participant may find the clock the next most salient stimulus, after the ongoing task. Indeed, the clock and the ongoing task may be the only stimuli presented to the participant (see below for description of clock

presentation in previous studies). Arguably, this type of TB PM task is more externally-prompted than EB PM because all the information regarding when to carry out the intention is available to the participant. The hypothesis then that TB PM makes more demands on self-initiated retrieval processes is simply not apparent in this case. The notion that TB PM processing varies according to the nature of the presentation of the clock is perhaps analogous to the proposition that EB PM has different processing requirements according to the properties of the cue (e.g. categorical vs specific cues, Einstein et al., 1995, experiment 2). Evidence for this hypothesis from neuroimaging studies will now be discussed.

## ***4.2. Time-Based Prospective Memory***

### **4.2.1. Neural Basis of Time-Based PM**

The hypothesis that the nature of the presentation of the clock may affect the cognitive processes recruited in TB PM tasks stems not only from the first three experiments discussed in Chapter 3, but also from evidence from neuroimaging studies. Okuda, Frith & Burgess (2004, submitted) first discuss this possibility when they showed a differential pattern of activation in two TB PM tasks. In an earlier study, Okuda et al., (2002) conducted a PET study of PM tasks in which participants were instructed to perform mental arithmetic as the ongoing task and then clench their fist at particular cues. In the EB version participants clenched when a specific digit was presented within the ongoing task stimuli. During the TB version participants were asked to clench after particular time intervals (about 30 seconds). Crucially, no clock was presented in the TB task because the investigators sought to maximise the difference between the time and event versions, such that full time estimation was required. Previous neuroimaging studies of EB PM have established activation in the rostral prefrontal cortex, particularly Brodmann's area 10 located in the anterior part of the prefrontal cortex (Okuda et al., 1998; Burgess, Quayle & Frith, 2001; Burgess, Scott & Frith, 2003; Okuda et al., 2004). In this TB versus EB PM study similar areas of activation were reported. Compared to just performing the ongoing task alone, both types of task activated the left anterior frontal sulcus, the right middle frontal gyrus and the left hippocampus. The left superior frontal sulcus was described as showing more activation in the TB version of the PM task.



The later study by Okuda, Burgess & Frith (2004, submitted) again compared a TB and EB PM task, but in this study the investigators presented participants with a digital or analogue clock during the TB task. Activation differences between the TB and EB PM tasks in the earlier study could be explained by the need for time estimation processes. Thus by providing a clock, an aim of this study was to attempt to dissociate processes involved in maintaining and retrieving the TB intention from these time estimation processes. The experiment revealed a dissociation between activation in the rostral prefrontal cortex for TB and EB prospective remembering. The medial region of this area was more active during the TB version whilst the lateral region of the rostral PFC showed more activation during the EB version of the task. This pattern occurred regardless of the ongoing tasks used (syllable judgement of words or shape judgement of rectangles) or the type of clock presented (digital or analogue). The authors argued that the results could not be related to differences in performances of the two types of PM task i.e. related to task difficulty or performance of the ongoing task. Instead they contend that the activity is likely to be directly associated with processes involved in the PM task itself, such as planning, maintenance and execution of the intentions. The patterns of activation were in concordance with previous studies (Burgess et al., 2001; Burgess et al., 2003) supporting the notion that rostral prefrontal cortex plays a key role in prospective remembering.

Of key relevance here is that Okuda and associates report a different pattern of activation for the TB task in this study compared to the earlier study in which there was no clock presented to the participants. To the extent that dissociations in activation may represent dissociations in cognitive processes (see Henson, 2005), the combined evidence from these studies indicates the possibility that a different set of processes were actively involved in the time task without a clock, compared to with a clock. Indeed, the TB task without the clock shared more common activation areas with the EB version of the second study. Okuda et al. frame this in light of a new model of the functioning of the rostral prefrontal cortex – the Gateway hypothesis (Burgess et al., 2005; Gilbert et al., 2005). This hypothesis (discussed in Chapter 1) describes the rostral prefrontal cortex as a gateway that mediates an attentional bias between stimulus-independent thoughts (SIT) and stimulus-orientated external cognitions (SOT). The region is further functionally divided with the proposal that lateral rostral PFC modulates attention towards internal thoughts and goals, including switches between internally- and externally-guided behaviours, whereas medial rostral PFC

plays a role in the orientation of attention towards SOT cognitions. Okuda and colleagues (submitted) use this proposed dissociation in their interpretation of the PM imaging results, arguing that lateral PFC is activated during EB tasks because of the switching between internal thoughts (cue rehearsal) and monitoring the external stimuli for the cue. Similarly, in the TB task without a clock, lateral PFC is also found because of the reliance on internally-guided processes (i.e. internal time-estimation and self-initiated retrieval processes). In contrast, the TB task with a clock activates medial PFC of the orientation towards the external world (i.e. the clock-watching).

Although this is a relatively new hypothesis of rostral PFC function there are several lines of evidence that supports the proposal, including neuroimaging and neuropsychological studies (see Chapter 1, section 1.3.2.). However, as a theory it is in its infancy and undoubtedly will be refined and developed as new research accrues. Nevertheless, the differential patterns of activation in the two TB tasks does require explanation and it is easy to fit the presence and the absence of the clock into theoretical accounts of PM that emphasise the degree of internal cueing as a key variable. As mentioned in Chapter 2 and 3, theoretical accounts of TB PM are sparse compared to EB PM, however I will now consider the accounts available in light of the proposal that the nature of the presentation of the clock is a crucial factor. I will then review this proposal in relation to previous empirical studies of TB PM. Finally, I will introduce experiment 5, which is intended as a direct test of the proposal that TB PM processing varies according to the nature of the presentation of the clock.

#### **4.2.2. Cognitive Accounts of TB PM with Respect to the Nature of the Clock**

The idea that EB PM requires more continuous attention is in line with Smith's (2003) model of EB PM that states there is constant strategic monitoring for the cue and this is reflected in the RTs of the ongoing task. As touched on in the previous Chapter, a prediction can be developed, from combining the research of Smith on EB PM and the Test-Wait cycle (e.g. Harris & Wilkins, 1982; Ceci & Bronfenbrenner, 1985; Park et al., 1997), that RTs and/or accuracy of the ongoing task may fluctuate across the retention interval (RI) in TB PM (see also West & Craik, 1999). During the 'Wait' periods of the RI, the performance of the ongoing task may be equivalent to having no intention because few

resources for monitoring are being used. During other periods of the RI (e.g. Test) ongoing task performance may be impaired (compared to a baseline no intention condition) because of the demands made on self-initiated retrieval and monitoring processes. This attentional disengagement hypothesis is consistent with the results of experiments 2 in which clock-checking behaviour was lowest during the middle period of the RIs. Einstein et al., (1995), Park et al., (1997) and Logie et al., (2004) all found evidence for the Test-Wait time monitoring strategy as measured by their participants' clock checking behaviour.

However, the preceding analysis of TB PM may not extend to TB situations in which there is no clock available, such as experiment 3. In these cases full and constant time estimation and monitoring is mandatory if the intention is to be executed at anything like the correct point in time. The use of 'wait' periods (at least over short RIs) may be counterproductive because one would lose track of how much time has passed and one could forget altogether about the intention (because there is no clock acting as a cue). So the more strategic route to successful PM performance might be to continuously monitor the passing of time (i.e. maintain the psychological clock). Of course, this strategy would place continuous demands on cognitive resources (Zakay & Block, 1997; 2004), in contrast to the 'Test Wait' cycle in which there are periods where resources are 'freed-up'.

One important element of remembering TB intentions then is the availability of a clock, as it is predicted that this has an impact on the time monitoring strategy one can use. The time monitoring strategy utilised (i.e. Test-Wait cycle or continuous time estimation) will, in turn, affect the degree of cognitive resources available during RIs and this will be reflected in ongoing task performance (Smith, 2003). Hypotheses for experiment 5 will shortly be discussed below based on this theoretical account.

#### **4.2.3. Clocks in previous TB PM Research**

The hypothesis submitted is that the nature of the clock affects the recruitment of cognitive processes. If the clock is present for participants to use then fewer self-initiated retrieval processes are required because the clock can be consistently watched, acting as the cue for intention performance. Similarly, if there is a clock present for participants during PM tasks then this may encourage them to use a Test-Wait strategy for time monitoring, rather than continuous internal time estimation. This different pattern of time monitoring is likely to be

reflected in their ongoing task performance, as described above. Studies from different researchers and labs have varied in the presentation of their clock despite the predicted large influence the nature of the clock can have on participants' performances.

For example, Einstein et al. (1995) in their first experiment used a large digital clock placed behind participants. Participants had to physically turn around to look at the clock in order to see how much time had passed. In a third experiment comparing TB and EB PM in older and younger adults, they changed the clock such that participants just pressed a key to reveal the clock on the screen (on which the ongoing task was presented). Both experiments found an age-related impairment in TB PM. Park et al., (1997) asked participants to pull a lever located at the side of the computer monitor for their participants. The lever was attached to a clock and pressing a different button on this clock briefly revealed the time elapsed from the beginning of the experiment. These researchers also found an age effect. Logie et al., (2004) used a computer screen to display the clock, which was placed at a 90° angle to the display of the ongoing task, so that both could not be seen at the same time. Logie and colleagues in the description of the clock within their methods section foresee the hypothesis put forward here by stating: *'they [participants] could not see the screen while looking at the clock and vice versa; therefore, the clock could not function as an external, visible cue'* (p. 445). Older adults were impaired on both the TB and EB PM tasks in this investigation when there was also a high secondary working memory load. Surprisingly, in the study by D'Y'dewalle et al., (1999) in which no age effects on TB PM were found, the clock was displayed 1m away from the participants and they had to turn over their left shoulder to check it (thus the clock was not a constant cue). However, the authors attribute the good performance of the elderly in the TB task to the slow rate at which the ongoing task stimuli were presented, leaving ample time for clock checking.

The difficulty in trying to isolate the impact of clock presentation on PM or ongoing task performance within past studies is that other variables differ quite dramatically across the experimental procedures, for instance, the ongoing tasks used and the number of PM responses produced. It is also possible that a variety of qualities relating to the clock can affect PM performance, such as clocks that can be 'revealed' compared to those which are presented physically but require 'turning to'. A possible hypothesis is that the physical presence of a clock – even if it is out of sight – is more of an external aid than a

'revealable' clock on the computer screen. However, in order to establish that the presentation of the clock is a critical feature of TB PM processing I conducted an experiment to test the hypothesis directly.

### **4.3. Experiment 5**

#### **4.3.1. Aims and Hypotheses**

The purpose of experiment 5 was to pursue the results of experiments 1-3 in which a different pattern of ongoing task performance was revealed between a TB PM task in which a clock was presented to participants and the same task in which there was no clock available. Thus, the main experimental comparison was between participants' performances of the ongoing tasks in a TB PM task with a clock present and a TB task without a clock present and baseline performance (no TB PM demands).

Experiments 1 and 2 showed faster RTs to the ongoing task when they also had to recall TB intentions, whereas experiment 3 participants' produced slower RTs to the ongoing task during the condition with the PM demands. An explanation of this finding is that participants experienced a 'deadline' effect in experiments 1 and 2. By observing the approaching time deadline for the intention they sped up (with no apparent cost to accuracy). If this finding can be replicated then, there are many implications for everyday life. However, if the finding is not replicated then the alternative explanation (that the results were simply due to slower task resumption after the externally-cued side switch) must be evoked.

Four predictions were made on the basis of the theoretical and empirical background described. Firstly, if providing a clock on the screen during the TB PM task does reduce the demand on internally-guided processes, then better ongoing task and PM performance is predicted in this condition than compared to the no-clock condition. Secondly, if experiments 1 and 2 revealed a true 'deadline' effect, then it is predicted this same effect will occur in the clock condition in this experiment – with participants showing faster RTs to the ongoing task. Thirdly, it is expected that the Test-Wait-Test-Exit cycle of time monitoring is not an appropriate strategy for TB PM tasks in which there is no clock present. Instead, participants should monitor internally their own psychological passage of

time, processes which are likely to impinge on cognitive resources (Zakay & Block, 1997). Because of these differences in time monitoring strategy, it is predicted that there will be differences in ongoing task performance across the RI between the clock and no-clock conditions. Participants may show signs of attentional disengagement from the PM task in the clock condition between PM responses (i.e. produce faster RTs to the ongoing task), however, in the no-clock condition they are likely to produce slower RTs all through the RIs. Finally, the results of experiments 1 to 4 implicated possible self-initiated task switch preparation processes leading up to the PM response, indicated by slower RTs to the ongoing task in this period. Thus, it is predicted that there will be a significant slowing in ongoing task performance leading up to the PM responses in both the clock and no-clock condition (since both require a switch to the PM task).

#### *4.3.1.1. Hypotheses Experiment 5:*

In summary the hypotheses for experiment 5 are as follows:

##### The Effect of Internal/External Cueing on Task Performance

###### Hypothesis 1:

Expect differences in ongoing RTs, ongoing accuracy and possibly PM performance between no-clock and clock TB PM conditions because of differing levels of environmental support for task. Specifically, it is expected that participants will perform more poorly in the no-clock condition (in terms of ongoing task and/or PM performance) because of heavier reliance on self-initiated retrieval and time estimation processes.

###### Hypothesis 2:

In previous experiments 1 and 2 – participants performed the ongoing tasks faster during the PM clock conditions, this was attributed to a ‘deadline’ effect. I expected to find this same pattern of performance during the clock condition but not the no-clock condition.

##### Changes in Task Performance across the Retention Interval

###### Hypothesis 3:

Expect some differences in ongoing task performance across the retention interval in the clock condition but not in the no clock condition (because attentional disengagement possible in clock condition but constant time estimation and self-retrieval processes required in no-clock condition).

Hypothesis 4:

However, might expect significant slowing in both the clock and no-clock conditions as approach PM responses because of self-initiated preparation PM task-switching processes.

### **4.3.2. Method**

#### **Participants & Design**

Twenty-five adult volunteers recruited from a participant database ran by the UCL Psychology department participated in the experiment in return for monetary compensation. Participants were aged between 18 and 28, 14 were female and 11 were male. Participants completed a health screen questionnaire to establish any history of neurological or psychiatric disorders, but no participants were excluded on this basis. All participants reported a similar level of educational background, with the majority being current UCL undergraduates. Testing was administered on an individual basis in a separate cubicle in a session lasting approximately 55 minutes. All participants performed all three conditions of the experiment in this repeated measures design (clock, no-clock and ongoing task only i.e. no PM demands). Each condition was presented as two blocks lasting 6 minutes. The order of block presentation was fully counterbalanced across participants.

#### **Materials & Equipment**

##### **The Ongoing Tasks**

The presentation of the stimuli and response timing were performed on an IBM compatible Dell notebook controlled by software written in Matlab. The display screen was split into four quadrants by two white lines centrally aligned horizontally and vertically. The four tasks were presented simultaneously in each quadrant. Each task consisted of two coloured stimuli appearing on a black background on the left and the right (see Figure 4.1.). Participants were instructed that each task required them to make a decision determining

the correct response from the two stimuli. The correct response depended upon the task demands, which were as follows: Task 1) decide which angle is bigger; Task 2) decide which face is happier; Task 3) decide which letter is nearer to the end of the alphabet and Task 4) decide which number is closer to 50. Participants pressed either the left or right arrow key (on a QWERTY keyboard) according to the position of the stimuli that they believed represented the correct answer (i.e. on the left or on the right). As soon as a participant had made a response, two more stimuli immediately appeared on the screen, thus producing self-paced trials. The stimuli on screen (including the inactive task stimuli – see below) changed colour after every trial so it was clear when the next trial had appeared. The colour of the stimuli was chosen randomly on each trial from a set of four different colours, these were dark blue, cerise, pink and green. Above the two stimuli of each task written in white, Arial size 40 font and aligned left was a short reminder of the demands for each task, for example, ‘bigger angle?’ ‘closer to 50?’ By permanently displaying the task instructions, there was no demand on working memory to maintain the instructions for each task. Each pair of stimuli was generated pseudo-randomly according to a set of parameters that maintained a consistent level of difficulty within each task. The full details of the tasks and the parameters are as follows:

#### Task 1) Biggest angle?

Two angles, each created from two straight lines 2 cm in length, were presented. The two angles were displayed at any rotation (generated randomly) but were constrained such that the difference between them never exceeded 8° (minimum difference between them was 4° and the maximum difference was 11°). Participants made a perceptual discrimination of which angle was bigger and responded accordingly.

#### Task 2) Happiest face?

This task constituted two circles, 2.5 cm in diameter. Each circle contained a face: with eyes, a nose and a mouth. The task was to decide which face was happier out of the two and this was established by the expression of the mouth. The mouth, on either face, was one of the following on each trial: a down turned smile, a straight line or an upturned smile. Naturally, these mouth expressions represented sadness, neutrality and happiness, respectively. The program randomly generated which expression each face took on a trial-by-trial basis, but the faces always had different expressions from each other. Participants



were required to always choose the smiling face but choose the neutral face when a smiling face did not appear.

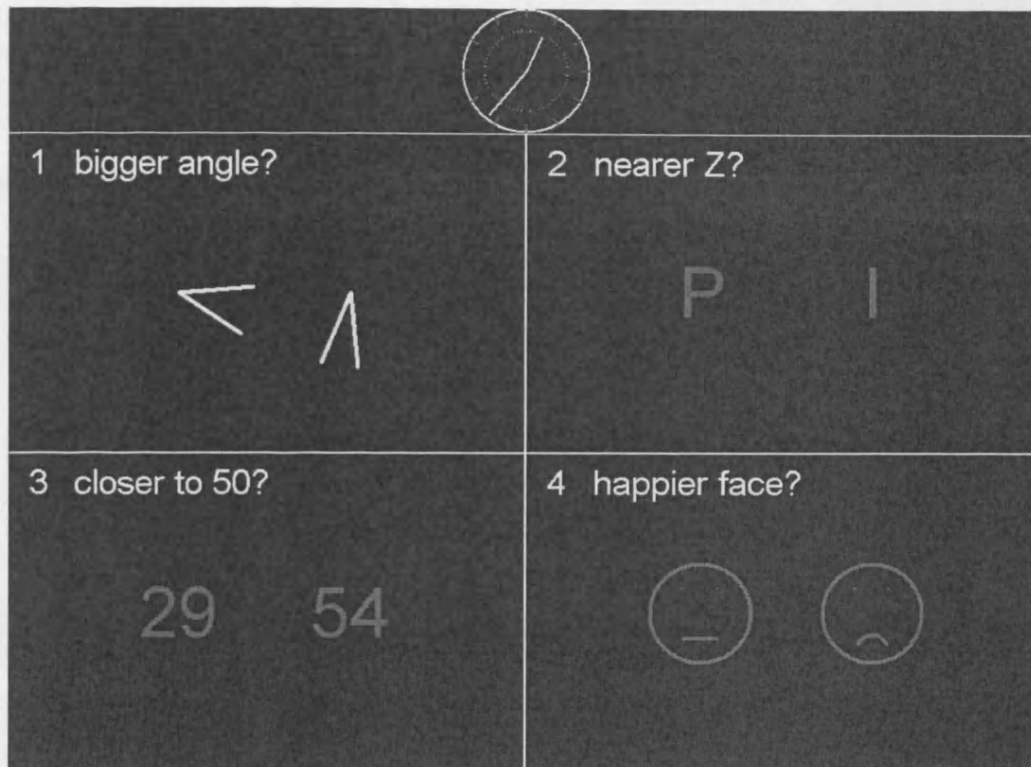
#### Task 3) Nearest to Z?

Two letters, 1.5 cm tall, 1cm wide in Arial font size 80, from the English alphabet appeared on each trial of this task. The letters were generated randomly by the program but were always taken from the middle 14 letters of the alphabet (G – T). There was a minimum distance of four places between the two letters (e.g. M and N could never appear, but M and R could). Participants simply had to determine which letter was closer to the end of the alphabet.

#### Task 4) Closer to 50?

Two integers from the range 25 to 75 were presented for this task 1.5 cm tall, 2 cm wide (together) and in Arial font size 80 on each trial. One integer was always greater than 50 and the other was always less than 50. The integers were chosen randomly by the program but there had to be a minimum distance of six between them (e.g. 54 and 49 could never appear, but 54 and 46 could). Participants were instructed to choose the integer closest to 50.

Figure 4.1. The screen design in the PM clock conditions in Experiment 5



At any one time, only one task (i.e. the two stimuli & instructions for that task) was active and thus considerably brighter than the other three inactive tasks, which remained difficult to see whilst inactive. Participants were instructed to respond to the brighter task throughout the experiment, whichever task this may be. Thus, the computer program switched the participants between the four tasks by altering the brightness of the tasks. A task switch was generated randomly either after 15 seconds or after 50 seconds throughout the whole experiment. The program also randomly determined the task that became active after a switch, such that all three inactive tasks had equal chance of becoming active. The rationale for this 'multitasking' approach to the ongoing tasks was to firstly ensure that participants did not reach ceiling on either the ongoing tasks or the PM task (because of the repeated measures design) or become too fatigued with the same ongoing task. McDaniel & Einstein (2000) commented that *'changing the activity periodically might retain a higher level of absorption in the ongoing activity'* (p. S140), and thus reduce the chance of participants 'zoning out' or achieving ceiling effects. Secondly, this multitasking approach

is more ecologically valid (Burgess et al., 2006). The previous Chapter demonstrated that these switches between the ongoing tasks should not interfere with PM processing.

#### Time-Based PM Task

The difficulty for the experimental design of comparing PM ability with and without a clock present is that individuals will produce a lot of variation in how often they make a PM response in the no-clock condition. This will lead to differences between the conditions in the length of the retention intervals and as this variable can have an effect on PM performance (e.g. Hicks et al, 2000), it was necessary to control for this. In order to achieve this, the RIs in the clock condition were based on the RIs of the previous participant's no-clock PM responses. Thus, the computer programme extracted the length of time between the PM responses within the no-clock condition and used these as the basis for the next participant's RIs in the clock condition. The method of accomplishing this is described below.

#### Clock Condition

During the clock conditions an analogue clock 3.5cm in diameter was displayed centrally at the top of the screen. The lay-out was of a typical analogue clock but with a minute and a second-hand only (see Figure 4.1.). The individual minutes were demarcated on the clock with red lines and the 'hourly' points were demarcated with longer red lines (these actually represented 5 minutes, 10 minutes, 15 minutes etc). Participants were instructed to remember to press the Space Bar whenever the minute hand of the clock reached 5 minutes and the seconds hand hit the 12 o'clock position (i.e. the clock would normally be considered to signify the 1 o'clock position). Participants were informed that the clock would start at different points, for example at 4 minutes 23 seconds in which case it would be 37 seconds before they needed to remember to press the Space Bar. Alternatively, the clock hands might start at the position 3 minutes 10 seconds in which case the correct time to press would be 1 minute 50 seconds later. These instructions were clarified by the experimenter as necessary and the practice ensure participants understood completely. When the Space Bar was pressed the screen flashed white and the clock hands reset in the correct position for the next RI.

As described above, the RIs (i.e. the time between the starting position of the clock and the correct time-point at which to make the PM response, signified by the correct position of the clock hands) were matched to the previous participants' no-clock PM responses. Consequently, the RIs in the two conditions were matched across participants. An extra participant was tested at the beginning of the experiment to provide the first set of matched retention intervals; their data was not included in the analyses.

#### No-Clock Condition

Obviously, in this condition there was no clock present on the screen and instead of participants having to use the clock to determine the correct time to make the PM response, they were instructed to simply press the Space Bar every time they thought 30 seconds had passed. Participants were further informed that they should not attempt to use any strategy to help them to do this (such as counting) as this would interfere with their ongoing task performance. Instead, they were instructed to simply estimate the time passed. Again the screen briefly flashed white when a PM response was made.

#### Ongoing Tasks Only Condition (Baseline)

As a comparison condition participants also performed just the ongoing tasks alone, with no extra PM demands. This was considered the participants' baseline performances of the ongoing tasks.

#### Procedure

On arrival, participants were told the experiment was investigating how people perform on complex tasks, such as multi-tasking. Participants were then asked to remove any watches or other time-keeping devices and these were kept out of sight for the entire experiment. The instructions for the four basic tasks were presented on a sheet of paper. After reading these instructions, the experimenter questioned the participant to ensure they understood the task demands.

Participants were told that they must respond to the tasks using the index finger of each hand, left index finger over the left arrow key and right index finger over the right key. By asking participants to use both hands for the ongoing tasks throughout the experiment we ensured that they could not use their spare hand as an external cue for the PM demands, by,

for example, keeping their fingers over the PM response keys. Participants then performed 60 seconds practice of the four ongoing tasks in order to familiarise themselves with the display, the tasks and the means of responding. In this practice block, participants performed 15 seconds of each ongoing task.

Following this practice, participants were given a second set of instructions on paper regarding the prospective memory elements of the experiment. They were instructed that during some sections of the experiment they might also be required to do an extra task, as well as the four basic tasks. They were then provided with the instructions regarding the different TB PM conditions and performed a practise of the clock condition. Before beginning this 1 minute practice block, participants were told that the clock would start at the 4 minutes 30 seconds point and thus they had 30 seconds before they would need to press the Space Bar. They were encouraged to use this as an aid for judging the length of 30 seconds for the no-clock blocks.

A verbal prompt from the experimenter to press the Space Bar was given if they had not pressed the Space Bar 10 seconds after the correct time. Any other instructions were clarified by the experimenter as necessary. Participants then began the experiment, and were reminded to perform the ongoing tasks as quickly and accurately as possible and that the extra tasks were equally as important.

### **4.3.3. Results**

These data were subjected to a series of data processing steps before analyses were executed. For all conditions and analyses, calculations of mean RTs of the ongoing tasks excluded error and post-error trials, the first trial of a block, pre and post PM response trials (to remove eye/finger movement noise), post task switch trials (to remove switch costs) and finally trials above and below 3 standard deviations from the mean (to remove outliers). Two participants made 0 PM responses in their first no-clock block and as a result, their matched clock block participants made no PM responses in their first clock blocks. The analyses of RTs and error rates presented below exclude ongoing task data from just the respective blocks of these four participants. Nonetheless, ongoing task data was collapsed across the 2 blocks of the same condition, thus the following analyses do include these

participants' data from the second blocks of the same conditions, in which they produced accurate PM responses.

#### *4.3.3.1. Ongoing Tasks Analyses*

The principal dependent variables of interest in this experiment were the accuracy and RTs of the ongoing tasks. The design of the experiment afforded two possible ways of surveying this data in order to analyse the effects of internally- and externally-cued TB PM. The four ongoing tasks could be analysed separately. For example, relevant trials from participants' responses to task 1 (collapsed across both blocks of the same condition) could be included to calculate the average error rate/RT for task 1 in each condition, and so forth for each task. An alternative approach was to collapse the four ongoing tasks across each condition. Thus, collapsed scores could be calculated by finding the mean of the mean of the four tasks for each condition (e.g. mean of meantask1\_clock, meantask2\_clock, meantask3\_clock, meantask4\_clock).

#### *Separate Task Analyses*

Collapsing across the four ongoing tasks would increase statistical power because of increased sample size, and so this was the preferred approach, but for this to be appropriate it was important to establish that one ongoing task was not having a particular effect in one particular condition (i.e. that there was no condition x task interaction). With regard to this, error rates and RT data were subjected to a 4 (ongoing tasks: 1,2,3,4) x 3 (condition: clock, no-clock, baseline) repeated-measures MANOVA. There was a main effect of task on error rates,  $F(3,21) = 16.761$ ,  $p > .001$ , no main effect of condition and no significant condition x task interaction, ( $p > .05$ ). These findings were mirrored by the RT data, with a main effect of task,  $F(3,21) = 33.36$ ,  $p < .001$ , no main effect of condition and no significant interaction, ( $p > .05$ ). By collapsing across the conditions variable, the main effect of task was investigated further. T-tests revealed that the significant difference in error rates lay primarily between task 2 (low error rate with a mean of 5.43%) and the other tasks. For instance, there was a significant difference between task 2 and task 4 which produced the highest error rate with a mean of 11.16%,  $t(23) = 5.75$ ,  $p < .0001$ , one-tailed. Similarly, in terms of RTs, participants produced the fastest responses in task 2 (mean of 739.34 ms) and

the slowest responses in task 4 (mean of 1217.39ms), a contrast which also produced a significant difference  $t(23) = 9.47, p < .0001$ , one-tailed.

The non-significant interactions between task and condition, combined with the randomisation of the ongoing task schedule across all participants and conditions, provided the rationale for pooling across the four ongoing tasks. Thus, mean RTs and error rates from this point forward were calculated as described above (collapsed across tasks). The rest of the results are split into analyses according to the hypotheses.

#### *4.3.3.3. Hypotheses 1 and 2 – The Effect of Internal/External Cueing*

The first set of analyses looked at hypotheses 1 and 2, which concerned the effect of the presence and absence of the clock on ongoing task performance. Mean error rates are shown in Figure 4.2. and Figure 4.3. displays the mean RTs. Mean error rates from each condition, collapsed across the four ongoing tasks, were submitted to a repeated measures MANOVA with condition as the factor (baseline, clock TB PM and no-clock TB PM). The analysis with error rates indicated that the main effect of condition was marginally significant,  $F(2,22)=3.413, p=.051$ . Planned t-tests were performed on the mean error rates and revealed that participants made significantly more errors during the no-clock TB PM condition than compared to the baseline,  $t(23) = 2.26, p=.017$ , one-tailed, and the clock conditions,  $t(23) = 2.41, p=.012$ , one-tailed. The same MANOVA conducted with RT data revealed a non-significant main effect of condition, ( $p > .05$ ). Nonetheless, participants produced slightly, but not reliably, slower RTs during the clock condition, a likely consequence of eye movements to the clock. Indeed, bearing in mind that participants were glancing at the clock during this condition, it is noteworthy that the no-clock condition still shows most disruption to accuracy.

Figure 4.2. Mean error rates of ongoing tasks - collapsed across tasks and 2 blocks

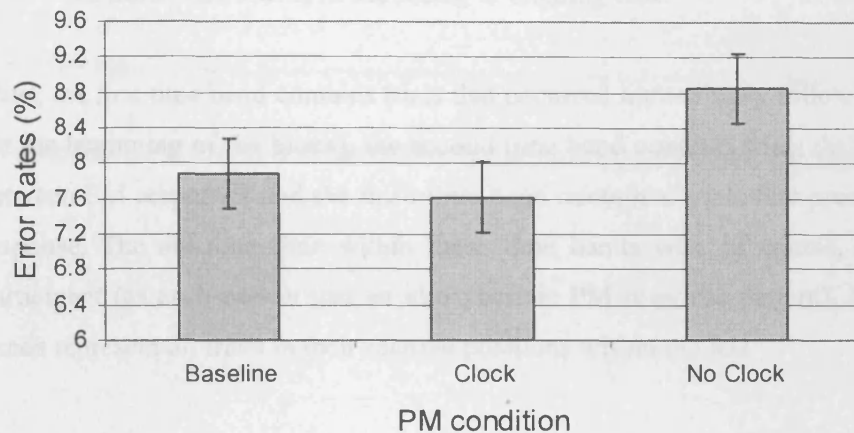
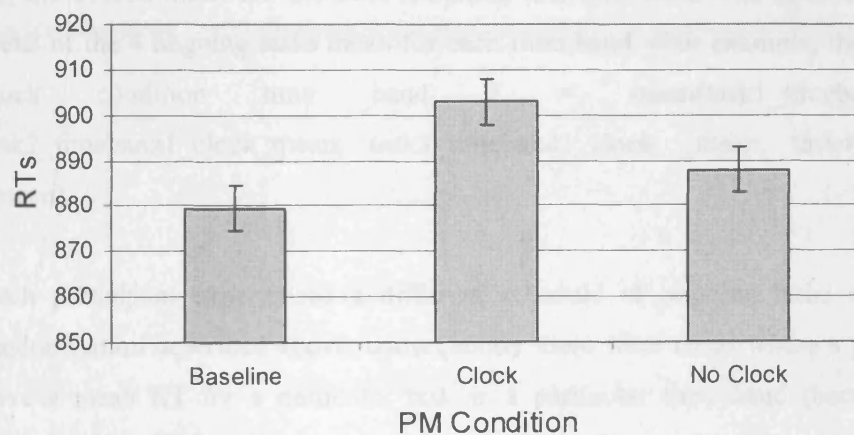


Figure 4.3. Mean RTs of ongoing tasks - collapsed across tasks and 2 blocks



#### *Hypotheses 3 and 4 – Retention Intervals*

The next set of analyses was conducted to compare ongoing task performance across the RIs, in order to test hypotheses 3 and 4. (The following analyses were also performed with the error data but there were no significant results thus just the RTs are reported). The RTs (excluding the same trial types as described above) were split into 3 equal time bands between PM responses, using the following procedure:

- 1) The RIs between each PM response were calculated,
- 2) Then divided into three equal time bands,



- 3) The RTs from each trial were then assigned to a time band accordingly; in addition, the trials were still split according to ongoing task.

Thus, the first time band contains trials that occurred immediately following a PM response (or the beginning of the block), the second time band contains trials that occurred midway between PM responses and the third time band contained trials that preceded the next PM response. The absolute time within these time bands was, of course, different for each participant (as each person had an idiosyncratic PM response pattern). However, the time bands represent all trials in their relative positions within the RIs.

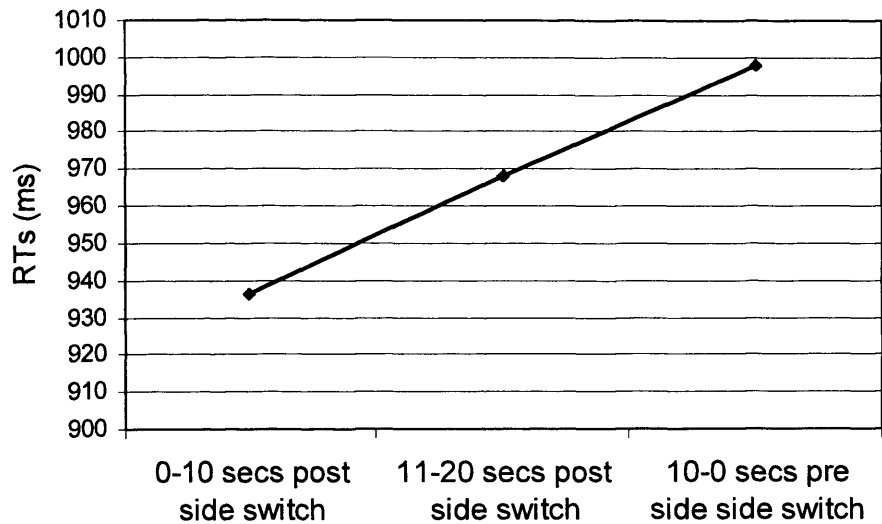
### *Clock Blocks*

After trials were split into the 4 ongoing tasks and also into the correct position within the RI, the overall mean RT for each condition and time band was calculated by finding the mean of the 4 ongoing tasks mean for each time band. (For example, the mean RT for the clock condition time band 1 =  $\text{mean}(\text{task1\_timeband1\_clock\_mean}, \text{task2\_timeband1\_clock\_mean}, \text{task3\_timeband1\_clock\_mean}, \text{task4\_timeband1\_clock\_mean})$ ).

Each participant experienced a different schedule of ongoing tasks as a result of the randomisation described above, consequently there were cases where a participant did not have a mean RT for a particular task in a particular time band (because they did not perform any of that task during that time band). In these cases, a mean collapsed across the ongoing tasks was not calculated for that participant, and they were excluded from the MANOVA. This exclusion process left 21 participants in the clock condition and 19 participants in the no clock condition.

The mean RTs for each time band of the clock condition were submitted to a repeated measures MANOVA (with the levels of time band: 1,2,3). The main effect of time band approached significance,  $F(2,19) = 3.282, p = .06$ . The mean RTs for each time band of the RIs are shown in Figure 4.4. As the graph displays, the mean RTs increased linearly across the RIs and indeed this was borne out in a statistical test, there was a significant linear trend,  $F(1,20) = 6.892, p = .016$ .

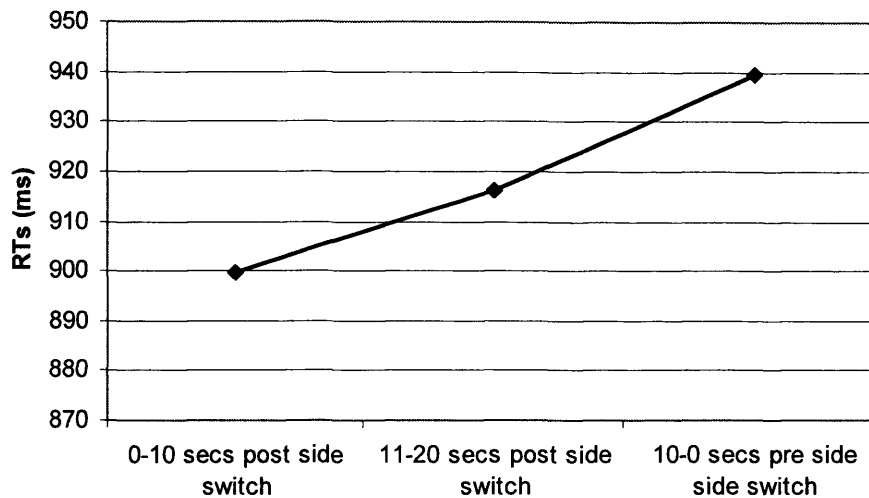
Figure 4.4. Mean RTs of trials within 3 time bands of PM retention intervals in clock blocks - collapsed across 4 ongoing tasks



#### *No Clock Blocks*

The same procedure to calculate mean RTs for each time band of the RIs was employed in the no-clock condition and again, a repeated measures MANOVA was conducted on these RT data (with the levels of time band: 1,2,3). There was a significant main effect of time band,  $F(2,17) = 5.655$ ,  $p = .014$ , and this transferred into a significant linear trend,  $F(1,18) = 11.64$ ,  $p = .003$ . In this condition too then, RTs of the ongoing task gradually slowed across the RI and were slowest as the participants approached the point at which they produced a PM response, see Figure 4.5.

Figure 4.5. Mean RTs of trials within 3 time bands of PM retention intervals in no clock blocks - collapsed across 4 ongoing tasks



### *PM Task Performance*

The majority of PM studies use PM performance as the key dependent variable; however, this measure is complicated in the present experiment by the fact that the no-clock condition can produce a range of PM RIs because of time estimation differences. This makes it difficult to assess performance in this condition (i.e. have participants forgot to make a PM response or have they just produced long RIs?). Instead, the important point to establish is that the participants are actually carrying out the PM intentions and that the number of PM responses is comparable across conditions. Thus, it is necessary to check that the mean RIs across the clock and no clock conditions are similar, in order to eliminate RI differences as the explanation for performance differences between the two conditions. Similarly, it is also necessary to check that there are no differences in the number of PM responses between the two blocks of the same condition (i.e. block 1 and 2 with the clock and block 1 and 2 of without the clock) since the previous analyses have collapsed error rates and RTs across both blocks (see Table 4.1.).

Table 4.1. Displays the mean total number of PM responses and the mean RI lengths in each of the PM block in experiment 5

	<b>Mean Total Number of PM Responses</b>	<b>Mean Length of Retention Intervals</b>
Clock Block 1 N=22	8.77 (SD=3.17)	33.43 secs (SD=10.72)
Clock Block 2 N=24	8.63 (SD=3.09)	37.20 secs (SD=11.91)
No-Clock Block 1 N=22	8.95 (SD=2.95)	36.02 secs (SD=12.32)
No-Clock Block 2 N=24	8.29 (SD=3.14)	39.05 secs (SD=13.45)

A 2 (condition: clock, no-clock) x 2 (block: 1<sup>st</sup>, 2<sup>nd</sup>) repeated measures MANOVA was conducted on these data and revealed no significant main effects or interactions between condition (clock or no-clock) and block (1 or 2) in the total number of PM responses (all  $F < 1$ ). The same MANOVA was conducted with the mean length of RI data. This showed no significant main effect of condition and no significant interaction ( $F < 1$ ). There was a significant effect of block,  $F(1,19)=4.54$ ,  $p < .046$ , so this was followed up with post hoc t-tests to check if there were significant differences between the two blocks of the same type. Paired t-tests revealed no significant differences in mean RI length between blocks 1 and 2 of the no-clock condition, ( $p > .05$ ), and blocks 1 and 2 of the clock condition, ( $p > .05$ ).

#### Clock Match Accuracy

To inspect the accuracy of participants PM clock responses (i.e. how accurately participants responded to clock) a clock match accuracy score was computed. This score represented the mean absolute difference between participants' no clock PM responses & their matched participant's clock PM responses. For the first no-clock block and the equivalent first clock block this score was on average .996 seconds. For the second no-clock block and its equivalent clock block, this score was on average 1.24 secs. Clearly, participants were very accurate in their externally-cued PM responses (i.e. they pressed the PM response key at the correct times).

#### PM Performance Summary

The results above demonstrate that participants were performing very similarly in both the clock and the no clock PM blocks since the mean RIs matched and the total number of PM responses matched. This suggests any differences between the clock and no-clock conditions cannot be attributed to differences in RIs or total PM responses. In addition, the results justify collapsing mean error rates and RTs across the two blocks of the same condition. No significant differences were found between the total numbers of PM responses made in each block of the same condition. Furthermore, paired t-tests indicated no significant differences between the mean RIs of each block of the same condition.

#### **4.3.4. Discussion**

To summarize, there were two main results in experiment 5. First, participants were significantly less accurate in their performance of the ongoing tasks in the no-clock condition compared to the clock and baseline conditions. However, there were no overall mean RT differences between the three conditions. Second, the analyses of ongoing task performance across the RIs clearly demonstrated a significant linear trend in RTs in both the clock and no-clock condition, with participants slowing as they approached their PM responses. These findings were present despite no significant differences between the length of the PM RIs in the clock and no-clock conditions.

##### *Hypothesis 1:*

This is the first behavioural study to investigate the effect of clock presentation on TB PM. The first hypothesis predicted that the performance of the ongoing tasks would be poorer in the no-clock condition compared to baseline performance and compared to the clock condition. This hypothesis was supported, as demonstrated by the higher error rates to the ongoing tasks in the TB PM condition without the clock. These results are consistent with the notion that a TB PM task involves different processes according to the degree of cueing provided by a clock (i.e. the clock's availability). During the no-clock condition participants must maintain their own time monitoring and generate the PM responses entirely from internal prompts. The demands on these self-initiated retrieval and time estimation processes are likely to make extra demands on cognitive resources (Craik, 1986; Block & Zakay, 1997; Zakay & Block, 1997), and therefore affect performance of the ongoing tasks. Differences in TB PM performance may be a consequence of the level of internal time estimation as well as the degree of self-initiated retrieval used by the

participant. Extrapolating this hypothesis further, the demands on these self-initiated processes could also change according to the type of clock – i.e. whether it requires a button press to reveal the clock or merely a turn of the head. The type of clock might affect the strategy participants take to perform the TB PM task. For instance, participants might be more inclined to use and check physical clocks more regularly because it is perceived as easier, leading to improved ongoing task performance. Harris & Wilkins (1982) discuss the possibility that individuals may vary in their time monitoring strategies and Einstein et al., (1995) also consider this possibility when describing the difference in the clock-checking behaviour of their older and younger adults. Einstein and colleagues pre-empt the present experiment and make the following comment in their excellent discussion: *'In the absence of external cueing from someone (e.g. an experimenter) or something (e.g. an alarm clock or perhaps even a clock within the person's field of vision), monitoring or testing the clock seems to be entirely self-initiated'* (p. 1006). They are relating the self-initiated nature of the clock checking to age-related decrements in TB PM performance. However, the point may be broader than they discuss, such that future studies could manipulate the presentation of the clock and measure any subsequent variation in time monitoring strategies.

Given that the no-clock condition produced poorer ongoing task performance than the clock conditions, the current study is consistent with experiments 1 to 3. However, accuracy of the ongoing tasks was affected here, as opposed to RTs in the previous experiments. There is no immediate explanation for this difference, except to say that the ongoing tasks were very different between the first set of experiments and the present study. One can merely surmise that the manner by which removing the clock compromises the ongoing task in TB PM is dependent on the type and complexity of the ongoing task(s). This could easily be tested in future experimental studies.

An alternative interpretation of why participants showed reduced accuracy in the no-clock condition is because they were also counting 30 seconds to produce an accurate RI. This is not a persuasive argument for four reasons. Firstly, participants were instructed quite clearly not to use a strategy for the 30 second RIs, instead they were instructed to simply to guess when they thought 30 seconds had passed. Secondly, if they had been counting the interference would have also generated longer RTs in the no-clock condition, this was not the case. Thirdly, if they had counted participants would have been likely to show

particularly low accuracy and long RTs in the fourth ongoing task, the number task, again this was not the case. Finally, the ongoing tasks, and the multitasking style of the experiment, were chosen after a series of pilot studies had showed that they were sufficiently engaging to prevent any verbal rehearsal of the intention. Participants in the pilot studies were asked to do the tasks with and without counting to 30 seconds and RT changes were apparent.

The current findings are in line with neuroimaging studies that demonstrated differences in neural activation of TB PM (Okuda et al., 2002, Okuda et al., 2004, submitted). A TB PM task with a clock present showed different activation patterns to EB PM and these activations were different to those produced from participants undergoing a TB PM task without a clock. The Gateway hypothesis of rostral PFC function was provided as the framework for these results. TB PM without a clock and EB PM activated a similar neural region in the rostral PFC; a region hypothesised to play a role in co-ordinating attention with regard to stimulus-independent internal thoughts and switches between stimulus-independent thoughts and stimulus-oriented external thoughts. The TB PM task with a clock generated activity in a different area of the rostral PFC – an area that is associated with the attentional modulation of externally-oriented behaviour. Thus, the interpretation of these patterns of activation is based on the degree of reliance on self-initiated processes. Crucially, the EB task is actually posited to use more, or equivalent, self-initiated processes than the TB task with a clock. A general implication here is that TB PM cannot be presumed to have a greater reliance on self-initiated processes than EB PM ( Craik, 1986; Einstein et al., 1995; Cicogna et al., 2005). The multiprocess model of EB PM (McDaniel & Einstein, 2000) contends that EB PM tasks can vary in their dependence on self-initiated processes according to the particular parameters of each task. It is perhaps entirely reasonable then to suggest that TB PM tasks can also differ in the degree to which automatic versus executive processes are recruited. Indeed, I would propose a multiprocess framework for TB prospective remembering, as well as EB. Although the factors that affect the processes recruited are likely to be different. From the outcome of this study, it would seem one factor that influences this is the nature of the presentation of the clock. This factor certainly needs to be more systematically studied in future TB PM research and may account for some of the inconsistencies in the PM and ageing literature (Chapter 2, section 2.6.).

### *Hypothesis 2:*

The proposed 'deadline' effect of experiments 1 and 2 was not replicated in the present study. Participants did not respond faster to the ongoing tasks during the clock TB PM conditions. This implies that the faster RTs in the two PM clock conditions of the first two experiments may be attributable to participants' faster recoveries from the self-initiated side switch, compared to the automatic side switch in the non-PM conditions. The present findings therefore do not support the 'deadline' effect hypothesis.

### *Hypotheses 3 and 4:*

The final hypotheses of this study concerned the change in ongoing task performance across the RIs in the TB PM task conditions. Previous cognitive accounts of TB PM have described fluctuations in the consumption of attentional and cognitive resources across the RI, such as the Test-Wait-Test-Exit cycle proposed by Harris & Wilkins (1982). Park et al. (1997) have characterised the 'Wait' period of this cycle as a potential period of 'attentional disengagement' from the PM task. As discussed in the introduction, a direct prediction of these time monitoring accounts then are that during specific periods within the RI (e.g. the 'Wait' periods) ongoing tasks should be performed more rapidly, as more cognitive resources are available. An analysis of RTs across the RI found that in the final third period of the RIs, RTs were considerably greater than those within the first period. Indeed, there were significant linearly increasing RTs across the PM RIs in both the clock and no clock conditions. This is consistent with the Test-Wait model of time monitoring of Harris & Wilkins (1982) since the availability of cognitive resources during the 'Wait' period enabled faster ongoing task performance.

Recall, however, that these models of time monitoring are based on participants being able to 'test' or check time elapsed with the aid of an external clock. In the present experiment, the condition without a clock produced a similar pattern of RTs across the RI. Models of prospective time estimation include a description of an internal cognitive counter that accumulates time signals (which relate to the duration of time passed) and thus requires continuous attentional resources (Wearden, 2004; Zakay & Block, 2004). This attention subsuming cognitive counter can interfere with non-temporal processing. Following this theoretical position, there would be no expected fluctuations in RTs across the RI of the no-clock condition.



How then can the similarity of the RT patterns between the two TB conditions be reconciled? Two alternatives will now be discussed. One possibility is that participants in both TB conditions are showing a slowing in ongoing task performance towards the end of the RI because of self-initiated task-switch preparation processes for the PM task; the role of time monitoring processes are actually irrelevant. This was predicted by the fourth hypothesis as a result of the previous experiments in this thesis and also has empirical support from the voluntary task-switching literature (e.g. Arrington & Logan, 2004, 2005). This supposition can certainly account for the data from experiments 1 to 3. Nevertheless, the supposition that the linear increase in RTs is due to executive task-switch processes is not mutually exclusive from the Test-Wait cycle account, at least in the condition with the clock. Indeed, it is possible that the RIs in this experiment were simply too short to be sensitive to other 'wait' periods. Or the opposite, the time bands were not fine-grained enough to detect changes in ongoing task RTs. This seems to be a general problem with current theories of time monitoring in TB PM: there are no elucidations of how the length of the RI changes the strategy employed. Further experiments that manipulate the length of the RIs and measure the RTs across these different lengths would need to be conducted in order to resolve these issues.

The second possibility, to account for the similar pattern of RTs in both TB PM conditions, is that the Test-Wait cycle of time monitoring can also be applied to internal time estimation. In other words, participants may show a similar cycle of attentional allocation to internal time monitoring, with few resources devoted to this task at the beginning of the RI. There is little suggestion of this in the time estimation literature (see Zakay & Block, 2004 for a review) but the implication from this account would be that participants would produce short RIs because early time signals would not have been processed properly (Block & Zakay, 1997). Actually, the mean length of RI in the no-clock conditions was not far off 30 seconds (36.02 secs, SD 12.32 in block 1 and 39.05 secs, SD=13.45 block 2). Clearly, there is no control condition, in which participants just performed the time estimation task, with which to compare the length of RIs generated. However, the general accuracy of the RIs produced in the no-clock condition would suggest that participants maintain continuous attention to time monitoring. Nevertheless, the data from the present

experiment cannot determine the correct theoretical position from these options without further experimentation.

The studies thus far provide strong evidence that PM is a cognitive task that relies heavily on internally-guided control processes. However, they also indicate quite persuasively that the reliance on these self-initiated processes can differ according to attributes of the PM task. Previous research has focussed on the factors in EB PM that modulate the dependence on self-initiated, strategic processes (e.g. Einstein & McDaniel, 1990; McDaniel & Einstein 1993; Einstein et al., 1995; Einstein et al., 1997; Guynn et al., 1998; Marsh & Hicks, 1998; McDaniel et al., 1998). Moreover, researchers have emphasised that TB and EB PM differentially rely on self-initiated processes, with the former making more demands on these internal control mechanisms (Craik, 1986). Experiment 5 has demonstrated that this last assumption must be questioned. Instead, the evidence implies a hierarchy of dependence on self-initiated processes that crosses the type of PM tasks. The hierarchy might look something like this:

- 1) TB PM without a clock available: places very high demands on time monitoring/estimation (which is thought to make demands on strategic processes (Zakay, 1993; Zakay & Block, 2004) & self-initiated retrieval processes.
- 2) EB PM – Under certain task parameters EB PM can evoke little strategic monitoring and instead proceed relatively automatically e.g. if reflexive-associative processing occurring (McDaniel et al., 1998). However, EB PM can require strategic monitoring (Smith, 2003). Multiprocess framework posits the parameters of the EB task that mitigates the processes involved (McDaniel & Einstein, 2000).
- 3) TB PM with clock not on screen but available (e.g. ‘revealable’) – Expect this to require some self-initiation to check the clock but the clock then reduces need for full time estimation and once the clock is checked this can act as an external cue for the intention.

- 4) TB PM with clock always on the screen – external cue (clock) is obvious & participants know when target will occur. Requires little time estimation, little self-initiation & minimal strategic monitoring. However, eye movements to clock may reduce the performance on the ongoing task.

Experiments 1 to 3 initially suggested the distinction between the TB PM tasks (i.e. the presence of a clock and the absence of it), and experiment 5 confirmed this. Consider experiments 3 and 4 however, a similar pattern of results was demonstrated (in terms of ongoing task performance) between TB PM without a clock and EB PM. Despite this, in the proposed hierarchy above TB PM without a clock is posited to depend more heavily on self-initiated processes than EB PM. Although this makes theoretical sense, the claim nevertheless requires empirical substantiation since previous comparisons of TB and EB PM, which are notably rare, have always included a clock of some description in the time version of the task. This purpose of the next experiment was to provide this empirical support.

Before discussing the next experiment in more detail, a review of experiments that have directly compared TB and EB PM is necessary. Performances on TB and EB PM are infrequently compared within the same experiment. The exceptions to this have been ageing studies in which older and younger adults are tested on both types of PM (e.g. Einstein et al., 1995), and two TB studies (Cicogna et al., 2005; Cook, Marsh & Hicks, 2005). Ageing studies compare performance on these types of tasks in order to determine which generates the largest age-related decrements. This, naturally, is useful for real-life applications since strategies can be developed to overcome these deficits (e.g. Gollwitzer & Schaal, 1998). The outcomes of these studies are also useful in constraining PM theorising, as described in Chapter 2. By establishing if the proposed hierarchy is accurate, these experiments hope to achieve the same aims.

The goal of Cicogna and colleagues' experiment with a young population, was to investigate the effect of interpolating another intention (either TB or EB) within the RI of a first TB intention. This is an extremely common scenario in everyday life (Ellis, 1996); a little introspection reveals that it is rare indeed we are burdened with only one future intention (Kleigel et al., 2000). Moreover, in most cases a pair or group of intentions is a

mixture of both TB and EB PM tasks. To the extent that TB and EB PM both involve the following characteristics, submitted by Ellis (1996), then we would expect some overlap of processes:

- 1) formation and encoding of intention and action,
- 2) a retention interval,
- 3) a performance interval i.e. period during which the intended action should be retrieved,
- 4) initiation and execution of intended action,
- 5) evaluation of outcome (see also Martin, Kliegel & McDaniel, 2003).

Cicogna et al. (2005) hypothesised that because there is overlap in strategic processing then a dual mixed-intention condition should produce interference to one or both intentions, but that this interference would be much stronger when the two intentions are both TB. Essentially, two TB intentions will require double time estimation and the operation of two 'psychological' (or internal) clocks. Their methodology was to give participants an extra intention (e.g. remember to press a specific key after 4 minutes (TB), or remember to press a specific key when a target word appears (EB)) during the RI of the main PM TB task i.e. after participants had already started the main task. Interestingly, the authors reported a facilitation effect to the main TB task when an interpolated TB task was added (although this came at a cost to the interpolated TB task). This is comparable to reports from participants involved in a naturalistic procedures who claimed that remembering one intention would also remind them of another approaching future (but unrelated) intention (Morris, 1992; Sellen et al., 1997). It is also consistent with a previous report that an increase in the numbers of intentions improved overall PM performance (Park et al., 1997).

Participants in the Cicogna et al. study who had to execute an interpolated EB intention performed slightly, but not statistically, poorer on the main TB PM task. Cicogna et al. suggested that: *'the sharing of attentional resources between cue detection and time estimation, lowering the frequency of clock checking, might account for the impairment of performance on the main task'*(p. 237). In other words, they are proffering that it is the demands made on self-generated processes that produces the interference, i.e. strategic cue monitoring and strategic time monitoring. The claim is difficult to uphold given that it was not a *significant* effect of the interpolated EB PM task on the main task. However, some support for this viewpoint is provided by an experiment conducted by Cook, Marsh &

Hicks (2005, experiment 3). They report reduced performance in a TB task when it was combined with an EB PM task. Two accounts were provided for this effect; firstly, and consistent with Cicogna et al., that strategic monitoring for the cue interfered with time-monitoring because of the increased load on working memory (Marsh & Hicks, 1998; Marsh et al., 2003; Smith, 2003). By making extra demands on executive resources, the participants were forced to rely on automatic associations between the TB intention and the context in which the correct target time was expected to occur in order to successfully execute the intention.

This account is relevant in this study because their objective was to explore the role of context in the retrieval of TB intentions. Participants were expecting that the correct moment to make the PM response would occur whilst performing a specific type of ongoing task (syllable-judgements) i.e. during a specific context. When this expected context did not coincide with the correct time to perform the intention (as manipulated by the researchers), participants often missed making the PM response. It was therefore assumed that an association between the activity and the expected context had occurred during intention formation and without this context the intention was more difficult to retrieve. When the correct context did appear, there was a robust contextual cueing effect. As described, with the addition of the secondary EB task participants Cook et al., argued that participants relied on the automatic association with the context to evoke the TB intention. Consequently, when the context did not occur participants missed the correct response times.

The second account considered by Cook et al. for explaining the decline in performance during the dual-intention condition is that participants simply chose to allocate their attention to the other tasks, at the expense of the time task. Marsh, Hicks & Cook (2005) claim that participants can make strategic choices about the allocation of their attention according to metacognitive factors (e.g. perceiving one task as more important than another). This explanation is applicable to Cicogna et al.'s data since they found a facilitation of the main task when they added a second TB task. This facilitation came at a cost to the interpolated time task suggesting that participants perceived this interpolated task as less important, perhaps because the instructions were presented after beginning the main task. As Cook et al. highlight the two accounts they discuss are similar, differing only

on *'whether or not the deficit is caused by more versus less strategic processing on the participants' part'* (p. 356). Unfortunately, their methodology cannot distinguish between the two accounts.

As discussed previously in this thesis, Smith (2003) has reported that ongoing task performance can act as an index of strategic processing, such that there is a cost to the ongoing tasks when increased strategic monitoring (or 'preparatory attentional processes') is required to successfully execute the PM task. The studies by Cicogna et al. and Cook et al. failed to measure their participants' ongoing task performances, by inspecting RTs and accuracy, and therefore perhaps reducing the studies' sensitivities to interference and to changes in strategic processing and attention allocation. The present experiment was designed to address this shortcoming and use the ongoing task performance as the key dependent variable. This also addresses the problem of comparability between TB and EB PM. As described in experiment 5 measuring PM performance in a no-clock TB PM task is somewhat meaningless given that a participant may not have forgotten to make a PM response, but simply judged time poorly. By evaluating ongoing task performance rather than PM performance this difficulty is overcome and a measure of strategic processing is possible.

## **4.4. Experiment 6**

### **4.4.1. Aims and Hypotheses**

To summarize, the present experiment was designed to test the hypothesis that TB PM without a clock requires more internally-generated control processes than EB PM, and thus provide support for the hierarchy proposed above. Performance of the ongoing tasks was compared in conditions with only EB PM intentions and only TB intentions (without a clock). The present experiment also investigated the degree of shared processing between these two types of PM tasks by measuring any change in ongoing task performance during dual-intention and mixed intention conditions. The paradigm for this experiment was identical to experiment 5, but it is worth highlighting features of the experimental design that are direct attempts to improve previous methodologies:

- 1) Use of a repeated-measures design rather than a between-subjects design. If participants do produce individual strategies for attention allocation, such that they make choices about which task to devote more attentional resources to (Marsh, Hicks & Cook, 2005), then by testing the same participants in the different conditions this variable is controlled.
- 2) Compare the time- and event- mixed intention condition to: a dual-time intention condition, a dual-event intention condition as well as a single-time intention condition, a single-event intention condition and a baseline condition (with no intentions). These comparison conditions allow for a more clear conception of the interference caused by a mixed dual-intention condition. Cicogna et al. did include a dual-time intention condition but not a dual-event condition. Moreover, in their experiment the second intention was added during the RI of the main TB task (i.e. once they had already begun the task), which may have affected participants' attentional allocation strategy.

With the conditions of the experiment specified it is now possible to introduce a series of hypotheses.

#### *4.4.1.1. Hypotheses Experiment 6*

##### Hypothesis 1:

Based on the assumption that there is increased reliance on self-initiated retrieval and time estimation, poorer performance of the ongoing tasks in the no-clock TB PM conditions compared to baseline and the EB PM conditions was predicted. In addition, there will be some reduction in ongoing task performance in the EB conditions compared to baseline, as found in experiment 4 of this thesis and by Smith (2003), but that this decline will not be comparable to the TB conditions.

##### Hypothesis 2:

The prediction regarding the effect of the mixed dual-intention condition is a little trickier. The inclusion of the other dual-intention conditions allows for proper comparison conditions. However, the empirical evidence reviewed above cannot distinguish between two possible outcomes for the mixed dual-intention condition. For example, it is possible to argue that a decline in performance of the ongoing tasks in the mixed condition compared

to baseline and the other dual intention conditions will occur, due to overlapping processing requirements e.g. strategic monitoring for cue and strategic time monitoring (e.g. Cook et al., 2005). As discussed in the introduction to experiment 5, neuroimaging data also suggests there may be similar neural mediation of no-clock TB and EB PM (Okuda et al., 2002; Okuda et al., submitted), which indicates that there will be shared processing and thus interference. The null hypothesis, however, is that there will be no extra interference to ongoing task performance from the mixed intention condition. Cicogna et al. (2005) showed no significant interference effect from adding an interpolated EB task to a main TB task. If the null hypothesis is true then the expectation is that performance of the ongoing tasks in the mixed intention condition would be comparable to that of the single-TB condition. This is because the mixed intention condition does contain a TB demand, so the demands on time estimation and self-initiated retrieval will be equal to this.

#### Hypothesis 3:

It was also hypothesised that although there might be significantly poorer performance of the ongoing tasks in the single intention conditions and baseline, there would be no differences in ongoing task performance between the single-intention and the dual-intention conditions of the same PM task type. This is because studies have demonstrated that two sets of intentions can facilitate the remembering of another intention (Morris, 1992).

#### Hypothesis 4:

Finally, it was hoped this experiment would replicate the results of one aspect of experiment 5; ongoing task performance should decline across the RI in the TB PM conditions because of voluntary task-switch preparation processes.

### **4.4.2. Method**

#### *Participants & Design*

Twenty-four adult volunteers recruited from a participant database ran by the UCL Psychology department participated in the experiment in return for monetary compensation. Participants were aged between 18 and 35, 13 were female and 11 were male. Participants completed a health screen questionnaire to establish any history of neurological or psychiatric disorders, but no participants were excluded on this basis. All participants



reported a similar level of educational background, with the majority being current UCL undergraduates. Testing was administered on an individual basis in a separate cubicle in a session lasting approximately 55 minutes. All participants performed all six conditions of the experiment in this repeated measures design. The six conditions are presented in Figure 4.7. Condition orders were fully counterbalanced across participants.

## Stimuli & Materials

### The Ongoing Tasks

The presentation of the ongoing tasks was identical to that described in experiment 5.

### Prospective Memory Tasks

#### TB Prospective Memory Conditions

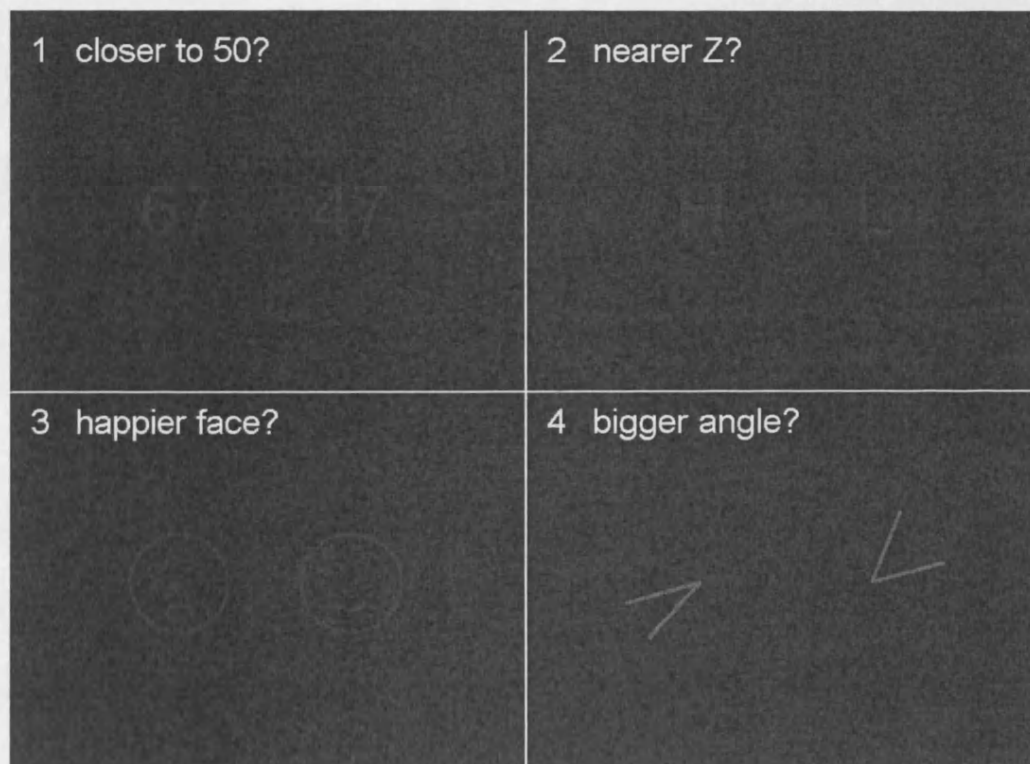
In the TB PM conditions participants were asked to perform the four ongoing tasks and were also required to remember to press a PM response key (instead of responding with the arrow key) after a certain amount of time had passed. The PM response key was assigned to either the Space Bar or Left Control Button and this assignment was counterbalanced across participants. In the single TB intention condition, participants were required to press the PM response key whenever they thought 30 seconds had passed (PM 1 response). In the dual-intention condition they were told they had to press the one PM key after they thought 30 seconds had passed (PM 1 response), but the other key whenever they thought 2 minutes had passed (PM 2 response).

#### EB Prospective Memory Conditions

In the EB PM conditions the target events were created by the stimuli of the tasks turning a specific colour, specifically red or yellow (see Figure 4.6.). The program generated the target event schedule pseudo-randomly for each individual participant. In the single EB intention condition, the prospective memory targets appeared, with equal chance, after 10, 20, 30, 40 or 50 seconds (PM 1 response). In the dual EB intention condition the first target events appeared with the same parameters and in addition the second colour target event appeared, with equal chance, after 100, 110, 120, 130 and 140 seconds (PM 2 response). The target schedule was designed to have a variable schedule of target events in order to

prevent participants trying to predict the arrival of the next target according to the amount of time passed, and thus using time estimation processes. However, the average time between target events was 30 seconds for the first event and 2 minutes for the second event. If the participant did not make a prospective memory response to the target event colour, then the colour was presented again on every 2<sup>nd</sup> trial until the participant made the prospective memory response.

Figure 4.6. The screen design in the EB PM conditions – the red stimuli signifies the PM cue



#### TB & EB Prospective Memory Condition

Finally, in the mixed dual-intention condition participants received both TB and EB instructions. In this mixed condition, half the participants received a 30-second TB demand (PM 1 response) and an EB target schedule of approximately every 2 minutes (varied schedule as above), which again I will label the PM 2 response. The other half of the participants received the counterbalanced equivalent: an EB target schedule of

approximately every 30 seconds (varied schedule as above), labelled the PM 1 response, and a 2-minute TB demand (PM 2 response).

#### Ongoing Tasks Only Condition (Baseline)

As a comparison condition, participants also performed just the ongoing tasks alone, with no extra PM demands. This was treated as the participants' baseline performances of the ongoing tasks.

Block order, PM response keys and the colour of the EB PM targets were fully counterbalanced across participants. In all conditions, whenever a PM key was pressed the screen would flash white and then continue as before.

#### Procedure

The procedure was identical to that described in experiment 5 up until the point that the PM instructions were provided, the procedure was then as follows. Participants were given a second set of instructions on paper regarding the PM elements of the experiment. They were instructed that during some sections of the experiment they would also be required to do an extra task. They were told that the extra task would be different for each section of the experiment and that they would be required to learn thoroughly the new instructions before beginning each section. The instructions included examples of the PM demands. Participants then performed a 60 second practise block in which they were also required to remember an EB PM demand. They were instructed to press the Space Bar whenever they saw the tasks turn either red/yellow (depending on their assigned event colour), two targets occurred at the after 10 seconds 30 seconds. Again, they completed 15 seconds of each of the four ongoing tasks. A verbal prompt from the experimenter to press the Space Bar was given if they had not done so after 3 presentations of the PM cue. Any other instructions were clarified by the experimenter as necessary.

Participants then began the experiment, which was split into the six experimental conditions (see Figure 4.7.) each 6 minutes long. Before each block (i.e. condition) began, a screen informed the participants about the 'extra tasks' they would have to perform (i.e. the PM demands) or if they were just to perform the four basic tasks alone. Participants were informed that they could take breaks whenever these information screens appeared, for as

long as they required, before beginning the next block. The 30 second TB PM demand resulted in a total of 11 correct PM key responses. The 2 minute TB PM demand should have a total of 2 PM key responses. The EB PM conditions resulted in a different schedule of PM targets for each individual, thus the measure derived from these conditions was a percentage score of correctly identified targets.

*Figure 4.7. List of block types each participant performed in experiment 6*

**BLOCK TYPES**

Baseline
Baseline + Single TB PM
Baseline + Dual TB PM
Baseline + Single EB PM
Baseline + Dual EB PM
Baseline + Single TB + Single EB PM

**4.4.3. Results**

The data was subjected to the identical data processing steps as experiment 5, such that for all conditions and analyses, calculations of mean reaction times (RTs) of the ongoing tasks excluded error and post-error trials, first trial of a block, pre and post PM response trials (to remove eye/finger movement noise), post task switch trials (to remove switch costs) and finally trials above and below 3 standard deviations from the mean (to remove outliers).

Performance of the ongoing tasks, as the key dependent variable again, is discussed first. PM performance is then considered afterward. Two participants were excluded from all analyses because one participant had very long RTs in all conditions (mean: 1920 ms in baseline condition, group mean = 978.07ms) and one participant had very high error rates in all conditions (mean: 32.01% in baseline condition). In addition, where participants have produced inaccurate PM performances, their ongoing task data has been excluded from the relevant conditions. Reasons for exclusion were 0 or 1 PM responses in a particular PM condition, as this is cognitively similar to simply completing the block without the extra PM task. Their ongoing task data was included in the conditions in which these same participants produced accurate PM responses. Consequently, 4 participants had missing

data from the initial analyses on this basis. Including these participants' ongoing task data in the relevant conditions did not significantly change the outcome of the results. Moreover, this problem was partly eradicated by pooling over the single and dual-intention conditions, as will be explained below, which allowed 3 of the 4 participants to be re-entered into the subsequent analyses.

#### *4.4.3.1. Ongoing Tasks Analyses*

##### *Separate Task Analyses*

As with experiment 5, it was important to establish that none of the individual ongoing tasks were affecting error rates or RTs in any of the conditions specifically (i.e. that there was no condition x task interaction). This would provide further justification for analyses to be pooled across the four ongoing tasks. To this end, the accuracy and RTs of the separate ongoing tasks were subjected to a repeated measures MANOVA with the factors task (ongoing task: 1,2,3,4) and condition (baseline, single EB, single TB, dual EB, dual TB, dual mixed). The randomised schedule of ongoing task performance invariably resulted in not all participants performing all the 4 ongoing tasks in all 6 conditions. Indeed, only 10 of the 22 participants produced an entire data set that could be entered into these MANOVAs. For this reason, the results of the univariate test are reported because there were too few degrees of freedom available for the multivariate test. The ANOVA with these participants' error rates data revealed a main effect of task,  $F(3,30) = 4.328$ ,  $p=.012$ , and no main effect of condition ( $p>.05$ ) or significant task and condition interaction ( $p>.05$ ). The same ANOVA with RTs yielded the same pattern of results: a main effect of task  $F(3,27) = 22.28$ ,  $p<.001$ , and no main effect of condition or significant task and condition interaction ( $F < 1$ ). These analyses did not include all participants. As in experiment 5, the main effect of task in error rates and RTs was investigated further by collapsing across the condition variable. Replicating the results of experiment 5, the lowest error rates and fastest RTs were produced in task 2 (mean 4.7% and 842.04 ms) and the highest error rates and slowest RTs in task 4 (mean 9.73% and 1422.8ms). Paired sample t-tests between these two tasks revealed significant differences,  $t(22) = 3.9$ ,  $p=.001$ , and  $t(21) = 8.31$ ,  $p<.0001$  for error rates and RTs respectively.

The clear non-significant interactions combined with the randomisation of the ongoing tasks across all participants, strongly suggests it is justifiable to collapse RTs across the four ongoing tasks. Hence, averages reported for the subsequent analysis are the participants' mean error rates or RTs for the 4 ongoing tasks in the 6 conditions (see Burgess et al., 2001, 2003; Gilbert et al., 2005 for similar methodology in neuroimaging studies i.e. 'conjunction design').

### *Hypothesis 3: Number of Intentions*

The comparisons between the single intention and dual-intention conditions were considered next. It was predicted that there would be no difference between the single and dual intention conditions, consequently pooling across this variable would also be appropriate to increase statistical power (i.e. over the single and dual-TB conditions and over the single and dual-EB conditions). Thus, the following analyses would become comparisons between baseline, time- and EB PM and the mixed dual intention condition.

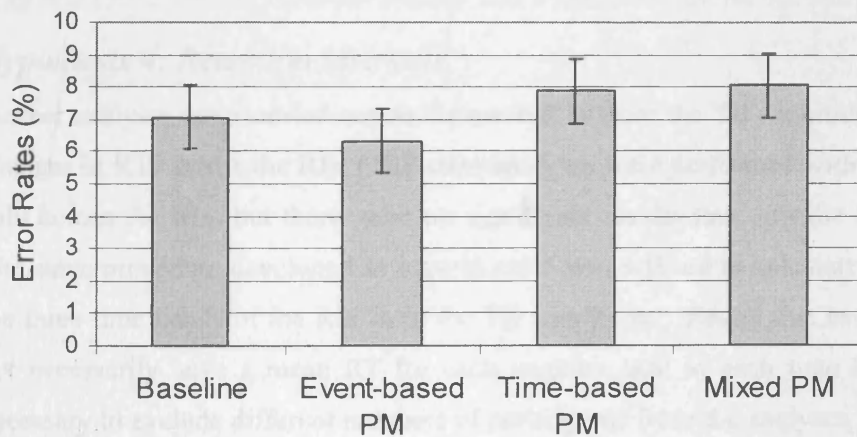
Thus, to ascertain if there were differences between the single and dual intention conditions in terms of ongoing task performance, error rates and RTs were entered into two separate repeated measures MANOVAs with the factors of PM task type (TB or EB) and number of intentions (1 or 2). The analysis with RTs yielded no significant main effects and a non-significant interaction ( $F < 1$ ). However, the analysis with error rates produced a significant main effect of task type,  $F(1,18)=8.25$ ,  $p=.010$ , but a non-significant main effect of number of intentions and a non-significant interaction, ( $F < 1$ ). Thus, performing a TB task increased error rates but having one or two intentions of the same type did not affect ongoing task performance. The remaining analyses were therefore pooled across this variable. Thus, averages reported from this point forward, for the TB and EB conditions, are participants' mean error rate and RT across the single- and dual-intention conditions (still also collapsed across the 4 tasks).

### *Hypothesis 1 and 2: Effect of PM demands:*

The next set of analyses looked at hypotheses 1 and 2, which were concerned with the effect of PM task type and the mixed dual-intention condition on ongoing task performance. Mean error rates from each condition were subjected to a repeated measures

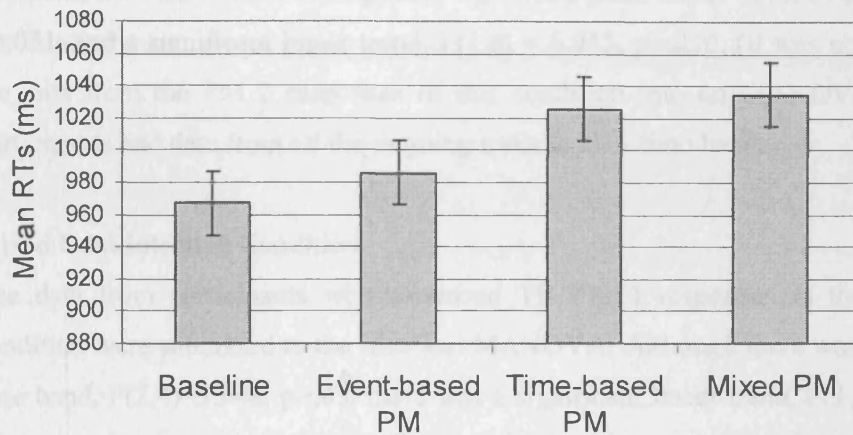
MANOVA with the single variable of condition (baseline, TB PM, EB PM and mixed dual-intention). This analysis yielded a main effect of condition,  $F(3,17)= 4.076$ ,  $p=.024$ . Planned t tests revealed that the TB condition was significantly less accurate than the EB condition, ( $t(20) = 3.26$ ,  $p=.002$ , one-tailed), and the mixed dual-intention condition was significantly less accurate than the EB condition, ( $t(20) = 2.6$ ,  $p=.017$ , two-tailed). Surprisingly, there were no significant differences between baseline performance and any of the three PM conditions. The mean error rates are shown in Figure 4.8. and illustrate quite clearly the increased error rates in the TB and mixed dual-intention conditions, as well as the rather intriguing finding that EB PM produced better accuracy than baseline performance.

Figure 4.8. Mean error rates of trials within PM different PM blocks - collapsed across 4 ongoing tasks and single and dual intention blocks



A MANOVA conducted on RTs with the single variable of condition showed no significant main effect,  $F(3,17)$ , 2.68,  $p=.080$ . Although, there was a general linear pattern of RTs, as shown in Figure 4.9 .

Figure 4.9. Mean RTs of trials within PM different PM blocks - collapsed across 4 ongoing tasks and single and dual intention blocks



#### *Hypothesis 4: Retention Intervals*

Further analyses were carried out on the mean RTs from the TB conditions in order to trace changes in RTs across the RIs. (The same analyses were performed with the error data (i.e. split across the RIs) but there were no significant results thus just the RTs are reported). The same procedure developed in experiment 5 was utilised to calculate the mean RTs for the three time bands of the RIs from the TB conditions. Recall that each participant may not necessarily have a mean RT for each ongoing task in each time band; this made it necessary to exclude different numbers of participants from the analyses below. There were three conditions that included TB RIs: the single TB PM condition, the dual-TB intention condition and the mixed dual-intention condition. The single intention condition is directly comparable to the no-clock condition of experiment 5 and will be considered first.

#### Single TB Intention Condition

The mean RTs for each time band of the single intention condition were submitted to a repeated measures MANOVA (with the levels of time band: 1,2,3). There was no significant main effect of time band,  $F(2,11) = .751, p = .494$ . Nevertheless, there was a hint of the general slowing pattern found in experiment 5.



#### Dual TB Intention Condition

An identical MANOVA was carried out with the mean RTs from the dual-intention condition for the short RI responses (i.e. the PM 1 responses for the 30 second instructions). This yielded a marginally significant main effect of time band,  $F(2,7) = 4.703$ ,  $p = .051$ , and a significant linear trend,  $F(1,8) = 6.955$ ,  $p = .030$ . (It was not possible to enter the data from the PM 2 responses of this condition into an MANOVA because only 2 participants had data from all the ongoing tasks in all 3 time bands).

#### Mixed Dual-Intention Condition

The data from participants who produced TB PM 1 responses in the mixed intention condition were submitted to the identical MANOVA. Although there was no main effect of time band,  $F(2,4) = 3.948$ ,  $p > .05$ , there was a significant linear trend,  $F(1,5) = 8.15$ ,  $p = .036$ . However, the same analysis with the participants who produced TB PM 2 responses (i.e. approximately 2 minute RIs) yielded no significant main effects or linear trends,  $F(2,2) = .223$ ,  $p = > .05$ . Note the small number of participants entered into this latter analysis however.

#### *PM Task Performance*

Again, the key issue with regards to PM performance is to ensure participants were carrying out the intentions correctly in each PM condition. The only measure useful for comparing between TB and EB based intentions is the total number of PM responses produced in each condition. Variance in the number of PM responses could account for differences in ongoing task performance between the conditions. To eliminate this explanation it is necessary to demonstrate the following:

- 1) That there were a similar total number of PM 1 responses in all the PM conditions.
- 2) That there were a similar total number of PM 2 responses in the dual intention conditions.
- 3) That there were a similar number of total PM 1 responses in the two counterbalanced versions of the mixed intention condition.

4) That there were a similar number of total PM 2 responses in the two counterbalanced versions of the mixed intention condition.

*Mean Number of PM Responses, Length of Retention Intervals and Correctly Identified EB Targets*

The number of PM responses each participant generated during the PM conditions was recorded. In the EB PM conditions a correct response was included if participants responded immediately to the target event, correctly inhibiting the response to the ongoing task. From these data, a score was calculated that represents the percentage of first time correctly identified target events. The means and standard deviations for the TB and EB PM responses appear in Table 4.2.

*Table 4.2. Mean number of PM responses and length of retention intervals in each PM condition in experiment 6.*

<b>Condition</b>	<b>Mean Number of PM 1 Responses</b>	<b>Mean Number of PM 2 Responses</b>	<b>Mean Length of Retention Intervals</b>	<b>Mean % of Identified Event Targets</b>
Single TB N = 22	10.64 (SD=4.72)	-	33.44 secs (SD=10.71)	-
Single EB N = 22	11.23 (SD=1.82)	-	-	96.26% (SD=10.07)
Dual TB N = 22	9.5 (SD=4.81)	2.91 (SD=2.39)	PM 1 = 33.75 secs (SD=13.22) PM 2 = 117.81 secs (SD=55.68)	-
Dual EB N = 22	11.55 (SD=2.39)	2.33 (SD=.483)	-	PM 1 = 97.09%, (SD=6.84) PM 2 = 95.24%, (SD=14.37)
Mixed Intention PM 1 = TB PM2 = EB N = 10	10.8 (SD=4.61)	2.4 (SD=1.07)	PM 1 = 34.43 secs (SD=14.75)	PM 2 = 92.78%, (SD=14.81)
Mixed Intention PM 1 = EB PM2 = TB N = 12	11.25 (SD=1.54)	2.5 (SD=1.45)	PM 2 = 138.93 secs, (SD=77.01)	PM 1 = 93.48%, (SD=13.03)

The total number of PM 1 responses were subjected to a 2 x 2 repeated measures MANOVA with PM task type (time/event) and number of intentions (single/dual) as the independent variables. There were no significant main effects and a non-significant

interaction (number of intentions variable,  $F < 1$ ), suggesting that the number of PM 1 responses were comparable across the single and dual intention conditions. The total number of PM 2 responses were also subjected to a repeated measures MANOVA with the single variable of condition (dual TB intention, dual EB intention and mixed intention). This yielded a non-significant main effect ( $F < 1$ ), indicating that participants PM 2 responses were similar across conditions. Two paired sample t-tests were conducted to ensure the two counterbalanced versions of the mixed intention condition generated comparable numbers of PM 1 and PM 2 responses. There was no statistically significant difference in the total number of PM1 responses in the two versions of the mixed intention condition, ( $p > .05$ ). This same was true of the total number of PM2 responses in the two versions, ( $p > .05$ ). Finally, a comparison of the mean length of the retention intervals of PM 1 responses was considered between all TB conditions. Because of excluded participants and counterbalancing, only 10 participants in the mixed intention condition produced TB PM 1 responses so these participants' RIs were compared. A repeated measures MANOVA with condition as the only factor (single TB intention, dual TB intention and mixed intention conditions) revealed a non-significant effect of condition on mean length of retention intervals of PM 1 responses, ( $F < 1$ ). These results indicate that participants performed the PM tasks appropriately across the conditions, and indeed comparably across the conditions. Henceforth, PM performance is not considered as a possible explanation for ongoing task differences.

#### **4.4.4. Discussion**

The aim of the present experiment was to compare the recruitment of internally-guided controlled processes in TB PM tasks without the presentation of a clock and EB PM tasks, and to measure shared processing. To summarize the results: as hypothesised, participants were significantly less accurate in the TB PM conditions than in the EB conditions. In addition, participants were less accurate in the mixed dual intention condition compared to EB, but performance in this mixed condition was no worse than in the TB conditions. Participants did show numerically slower RTs in the mixed condition than any of the other conditions, but this was not significant. Moreover, as predicted, participants did not differ in their performance of the ongoing tasks in the single intention and dual intention conditions, when the intentions were of the same type. Analyses demonstrated that PM

performance was comparable across conditions, thus any changes in ongoing task performance cannot be attributed to differences in PM responses or RIs. In terms of changes in ongoing task performance across the RIs of the TB PM responses, there was replication of the significant linear slowing as participants approached the PM response. However, the data did not always exhibit a statistically significant pattern of slowing.

Thus, the results of this experiment demonstrate that TB PM tasks without the presentation of a clock produce poorer ongoing task performance than EB PM tasks, supporting the first hypothesis and the hierarchy proposed in the introduction to this experiment. The interpretation of this cost is that the TB task is requiring conscious capacity for self-initiated processes, and thus taking resources away from the ongoing task. This interpretation is consistent with past research, which has shown increased impairment of PM performance in TB tasks compared to EB tasks in the elderly population (Einstein et al., 1995; Park et al., 1997; d'Ydewalle et al., 2001). Previous researchers have argued that the difference in performance of TB PM tasks compared to EB PM is due to the absence of external cues, which induces increased dependency on self-initiated retrieval (Craig, 1986; Einstein et al., 1995). Clearly, in the TB conditions in this study participants had to rely heavily on internal cues, because of the absence of a clock. However, in this study – for the very reason that there was no clock at all – the reduced accuracy could also be a result of loading on time estimation processes, given that time estimation requires at least some executive resources (Zakay & Block, 2004). I will consider this further below.

The second hypothesis concerned the effects of mixing TB and EB intentions. As discussed, current empirical evidence regarding the interference effects of mixing types of PM intentions is rather ambiguous. Moreover, theoretically there is little understanding of the shared mechanisms in TB and EB PM. For these reasons, a tentative hypothesis was proposed, which stated that poorer ongoing task performance is expected in the mixed intention condition compared to the other dual-intention conditions. The data showed that the mixed intention condition did not produce any slower or more inaccurate performance than the TB conditions (with the data collapsed across the single and dual intention conditions). This suggests that TB and EB PM are not loading on the same processes, at least for the tasks in this experiment. These data corroborate Cicogna and colleagues study who found no statistical difference in PM performance when mixing a TB PM task with an

EB PM task – although there was some slight non-significant reduction in PM performance in the mixed intention condition. They interpreted this slight interference as a sharing of attentional resources between cue detection, that is, strategic monitoring and time monitoring. There was also some evidence of shared processing from the pattern of RTs in this experiment, with a significant linear trend in RTs to the ongoing task. The data would suggest that it is the interaction of strategic cue monitoring and time monitoring that creates this slight interference since other stages of PM processing the mixed intention condition has in common with the dual intention conditions (e.g. encoding of two intentions, interruption of ongoing task).

However, this interpretation should be considered with caution for two reasons. Firstly, there were no significant RT differences between the TB and the mixed intention conditions. Furthermore, there were no significant differences in ongoing task performance between baseline and the EB PM conditions. According to previous research (Smith, 2003) impairments in ongoing task performance acts as index of strategic processing used for the PM tasks. The implication here is that the EB PM tasks in this experiment were not drawing heavily on internally-controlled strategic processes, and instead participants were using automatic association mechanisms to achieve this PM task (e.g. McDaniel et al., 1998, see Chapter 2, section 2.4.1.). This fits with the multi-process framework proposed by Einstein & McDaniel (2000) in which factors of the PM task and so forth affect the processes recruited. Several factors regarding the nature of this EB task might encourage participants to use automatic processes rather than load strategic monitoring. For example, the event-cue frequency is very high, averaging at every 30 seconds, and is consistently the same event-cue (i.e. red or yellow task stimuli). Given this frequency and consistency the PM task may become habitual which lends itself to automatic processing (Einstein et al., 1998). Moreover, the event-cue is specific; no categorical processing is required (e.g. make PM response to primary colours) which also increases PM performance because of easier recognition of the cues (and presumably reduces dependency on self-initiated processes) (Einstein et al., 1995; Ellis & Milne, 1996). If the EB PM task here is not depending heavily on self-initiated processes then this can explain the lack of interference in the mixed intention condition and why this condition produces ongoing task performance almost equivalent to just having a TB task. Nevertheless, the data still provides the necessary empirical support for the theoretical position that TB PM without a clock draws more

heavily on self-initiated processing than EB PM. I would argue that this is likely to be the case even if the EB PM did require more controlled processing.

Thus, the suggestion is that there is only slight shared processing in the mixed intention condition because the EB PM task is relying on less attentionally demanding retrieval and maintenance processes. Interestingly, another line of evidence is available from this experiment to support this suggestion, this evidence stems from a cognitive model of time estimation, which I will now briefly review.

Prospective time estimation requires attentional resources, such that as the non-temporal information processing demands increase then time estimation becomes less accurate. Under conditions of high attentional load fewer time units can be processed and consequently, the duration of time is perceived as shorter (Block & Zakay, 1997; Pouthas & Perbal, 2004; Wearden, 2004; Zakay & Block, 2004). Employing prospective time estimation as a secondary task thus permits a good understanding of the attentional demands of the non-temporal task (Zakay & Block, 2004). That is, increasing non-temporal attentional load – reduces length of time perceived – and so shorter RIs are produced which can be measured and compared. This is perhaps intuitive with everyday life; if we are busily engaged in another task then we may misjudge our TB PM task (e.g. miss the seminar that is at 5pm) because the passage of time feels shorter. The relevance for this study is that there were no significant differences in the mean length of RIs between the TB PM conditions, including the mixed PM conditions. In other words, participants did not produce shorter RIs in the mixed PM condition compared to the other TB PM conditions. In the mixed intention condition, they were able to process an equal number of time units. This suggests that indeed participants were carrying out the EB PM task with relatively non-attention demanding processes (although this does not imply that PM was achieved completely automatically e.g. self-initiated task switch requires executive resources as discussed in the previous Chapter), and can explain the lack of significant interference in the mixed intention condition.

The apparent lack of shared processing in the TB and EB PM tasks found in this study at first glance appears to conflict with the findings from neuroimaging studies (described in the introduction to experiment 5). Okuda et al., (2002) found similar activation patterns in

TB PM without a clock and EB PM. In a later study, Okuda, Burgess & Frith (submitted) relate this PM imaging data to the Gateway Hypothesis (see Chapter 1, section 1.3.2.). Okuda, Burgess & Frith argued that in the earlier study the TB PM task without a clock and the EB PM task both activated rostro-lateral PFC because of the load on internal control processes in the former, and the switching between internal processes and the external stimuli in the latter. However, in the present experiment the evidence suggests the EB PM task is not making demands on internally-guided strategic control processes for retrieval but instead relying on the external cues to bring the intention to mind, perhaps because the nature of the cue was colour-based. Conversely, the TB PM task is still heavily recruiting self-initiated processes. As a result, according to this Gateway Hypothesis this can explain the lack of interference between the conditions, as there is slightly different neural mediation.

The results for the third hypothesis are quite clear and in line with the prediction. Performance on the ongoing tasks was not impaired further by adding a second PM intention of the same type. In other words, performance in the single intention condition was identical to that of the dual intention condition. These data also fit with Cicogna et al., (2005) who found that when a TB PM task shares a portion of the RI with another prospective task – the overlap doesn't generate an interference effect (in terms of performance of main PM task). Indeed, they found slight facilitation of the main TB PM task when participants had two TB PM intentions (although a slight decrease in the interpolated PM task). This also supports the participants reports from Morris's (1992) naturalistic procedure, they maintained that remembering one intention can also remind them of another impending future (but unrelated) intention. Similarly, Kidder et al. (1997) found that participants performed better on a 12-interval condition (1 response every min) compared to a 6-interval condition (1 response every 2 mins). Other research has demonstrated that there is no effect of cue set size or frequency (Ellis, Kvavilashvili, Milne, 1999; Marsh et al., 2003), although participants can show practise effects. In the present experiment participants appeared to have used the same degree of strategic monitoring for the cue and the time for both sets of intentions. This is perhaps because both intentions were cued by the same stimuli in the EB task (i.e. the colour of the ongoing task) and the TB intention only required the calibration of one internal clock (i.e. 30 seconds and 2 minutes only required one psychological clock to operate, see Cicogna et al., 2005). The

implication is that imposing a second PM intention of the same type does not hinder participants' PM performance or ongoing task performance.

A final aim of the present study was to replicate the findings of experiment 5, which demonstrated a linear slowing of RTs to the ongoing task across the RIs in the no-clock condition. As argued previously, any slowing of RTs as participants approach a PM response may reflect voluntary preparatory task-switching processes (Arrington & Logan., 2004, 2005). After all, the pattern clearly cannot be attributed to increased clock-checking. These data partly replicates these findings. Certainly, in some of the RIs of the TB intentions the RTs to the ongoing tasks did follow a significant linear pattern – slowing down across the RI. This supports the framework for TB PM task-switching outlined in the general discussion of Chapter 3. Nevertheless, the data also presents inconsistency. RTs from the RIs of the single TB intention condition, although showing the equivalent pattern numerically, did not show a statistical linear slowing. Similarly, the RTs from the longer RIs (i.e. 2 minutes) did not follow this pattern. This could cast doubt on the interpretation that these RTs reflect preparatory task-switch processes. However, the number of participants entered into these analyses was greatly reduced because of missing data, undoubtedly minimising the statistical power available. Moreover, the longer RIs (i.e. 2 minutes) contained within them the shorter RIs (i.e. 30 seconds) it is thus conceivable that the cycle of the RTs within the short RIs disrupted the pattern of RTs across the longer RIs. As has become apparent, the design of the present experiment with four ongoing tasks was not ideally suited to trace fluctuations in RTs across the RIs. Future studies need to address this inconsistency by using a single ongoing task, and indeed single-intention conditions only. Further reasons for this apparent inconsistency in RT data across the RIs are discussed in Chapter 6, section 6.2.3.

#### **4.5. Summary**

The aim of this chapter was to evaluate the importance of internally-guided control processes in the successful execution of PM tasks. The assumption that TB PM tasks must rely more heavily on these processes is challenged by the results from experiment 5. In place of this assumption, I have offered a theory that maintains there is a hierarchy of dependency on self-initiated processes and this hierarchy crosses the TB and EB



distinction. Experiment 5 illustrates this point more precisely by demonstrating that a TB PM task in which the presentation of the clock is constantly available generates few demands on self-initiated processing, as indexed by ongoing task performance. Experiment 6 provides further support for the hierarchy by demonstrating that self-initiated processes have a more important role in TB PM tasks in which the clock is absent, compared to an EB PM task. The implications of this theory are evaluated in Chapter 6, section 6.3.3.

## Chapter 5

### ***Individual Differences in Internally-guided Control Processes in a Healthy Population***

#### ***5.1. Self-Regulation & Multitasking Revisited***

The present chapter aimed to investigate individual differences in the internally-guided cognitive control systems (self-regulation) of the healthy population. Recall from Chapter 1 that frontal patients can demonstrate deficits in this system, leading to self-regulatory or strategy application disorder (Shallice & Burgess, 1991; Goldstein et al., 1993; Levine et al., 1998, 2000; Burgess et al., 2000). Shallice & Burgess (1991) first describe Strategy Application Disorder (SAD) in three patients who showed inaccurate plan formation or modification, faulty marker creation or triggering and/or poor evaluation and goal articulation. All processes linked to the Supervisory Attentional System (SAS). Levine et al. (1998, 1999, 2002) discuss their frontal patients with SAD or self-regulatory disorder as an inability to regulate behaviour according to internal goals. Impairments in these internal control systems become most apparent in ill-structured tasks because there are a variety of different approaches to these tasks, such that participants must decide for themselves how they allocate their efforts (Alderman et al., 2003). The use of ill-structured tasks – or multiple subgoal tasks - with focal lesion and TBI patients has now produced considerable research attention (e.g. Bechara et al., 1994; Whyte et al., 1996; Goel & Grafman., 1997; Robertson et al., 1997; Schwartz et al., 1998; 1999). The application of these neuropsychological tasks to the healthy population is, however, minimal. Yet the use of these tasks seems entirely warranted to determine the cognitive processes that contribute to their success in the healthy population. The experiments described in this Chapter were developed for this aim and utilised modifications of the multitasking tests described in Chapter 1. I will briefly revisit the empirical and theoretical background to multitasking before discussing the new Advanced Multitasking Test.

The cognitive and neuroanatomical bases of multitasking are discussed in detail in Chapter 1 section 1.3.1. The current evidence seems to suggest three key components are vital to successful multitasking: retrospective memory (RM), planning and 3) intentionality (i.e.

PM) (Burgess et al., 2000). Patients with lesions to different areas of the PFC appeared to have slightly different impairments on the multitasking test. Damage to the left anterior and posterior cingulates were associated with impairment to the RM aspects of the test, right DLPFC damage produced deficiencies in the planning component, and rostral PFC damage gave rise to difficulties in task switching and plan and rule following – the intentionality aspects. The suggestion is therefore that there is a degree of independence between these components contributing to multitasking. The argument that the set of processes contributing to multitasking are relatively circumscribed is a core feature of the following experiments (see Chapter 1, section 1.3.1. for further evidence).

## **5.2. Self-Regulation in the Healthy Population**

As Burgess et al., (2000) describe, multitasking is a ubiquitous behaviour in everyday life. The workplace is the most obvious example in which people consistently switch between tasks, are interrupted, delay intentions and hold daily (or hourly) self-determined targets (e.g. Einstein et al., 2003). Despite this, research investigating healthy participants' performance on these tests is inadequate, with this population primarily only appearing as controls for the patient studies. For example, Alderman et al., (2003) created a simplified version of the Multiple Errands Test (MET-SV) for use as a clinical tool. They tested a control group (range 21-58, mean =29.2) on the task and found generally good performance in this group (89% of controls made few errors i.e. less than 7). Scores on the NART-R (an IQ measure) were not significantly related to errors on the MET-SV in this group, although there were significant age correlations. The authors argue that *the "MET-SV appears to have independence from the potentially biasing effects of general intellectual ability, familiarity with the environment and gender"* (p. 40). So how did their performance relate to everyday life? Correlations between the DEX questionnaire (a measure of everyday executive abilities) and the MET-SV were non-significant, but perhaps this is unsurprising given that the DEX was designed for use with brain-injured populations (although see Chan, 2001). Moreover, most of the control group performed close to ceiling on the MET-SV, producing little variance in performance. Other measures relating performance to everyday life were not included.

Levine et al., (2000) also tested a healthy control group as a match for their TBI patients. A strategy measure from their R-SAT correlated with a questionnaire measuring psychosocial outcomes, the Sickness Impact Profile (SIP), in the patient group. Patients with low strategy scores responded to SIP items that reflected impaired functioning in social and occupational situations. The corresponding correlations were not significant in the healthy group but this questionnaire also considers physical health as part of the assessment, again perhaps deeming it unsuitable for the healthy population. Thus, the use of inappropriate measures for the healthy population in these studies, combined with the ceiling performances, limits the conclusions that can be drawn about the processes that contribute to, or correlate with, multitasking in this group. Therefore, despite the ubiquity of multitasking few empirical studies have attempted to evaluate the processing characteristics in the healthy population.

Performance on multitasking tests appears to be unconnected to performance on other executive tasks and IQ tasks, in terms of cognitive processes and neural mediation in the frontal patient groups (Burgess & Shallice, 1991; Goldstein et al., 1993; von Cramon & von Cramon, 1994; Crepeau et al., 1996; Duncan et al., 1995; Alderman et al., 2003). An important question then is to what extent this is true within the healthy population. Alderman et al., (2003) as described above, provided some evidence that IQ and multitasking are relatively unrelated in a control population. Thus, if multitasking loads on a relatively discrete set of processes, as Burgess et al. (2000) posit, then these tests are a possible novel set of indicators. A range of individual differences can be expected on these sorts of task (e.g. Morrin, Law & Pellegrino, 1994, McFarlane & Laratello, 2002), which might offer an insight into: "*a person's ability to regulate behaviour according to internal goals*" (Levine et al., 2002, p. 451), as opposed to the patients' inability to do just that. Thus, extrapolating from the neuropsychological data somewhat, performance on these tasks in the healthy population might relate to skills such as time management, avoiding distractions, planning and remembering intentions (Burgess, 2000; Burgess et al., 2000). All skills which are crucial for everyday life. Experiments 7 and 8 were therefore also designed to investigate the relationship between multitasking performance and real life outcomes. Thus, providing a direct test of Burgess (2000) proposition that multitasking tests require a specific set of processes which are "*at the very heart of competency in everyday life*" p. 279).

### **5.3. Experiment 7**

The design adopted in this experiment was similar to an approach taken by Levine et al., (1998) in their study that compared patient groups and controls on a newly developed Strategy Application Test. Firstly, they administered an ill-structured multitasking test to their experimental groups. Secondly, they evaluated the contribution of processes secondary to strategy application/multitasking (e.g. RM) to their multitasking test and finally, they calculated correlations between performance on the multitasking test and other cognitive measures. Accordingly, these procedures were also present in experiment 7:

- 1) A multitasking test was administered to a group of healthy participants.
- 2) The contribution of secondary processes to multitasking was evaluated by measuring rule recall before and after administering the multitasking test.
- 3) Other cognitive tasks and real life outcome measures were administered to determine the relationship of these measures with multitasking.

In order to avoid the ceiling effects that healthy populations usually obtain on ill-structured tasks (e.g. Manly et al., 2002; Alderman et al., 2003) modifications were made to the Greenwich Test (Burgess et al., 2000). The development of this 'Advanced Multitasking Test' will now be described.

#### **5.3.1. Advanced Multitasking Test (AMT)**

As described in Chapter 1, section 1.3.1, Burgess et al., (2000) proposed the following criteria that comprise a multitasking scenario:

- 1) Many tasks
- 2) Interleaving required
- 3) One task at a time
- 4) Interruptions and unexpected outcomes
- 5) Delayed intentions
- 6) Differing task characteristics
- 7) Self-determined targets

#### 8) No immediate feedback

Thus, to create an advanced multitasking test, two new components were added to the basic Greenwich Test design. Firstly, an interruption task was added. Interruptions are specified as one of the key features of multitasking and are a common feature in everyday life, such as in the workplace (e.g. Hudson et al., 2002). An interruption can increase demands on self-regulatory processes, for example suspension of the ongoing task, resumption of the ongoing task and modification of plans (Zijlstra et al., 1999). The second component added was an extra PM load. Multitasking tests have a PM element (Burgess et al., 2000) and thus by adding an extra PM task overall task complexity was increased.

### **5.3.2. The Effects of Interruptions**

The effects of interruptions, although rarely touched in the neuropsychological literature, are studied in other research contexts, such as in the occupational and human computer interaction fields. I will briefly review this research in order to address design implications for the AMT.

Studies in these contexts have demonstrated that interruptions can be disruptive to performance of the ongoing task, and this has applications for the design of computer interfaces. For example, Gillie and Broadbent (1989) describe a study in which participants were interrupted during a computer task and report reduced ongoing task performance when the interruption task was similar and complex. Consistent with this, Adamczyk & Bailey (2004) showed that a peripheral task that interrupts an ongoing task has a greater impact on performance of the ongoing tasks, than if the same peripheral task is presented in between execution of the ongoing tasks. This effect was attributed to the reduced mental workload that occurs within ongoing task boundaries (Miyata & Norman, 1986). Both of these experiments utilised several ongoing tasks, mirroring elements of the multitasking tests (also see Edwards & Gronlund, 1998). Thus, to increase difficulty of the multitasking test the interruption task was presented exactly half way through the AMT, so that the participants were fully interrupted. Moreover, the instructions forced participants to carry out the interruption task immediately, as McFarlane (2002) has shown that forcing people to immediately engage in the interruption task seems to be more difficult than allowing

them to self-determine when to engage in the new task. In addition, although the interruption task was relatively simple to ensure participants understood instructions (and reduce the interruption lag, the time between receiving the interruption task instructions and beginning the interruption task – see Law et al., 2004), it was different from any of the subtasks in the AMT. There is some controversy over whether interruption tasks that are similar or dissimilar to the ongoing task are more disruptive (see McFarlane & Latorella, 2002 for review). During the AMT, however, individual participants will be performing different subtasks when the interruption task is presented. To control this variable then, the interruption task was designed to be completely different from all the subtasks. Dissimilar tasks may be more disruptive than similar tasks because of increased switch costs (Speier et al., 1999).

Finally, the interruption task was designed to be relatively open-ended, in order to load further self-regulatory (i.e. self-determined) processes (Burgess et al., 2000; see also Law et al., 2004). This type of interruption task also contrasted with Manly et al.'s interruptions (2002). Their study demonstrated that interjecting brief interrupting auditory alerts within a multitasking test improved the performance of a group of head injury patients. However, these alerts did not require participants to switch tasks. Instead, participants had been instructed to use them as a moment in which they could assess their current task performance. This was quite a different kind of interruption. Nevertheless, there is other evidence that interruptions may not be disruptive. A study by Law et al. (2004) should be mentioned at this point. They took a very similar approach to creating a multitasking test suitable for the healthy population but published their study after this experiment had been completed. They too introduced an interruption task to a basic Greenwich Test design, based on the same rationale. Participants were interrupted with a picture-naming task whilst they performed the subtasks. Participants were in one of 4 groups: 1) not interrupted, 2) early interruption (after 3 mins), 3) late interruption (after 7 mins) and 4) early and late interruption. There was no evidence in their study of the interruptions impairing ongoing task performance; indeed there was a hint of participants completing ongoing task items faster when given an interruption. Their conclusion that multitasking induces a difference cognitive demand to an externally-cued interruption task is consistent with many of the arguments in this thesis. Other studies showing facilitation of the ongoing task thanks to an

interruption have also previously been reported (e.g. Speier et al., 1999; Zijlstra et al., 1999)

However, Law et al., report only two measures from their multitasking test: an efficiency score (the number of items worth more points that were completed as a proportion of the number of items completed) and the number of items completed overall. Neither of these measures was affected by the interruption. Other measures may have revealed disruption however. Law and colleagues do not report, for instance, how many of their participants attempted all of the subtasks or followed their plans. It may be the intentionality aspects of the multitasking tests that are affected by interruptions based on the following rationale. The Zeigarnik effect (1927; 1938) is a well-established phenomenon in which participants recall interrupted tasks more successfully than completed tasks. This explanation proposed is that there is increased activation for the suspended task during the interruption (Zeigarnik, 1938; Lewin, 1951). This increased activation may interfere with the increased activation for PM intentions, as conceived in the intention superiority effect (e.g. Goschke & Kuhl, 1993; Altmann & Trafton, 2002). Einstein et al., (2003) demonstrated that even a 15-second interruption was detrimental to PM performance, and the authors argued the impact of the task-switch makes it difficult to 'reactivate' all of the task demands on finishing the interruption task. The effect of the interruption on PM performance was assessed within the present experiment by examining the impact of the interruption on the PM slide task.

The complexity of the task may also affect whether the interruption task has a positive or negative effect (Speier et al., 1999). Increasing complexity of the ongoing tasks can increase the disruptiveness of the interruption task. The AMT comprises an extra element of complexity compared to the Law et al. test, because an extra PM task was also included, for this reason I expected the interruption to make the AMT more difficult and produce a wide range of performances (see McFarlane & Larotello, 2002 for discussion on individual differences).

### **5.3.3. Prospective Memory Load**

'Intentionality' is a key component in multitasking tests (Burgess et al., 2000, see Chapter 1). For example, participants must remember to switch between the subtasks, they must



remember to follow their plan and so forth. Thus, to create the AMT increasing the load on these PM processes could increase task complexity. A TB PM task was added for this purpose. Participants were asked to write down the number and letter from a slideshow presented on a large screen every 30 seconds. They were informed that the number and letter change every 5 seconds. This loads on PM but also mimics some real life situations in which one might have to monitor for a certain time or event to arise whilst in a multitasking situation.

#### **5.3.4. Other Design Elements of the AMT**

Following Levine et al. (1998) the influences of extraneous variables on multitasking performance was controlled through: 1) Item difficulty; Levine and colleagues argue for simple subtasks in order to reduce the possibility that attentional capacity is directed away from strategy application and towards the tasks themselves. The subtasks used in the AMT were very straightforward for this population. 2) Measuring participants' recall of instructions and participants' understanding of the task demands. This was achieved by including cued and free rule recall measures prior to beginning the AMT and after finishing the test. It was also ensured that instructions for the AMT were available throughout the test.

#### **5.3.5. Cognitive and Real Life Measures**

RM is considered an essential component of multitasking (Burgess et al., 2000) and this was tested by including a word list recall test. I predicted that RM would correlate specifically with PM measures from the AMT, because RM is necessary for PM, although not sufficient (Burgess & Shallice, 1997). RM is less crucial for strategy application (Levine et al., 1998), except to recall the rules, and thus no relationship, or a very weak relationship, was expected between RM and the strategy score from the AMT. To test if the AMT is measuring a set of processes different to IQ, as suggested by the multitasking literature, the Raven's Advanced Matrices were also administered (Raven, 1976) with the prediction that participants' scores from this would not correlate with the intentionality scores of the AMT. However, there may be positive correlations between IQ scores and other AMT measures, because there is evidence of involvement of lateral PFC in both Raven's (Gray et al., 2003) and planning (Unterrainer et al., 2004). Finally, the real life

measures administered were relatively exploratory and opportunistic. Firstly, academic qualifications were gathered from participants since multitasking processes are likely to be essential to examination success, specifically the processes of planning, RM and PM. Similarly, because multitasking performance has been related to everyday planning and organisation (Burgess et al., 1998; Alderman et al., 2003; Knight et al., 2003), at least in clinical populations, participants also filled in a questionnaire concerning everyday time management skills and abilities, as well as lists of hobbies and interests. Time management entails prioritising goals, plus planning and scheduling tasks accordingly to the available time and resources (Lakein, 1973; Francis-Smythe & Robertson, 1999). Positive correlations were predicted between these questionnaires and scores from the AMT. Finally, a questionnaire concerning the participants' life satisfaction was also administered as a general life outcome measure.

### **5.3.6. Summary of Hypotheses**

Performance on the AMT

Hypothesis 1:

The extra task demands of this new AMT is expected to increase task difficulty by making more demands on self-regulatory processes, and thus produce a wide range of performances in the healthy population.

AMT Performance and Relation to Cognitive Measures

Hypothesis 2:

RM is necessary for PM, although not sufficient (Burgess & Shallice, 1997), so the hypothesis is that there will be a small positive correlation between PM scores of the AMT and RM test scores.

Hypothesis 3:

It was hypothesised that there would be a positive correlation between Raven's and the strategy scores of the AMT, but not the scores that represent the intentionality aspect of the AMT.

AMT Performance and Relation to Real Life Outcomes

Hypothesis 4:

Based on the clinical and lesion evidence, it was hypothesised that multitasking performance would correlate with measures of life outcomes.

### **5.3.7. Method**

#### Participants & Design

Participants were 83 undergraduate psychology students at University College London. Their mean age was 19.26 (SD = 1.26) and 11 were male, 72 female. All participants were fluent English speakers. This was a correlation design so all participants were subjected to the same procedure and tasks as described below.

#### General Procedure

Participants completed the tests, including the AMT, in one session. The tests were completed in the following sequence: immediate word list recall, Raven's matrices, the AMT, delayed word list recall and the questionnaires. The entire set of tests took approximately one hour 25 minutes. The description and the procedure for the AMT will be described first, followed by the other measures.

#### AMT Procedure

Participants were provided with all instructions for the AMT and supplied with all the handouts before beginning. After an opportunity to ask questions about any aspect of the AMT, the handout of the rules were briefly recollected whilst the rule recall tests were administered. Upon completion, participants were then given the rule sheets back and were allocated 4 minutes to look over them to establish answers to any questions they had not known. Participants then began the AMT. The same procedure was performed with the rule recall tests after the 15 minutes had elapsed, but after this all handouts and answer sheets were collected in before beginning the delayed word list recall.

#### Materials

##### Advanced Multitasking Test – Materials & Procedure

Three basic subtasks, modified from the Greenwich Task into pen and pencil tests, comprised the AMT, along with the interruption task and the PM slide task. Participants were given 15 minutes to complete the entire test. Thus, the AMT consisted of several

handouts for the participants: the list of rules for the whole task (16 rules), an answer booklet (10 sheets of lined paper), and the task stimuli. The time-based PM slide task, timer and overhead projector screen were visible to all participants at all times at the front of the room so participants could just glance up to monitor the time and check the slides.

#### The Subtasks of the AMT

The ongoing subtasks were chosen on the basis of pilot studies showing that each task took a similar amount of time to complete, although they did vary slightly in difficulty. The subtask stimuli consisted of the three tasks separated into sets A and B, each set containing 100 items on two pages. All pages were clearly labelled with the task number and the alphabetical set.

As with the other multitasking tests, there were far more items available than could be completed in the 15 minutes. This required participants to take a strategic approach to performing the task.

Task 1) Word Association - Each A and B set comprised 100 simple word items e.g. coffee. Participants were asked to write down the first word that came to mind on reading each word. They were informed that there were no right or wrong answers, but that they should just write down the first word that comes to mind.

Task 2) Mirror reading – Each A and B set contained 100 word items which were written back to front e.g. REWOLF. Participants were asked to identify the words that were presented as they appeared in a mirror.

Task 3) Where would you find a...? – Each A and B set consisted of 100 questions beginning with the phrase ‘Where would you find a ..?’ e.g. where would you find a stapler? Participants were asked to write down an appropriate answer to the question. They were informed there was more than one right answer.

As in the Greenwich Test there were certain rules attached to completing the AMT. These were presented as a handout to participants and comprised the following:

AMT Rules:

1) Score as many points as possible by answering items of the subtasks.

- 2) Attempt parts of both sets of the three subtasks (i.e. A and B).
- 3) Earlier items are worth more points than later ones in all subtasks.
- 4) Subtasks and items within the subtasks can be completed in any order.
- 5) There is one constraint on this: you cannot shift from set A of one subtask to set B of the same subtask or vice versa.

#### Rule Recall Tests:

To check rule understanding of the AMT two rule recall tests were administered. A free rule recall instructed participants to write down as many of the rules they could recall as possible in two minutes, this free recall was only included to aid rule learning. Subsequently, participants were given a cued rule recall. Participants answered nine questions about specific key rules (see Appendix A) and the scores for this are reported. Before beginning, participants were encouraged to read over any rules they were uncertain of. In addition, the rule sheet was available to participants throughout the 15 minutes of the test. At the end of the AMT the participants underwent the same cued rule recall.

#### Prospective Memory (PM) Slide Task:

A powerpoint presentation, displayed on a screen visible to all participants, consisted of 180 slides with one letter and one number on each slide chosen pseudo-randomly e.g. A7. Each slide was set to appear for five seconds. A digital timer was also projected on the screen and counted down from 15 minutes displaying minutes and seconds (due to an error in the programme the timer stopped with 59 seconds to go, this was accounted for in the scoring). Participants were instructed to write down the letter and number that were on display at each 30 second point. Importantly, it was emphasised that they should complete this task throughout the entire 15 minutes of the test.

#### Interruption Task:

The interruption task was presented on an overhead projector at 7 minutes 40 seconds (after the 30 second point so that participants could complete the PM slide task). This task consisted of the presentation of the names of forty famous people in a list e.g. the current U.K. Prime Minister, Tony Blair. Pilot studies showed that they were easily recognisable names. Again, though it was emphasised that there was no right or wrong answers. Due to the nature of the interruption task, no details were provided at the beginning of the test

about this task. The objective of the task was for each participant to choose and write down the ten people from the list that they would most like to meet, and then do the same for a relative (e.g. mother or father). This was explained within 20 seconds of putting the list on display. Participants were told to carry out the interruption task immediately and then return to the multitasking test (with no instructions regarding which subtask they should return to).

#### Measures Derived from the AMT

A range of scores was calculated for the AMT. These scores were based on dependent variables from previous multitasking tests (Levine et al., 1998; Burgess et al., 2000) and reflect the most strategic approach participants can take. The optimal strategy on this test was to score the most points whilst breaking the fewest rules. This could be achieved as follows: by attempting all sets of the 3 subtasks as instructed, by obeying the order rule and completing an equal amount of items in each of the sets of the 3 subtasks (as early items are worth most).

Thus, the measures were as follows:

- Pre test cued rule recall – total correct rules recalled out of 9.
- Post test cued rule recall - total correct rules recalled out of 9.
- 1 pt for attempting both sets of 3 subtasks.
- Number of subtasks attempted.
- Number of rule breaks.
- Number of subtask switches.
- Percentage Opt Score – see below.
- Total number of items completed.

#### Scoring of the Percentage Opt Score

This represents the deviance from the optimal percentage of items that should have been completed per subtask set. The score was calculated by finding the number of items completed in each subtask (e.g. word assoc. A) and dividing this by the total number of items completed. This produced a percentage deviance from the optimal number of items for each set. Minus signs were then removed and all the task deviance scores were totalled

to create the overall Percentage Opt Score. It takes into account the number of items each individual completed. Thus, 0 represents the most strategic time allocation for each participant and thus the larger the score from this – the poorer the performance (in strategic terms). (See Levine et al., 1998, 2000; Burgess, 2000; Manly et al., 2002 for similar scoring system.)

#### PM Task Score

- Score out of 28 for total number of times reported correct slide.

#### Interruption Task Score

The interruption task itself was a straightforward list-making exercise, thus there was no accuracy measure. However, what is a measure of interest is whether participants continued on the PM slide task whilst carrying out the interruption task as discussed in the introduction. Thus, the score was simply:

- 1 pt for continuing PM task during the interruption task

#### Other Cognitive Measures

##### Materials and Procedure

##### Word List Recall

As a measure of retrospective memory two word list recalls were administered to participants. Sixteen words were verbally presented at the beginning of the testing session (See Appendix A). Participants were then asked to recall as many of the words as possible within two minutes. The first recall immediately followed the presentation of the words; the delayed recall was administered at the end of the series of tests (approximately 45 minutes later).

- Participants were scored on the number of words recalled in the delay condition (out of 16).

##### Raven's Advanced Progressive Matrices (1976)

To assess fluid intelligence the Advanced Raven's Matrices were administered to participants using an overhead projector. The test is thought to be culturally fair and with

good reliability (Raven, 2000). Each problem was printed onto separate acetates so that they could be presented one at a time. The first seven Raven's problems were presented for ten seconds each and problems eight to twelve were presented for twenty seconds. The participants indicated the correct option on an answer sheet.

- Participants received a score out of twelve for the number of correct problems solved.

#### Other Measures – Real Life Outcomes

##### Materials and Procedure

Satisfaction with Life Questionnaire (Diener et al., 1985):

This consists of five statements concerning global life satisfaction. Participants answer using a 7 point Likert type scale ranging from strongly agree to strongly disagree. Studies suggest the scale has good internal consistency and reliability (Diener et al., 1985) and positive test-retest results (Diener et al., 1985, Pavot and Diener, 1993). Pivot et al. (1991) report the scale as suitable for a wide range of applications and age groups and as showing a high degree of convergence between peer and self ratings of life satisfaction.

- The sum of the five statement ratings produces one overall life satisfaction score.

##### Academic Qualifications Questionnaire

Details of academic qualifications were collected. Points for graded qualifications were then calculated according to standardised systems in the U.K. educational system. GCSE's, half GCSE's and O-Levels were scored according to the Department of Education guidelines. As Levels and A-Levels were scored according to the UCAS points system (see Appendix A).

Leading to 3 measures:

- Total qualification points (A levels, AS levels, GCSEs, half GCSEs or O-levels).
- Total A and AS level points.
- Total GCSE and half GCSE points.

##### Time Management and Hobbies Questionnaire



Six 5-point Likert-style questions on time management were developed for use with this sample (see Appendix A). These included questions on use of strategies for time management (diary keeping, revision plans, meeting deadlines etc). Participants' responses were calculated by summing their responses (1-5) for each question. A higher score on this questionnaire represents superior time management skills. Participants were also asked to list their hobbies and interests that they regularly participate in as part of their everyday lives.

This questionnaire therefore produced two measures:

- Total points on time management questions.
- Total number of hobbies.

### **5.3.8. Results**

#### *5.3.8.1. Performance on the AMT*

Hypothesis 1:

The hypothesis stated that the extra task demands of this new AMT would increase task difficulty by making more demands on self-regulatory processes, and thus produce a wide range of performances in the healthy population. Table 5.1. displays the descriptive statistics on the range of AMT scores.

#### Recall of Test Rules

Participants were tested with 9 cued questions and a free rule recall at the beginning of the test and at the end of the test. After the first rule recall tests participants were provided with some time to reread the instructions, which were also available throughout the test. Unsurprisingly therefore rule recall was very high, with 75 out of 83 (90.36%) of participants correctly answering 7, 8 or 9 questions before beginning the test and 81 out of 83 (97.6%) scoring 7, 8 or 9 at the end of the test. Table 5.1. displays the mean scores for both of these measures. Participants recalled an average of 4.87 (SD=1.62) rules before beginning the AMT and 5.89 (SD=1.59) upon finishing, on the free rule recall tests.

Table 5.1. Descriptive statistics of the AMT measures.

	N	Minimum	Maximum	Mean	Std. Deviation
Total subtasks attempted	83	1	6	<b>4.87</b>	1.64
Total rule breaks	83	0	3	<b>.20</b>	.62
Total number of switches during test	83	0	10	<b>3.96</b>	2.24
Percentage Opt Score	83	2.15	166.68	<b>64.23</b>	45.88
Total number of times reported a slide for PM task	83	1	70	<b>22.40</b>	11.41
Total number of times reported correct slide on PM task	83	0	28	<b>17.39</b>	6.93
Total percentage of slides correctly reported	83	0	100	<b>62.09%</b>	24.74
Total number of subtask items completed	83	33	202	<b>87.05</b>	28.14
Pre test cued rule recall	83	4	9	<b>8.04</b>	1.11
Post test cued rule recall	83	5	9	<b>8.54</b>	.77

As Table 5.1. illustrates there was a wide range of performance, with no hint of ceiling effects. A key measure – the Percentage Opt Score – which reflects participants’ strategic time allocation to the test, ranges from a number extremely close to 0 (an almost perfect strategy) to a much larger deviation score. The PM slide task also showed variable performance, ranging from 0 to 28 slides correctly reported, with a mean of 62.09% correctly reported. Moreover, only 59% of participants attempted all six tasks, another key measure of previously used multitasking tests (see Figure 5.1.). Rule-breaking was less common, however, only 10 participants (12%) broke order rules (see Figure 5.2.). Finally, the total number of items completed reflects a crude measure of speed, and again performances spanned a broad spectrum from 33-202 items completed.

Figure 5.1. Rule breaks frequency chart (subtask order rule breaks)

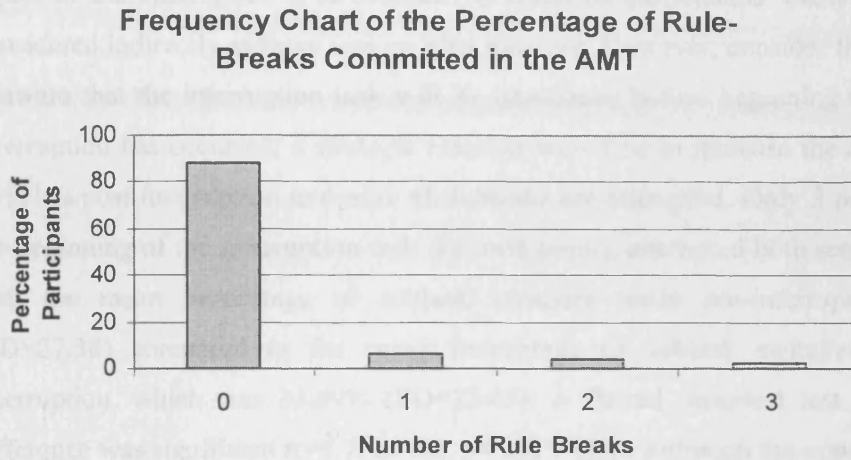
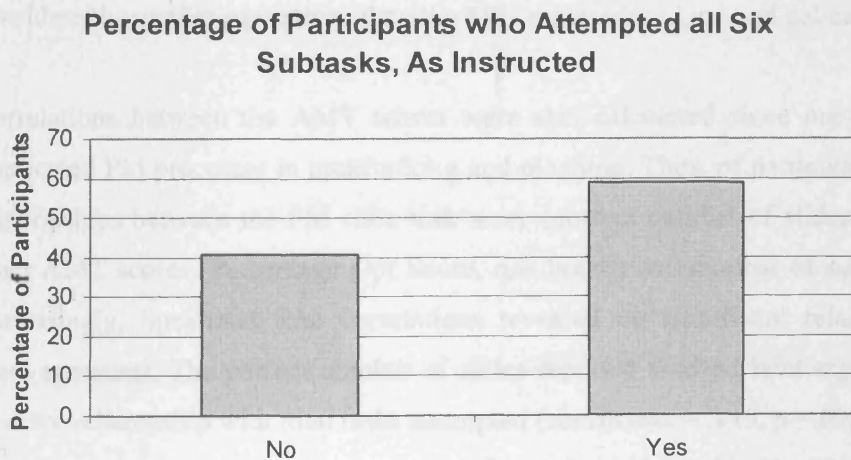


Figure 5.2. Rule following: attempted all 6 subtasks?



#### The Effect of the Interruption

The effect of the interruption on AMT performance can be assessed indirectly. Firstly, the mean percentage of participants who continued reporting the PM slides during the interruption task was of particular interest. Only 50.6% of participants performed the PM slide task during the interruption task, an interesting finding given the emphasis on the instruction that the PM task was to be performed throughout the 15 minutes. The number of

participants who reported any PM slides correctly during the interruption task was even lower (38 participants reported at least one slide correctly = 45.78%). Another interesting aspect of the interruption is to consider its effect on participants' plans. This can only be considered indirectly as there was no plan measure. However, consider that participants are unaware that the interruption task will be introduced before beginning the task. Once the interruption has occurred, a strategic reaction would be to increase the number of subtask switches post interruption to ensure all subtasks are attempted. Only 8 participants had, by the beginning of the interruption task (i.e. mid point), attempted both sets of all 3 subtasks. Yet, the mean percentage of subtask switches made pre-interruption was 60.18% (SD=27.38) compared to the mean percentage of subtask switches made after the interruption, which was 32.69% (SD=22.43). A Paired sample t test revealed that this difference was significant ( $t=5.7$ ,  $df=82$ ,  $p<.001$ ). Thus, although the opposite pattern might be expected, that more subtask switches would occur post-interruption to compensate for lost time, participants actually switched more often pre-interruption. Another measure of post-interruption behaviour, following Law et al., (2004), indicated that 48% of participants continued on the same subtask immediately following the interruption. This is a considerably smaller percentage than the 88% reported by Law and colleagues.

Correlations between the AMT scores were also calculated since previous research has implicated PM processes in multitasking and planning. Thus, of particular interest were the relationships between the PM slide task score (correct number of slides reported) and the other AMT scores (Percentage Opt Score, rule breaks and number of subtasks attempted). Surprisingly, Spearman Rho correlations revealed no significant relationships between these measures. The correct number of slides reported showed faint signs of a significant positive relationship with total tasks attempted (coefficient = .145,  $p = .09$ ,  $N = 83$ ), the total number of switches during the test (coefficient = .161,  $p = .07$ ,  $N = 83$ ) and a significant negative relationship with the Percentage Opt score (coefficient = -.155,  $p = .08$ ,  $N = 83$ ).

### *5.3.8.2. Relationship of AMT Scores to Other Cognitive Measures*

Hypothesis 2:

The relationship of multitasking scores to RM processes was investigated by calculating Spearman Rho correlations between the AMT measures and the RM measures. Table 5.2.

displays the correlation coefficients between the key AMT measures and scores from the two RM tests. Generally, the immediate word list recall and the delayed word list recall showed the same pattern of correlations with the AMT measures. Modest relationships were found between these tasks and the number of subtasks attempted, the number of subtask switches, the number of correct slides reported on the PM task and the total number of subtask items completed. However, the delayed word list recall also showed a modest correlation with the Percentage Opt Score. To be certain that rule understanding was not a factor in these relationships, the same correlations were calculated but excluding participants who scored less than 7 out of the 9 cued rule recall questions (but including those who scored 7). This led to 8 participants being excluded from the analyses.

*Table 5.2. Spearman Rho correlation coefficients between RM tasks and the AMT scores*

AMT Measure	N	Immediate word list	Delayed word list
		recall	recall
Total subtasks attempted	83	.195 p=.077 <sup>^</sup>	.265 p=.016*
Total rule breaks	83	-.090 p>.05	-.014 p>.05
Total number of switches during test	83	.206 p=.062 <sup>^</sup>	.287 p=.009**
Percentage Opt Score (see above)	83	-.084 p>.05	-.193 p=.081
Total number of times reported correct slide on PM task	83	.187 p>.05	.175 p>.05
Total number of subtask items completed	83	.323 p=.003**	.204 p=.064 <sup>^</sup>
Completed PM slide task during interruption task?	83	.055 p>.05	.129 p>.05

<sup>^</sup> Correlation approaches significance at 0.05 level (two-tailed).

\* Correlation is significant at 0.05 level (two-tailed).

\*\* Correlation is significant at 0.01 level (two-tailed).

Calculating the same correlations but only including participants who scored over 7 on the pre-test cued rule recall (N=75) produced a similar pattern of correlations but with stronger relationships (see Table 5.3. below which shows only the changes in significant correlations).

Table 5.3. Spearman Rho correlation coefficients between RM tasks and the percentage opt score including only participants who scored 7 or more on rule recall measure

AMT Measure	N	Immediate word list recall	Delayed word list recall
Total subtasks attempted	75	.240 p=.038*	.285 p=.013*
Total number of switches during test	75	.241 p=.037*	.302 p=.009**
Percentage Opt Score (see above)	75	-.195 p=.093	-.241 p=.037*
Total number of subtask items completed	75	.233 p=.044*	.114 p=.330

^ Correlation approaches significance at 0.05 level (two-tailed).

\* Correlation is significant at 0.05 level (two-tailed).

\*\* Correlation is significant at 0.01 level (two-tailed).

### Hypothesis 3:

Spearman Rho correlations between Raven's and the AMT measures revealed modest correlations between IQ and the following AMT measures: the total number of correctly reported slides in the PM task and the total number of subtask items completed. Table 5.4. displays the correlation coefficients for these measures. Identical correlations with the same 8 participants excluded from the analyses are also displayed in Table 5.4. These data indicate the same pattern of correlations with the addition of a relationship that approached significance between the Percentage Opt score and Raven's scores (negative) and a weaker relationship between total items completed and Raven's (positive).

Table 5.4. Spearman Rho correlation coefficients between Raven's scores and the AMT scores

AMT Measure	N	Raven's	N – part.s who scored 7+ on pre cued rule recall	Raven's
Total tasks attempted	83	.176 p=.112	75	.182 p=.118
Total rule breaks	83	-.014 p>.05	75	.022 p>.05
Total number of switches during test	83	.209 p=.058 <sup>^</sup>	75	.220 p=.058 <sup>^</sup>
Percentage Opt Score	83	-.122 p>.05	75	-.209 p=.072 <sup>^</sup>
Total number of times reported correct slide on PM task	83	.236 p=.016*	75	.227 p=.025*
Total number of subtask items completed	83	.290 p=.008**	75	.208 p=.073 <sup>^</sup>
Completed PM slide task during interruption task?	83	.000 p>.05	75	-.016 p>.05

<sup>^</sup> Correlation approaches significance at 0.05 level (two-tailed).

\* Correlation is significant at 0.05 level (two-tailed).

\*\* Correlation is significant at 0.01 level (two-tailed).

### 5.3.8.3. Relation to Real Life Outcome Measures

Hypothesis 4:

The final hypothesis concerned the relationship of AMT scores to real life measures. Participants reported their academic qualifications and completed the life satisfaction and time management questionnaires. To ensure comparability only participants reporting standard U.K. qualifications were included in the analyses. Seventy-five out of the 83 participants tested were in this category. However, analyses with these participants revealed no significant correlations between the 7 key AMT measures and the qualification measures (all  $p > .05$ ). Moreover, there was only one correlation close to significant between the AMT scores and the life satisfaction questionnaire total score. This was between the dichotomy score of whether participants continued on the PM slide task during the interruption task and life satisfaction (Spearman's Rho correlation coefficient = .215,  $p = .051$ , two-tailed). There were however, several significant correlations between certain AMT measures and the time management questionnaires as shown in Table 5.5.

Table 5.5. Significant Spearman Rho correlation coefficients between time management questionnaire and the AMT scores

AMT Measure	N	Time Management Questionnaire Score	Total Hobbies Listed
Total subtasks attempted	83	.173 p>.05	.233 p=.034*
Total number of switches during test	83	.236 p=.036*	.264 p=.016*
Percentage Opt Score	83	-.233 p=.034*	-.209 p=.057^

^ Correlation approaches significance at 0.05 level (two-tailed).

\* Correlation is significant at 0.05 level (two-tailed).

Calculating the same correlations but only including participants who scored over 7 on the pre-test cued rule recall (N=75) produced the same pattern of correlations, but the relationships become stronger.

### 5.3.9. Discussion

Ill-structured tasks have been used effectively to measure self-regulatory (or strategy application) impairments within clinical groups (e.g. Shallice & Burgess, 1991; Bechara et al., 1994; Levine et al., 1998; 2000; Knight et al., 2003). The aim of this experiment was to develop a suitable ill-structured test for measuring self-regulatory individual differences in the healthy population. Moreover, to investigate the possibility that multitasking situations may tap a specific set of processes which are related to everyday life proficiency within the healthy population. The first step towards this aim was developing the AMT.

#### 5.3.9.1. Performance on the AMT

The range of scores on the AMT suggests that it is a test sensitive to individual differences in the healthy population. Consider first the strategy score (Percentage Opt) reflecting how efficiently participants performed the subtasks to earn most points. To achieve the most efficient strategy participants several processes are required. Firstly, Burgess et al, (2000) argue that their analogous score from the Greenwich Test reflects planning processes; certainly an efficient strategy here would require planning the allocation of one's time. However, the Percentage Opt score cannot distinguish between successful plan and plan-



following processes, which are posited to be separate (Burgess et al., 2000). Levine et al. (1998) describe their efficiency score as reflecting supervisory attentional processes because participants must inhibit the usual tendency to complete items in the usual fashion (i.e. in spatial order). In the AMT, an efficient strategy similarly requires participants to avoid perseverating on one subtask. A range of deviations from the most efficient strategy is reflected in this sample of participants (2.15-166.68), presumably reflecting individual differences in the above-mentioned processes.

Another notable finding is that 41% of participants did not attempt both sets of the 3 subtasks, quite a large proportion of participants considering the instructions for this were so clear. Manly et al., (2002) found only 1 out of their 24 participants did not attempt every subtask in their modified Six Elements Test. Similarly, Law et al., (2004, experiment 2) report all of their 14 control participants attempting all subtasks (although their participants were given the instruction that they would lose points if they did not attempt all subtasks – this was not the case in the present experiment). Rule understanding is unlikely to be the explanation for the participants' failures since cued rule recall was high (which included a specific question about this rule). Moreover, the rules were available to the participants throughout the AMT. It is possible that participants did not consider this rule important and, as empirical studies from the PM field show, task importance is a crucial factor in remembering to perform an intention (Kleigel et al., 2004). Nevertheless, this is a deficient explanation because participants generated very few rule breaks and there is no reason to assume that the order rule should be considered more important than the rule to attempt all the sets of the subtasks. Certainly, there was nothing in the instructions to suggest this was the case.

Levine et al. (1998) discuss dissociation of knowledge from action in their patients. They describe this as: *'awareness of a strategy but a failure to apply it'* (p. 256). Many of their patients exhibited this dissociation and Duncan et al. (1995) have described other patients demonstrating this type of goal neglect. I will discuss this further below. However, the data here is indicative of a similar dissociation of knowledge from action in the healthy population, possibly because the AMT was loading so heavily on self-regulatory processes. Another possible explanation is that participants, although knowing the rule, simply forgot to carry out their intention to attempt every subtask i.e. it was a PM failure. This measure is

simply reflecting a failure of plan following. Levine et al. used a post test questionnaire to establish the reasons for the patients not carrying out the most effective strategy. Future studies with the AMT should use a similar procedure to glean the correct explanation for the surprisingly poor performance on this measure. Similarly, including experimental control conditions (such as with and without the extra PM task) may contribute to our understanding of why participants showed such goal neglect.

A crude measure of speed (Law et al., 2004) available is the total number of subtask items completed by participants. On this measure too, the range of performance was wide (33-202 items). This may relate to the number of switches an individual makes, given the cost of task-switching. If so, this perhaps undermines the usefulness of this measure since a participant could score highly by not switching subtasks (but be failing another key part of the test). However, analyses showed no significant correlations between the number of switches and the total number of items.

Clearly there are individual differences in the strategies participants utilise to perform this open-ended task. By analysing the relationship of the cognitive measures that correlate with AMT performance it is possible to gain insight into processes that are linked to self-regulation performance.

#### The Effect of the Interruption

The most notable effect of the interruption was to interfere with participants' performances of the slide PM task. Only half of all participants continued on the TB PM slide task whilst completing the interruption task. Instructions at the beginning of the task had told participants to perform the TB PM task throughout the whole experiment, for the entire 15 minutes, thus, participants had no reason to believe they were required to stop this task. Einstein, McDaniel, Willford, Pagan and Dismukes (2003) argued that *'interruptions exacerbate the difficulty of successfully maintaining an intended action over a brief delay'* (p. 160). This may explain why such a high proportion of participants ceased the PM slide task during the interruption. Of course, without a control group (including no interruption task) to compare with, it is difficult to understand the full effect of the interruption. McDaniel, Einstein Graham and Rall (2004) replicated the disruptiveness of the interruption task however, also showing that the length of the interruption did not affect PM

performance. Thus, the participants who took longer to perform the interruption task were not necessarily the same participants who did not continue on the PM slide task.

McDaniel et al (2004) provided two interpretations for this effect. Firstly, that interruption tasks create task switching costs and the processes involved in task switching interfere with PM. Secondly, that performing the interruption task '*mistakenly reduces tension for the PM intention – perhaps represented as a general goal to perform an action in addition to the ongoing activity*' (p. 541). Experiments 1 to 4 in this thesis provide evidence for the latter interpretation as they have demonstrated that task-switching processes do not necessarily disrupt PM processes. The increased activation for the suspended ongoing task (the Zeigarnik effect, Zeigarnik, 1938) is creating interference for the PM task; an effect potentially missed by Law and colleagues (2004), they reported no disruptive impact of the interruption, because they did not include a relatively pure PM measure. This interference may also account for the reduced subtask switches after the interruption task. The expectation was that participants would initiate more subtask switches after the interruption with the purpose of attempting all subtasks. Participants actually switched subtasks less frequently after the interruption, which is consistent with the explanation of a PM failure resulting from the interruption.

It is also possible that the change in ongoing task context during the interruption task generated the poor PM slide task performance. Cook et al., (2005) report that TB PM intentions are less likely to be performed if the context associated with carrying out the intention is not present (see Chapter 2, section 2.5). Participants encoded the PM slide task in the context of the three subtasks. Accordingly, the new list task, as a context not associated with the PM slide task, disturbed retrieval of this intention. Although the retroactive interference and the context explanations are not necessarily mutually exclusive, the challenge for further research is to design experiments that can dissociate between these theoretical possibilities. In the present experiment several dependent variables were not included that may help in this theoretical differentiation, for example, the length of time participants took to complete the interruption task was not measured, neither was accuracy of the interruption task. A more thorough understanding of the factors that mitigate the effects of interruptions seems warranted given the commonality in real life of workplace interruptions (e.g. Zijlstra et al., 1999).

Participants in the present experiment did not show such a tendency to return to the subtask they were previously working on prior to the interruption, compared to the participants in Law and colleagues' study. Law et al., argued that this tendency could be a planning heuristic aiming to minimise the impact of the interruption. Alternatively, the return to the suspended subtask may be a consequence of the 'tension', created by the unfinished task, inducing participants back to complete it. Although, Law and colleagues favoured the latter explanation, the non-replication of these findings would suggest that it might be a deliberate strategy by participants (i.e. some participants choose not to use this heuristic), rather than an automatic process, as implied by this latter suggestion.

#### Prospective Memory Slide Task

The mean number of slides reported correctly was approximately 60%. This is a somewhat disrupted performance compared to PM performances reported in the previous experiments of this thesis. For instance, in experiment 5 in the clock TB PM condition there was very high PM accuracy. Participants were involved in multitasking in experiment 5, in the sense that they switched between 4 ongoing tasks, although these switches were externally-cued. Thus, the demands made on self-initiated processing in the present experiment seem pertinent to the low performance on the PM task. Burgess et al., (2000) argues that PM is crucially involved in these types of multitasking tests, for example, in remembering to switch between subtasks and to follow one's plan. The relatively low performance on the secondary PM task supports this as it implies there is competition for these processes. This is only partially supported by the relationships between the PM score and the other AMT scores however. There are hints of appropriate correlations between the PM slide task and the strategy and multitasking scores, which suggests shared processes, but these correlations were very weak (see also Section 2.7.1). Further empirical work in which there is a comparison group with externally-cued multitasking test (or no other multitasking demands) or with a separate PM task is required. After all, the clock condition of experiment 5 is not an ideal comparison condition because of the other differences between the two methodologies (e.g. the extra rules to follow in the AMT).

#### *5.3.9.2. Relation to Other Cognitive Measures*

### Hypothesis 2: RM and AMT

Burgess et al., (2000) posited that processes involved in retrospective memory (RM) also contribute to multitasking. These processes are crucial for learning the task parameters. Moreover, RM is also theorised to be crucially involved in PM, to recall the content of the intention (Burgess & Shallice, 1997). There were strong correlations between measures of the AMT and the RM measures. For instance, there were positive correlations between the word list recall scores and scores reflecting PM processes, specifically the total number of subtasks attempted. This fits the cognitive model Burgess and colleagues (2000) propose, in which RM processes facilitate the learning of the task rules and enable PM. However, the correct number of PM slides reported did not correlate with these RM measures, perhaps because the RM component is very low in this PM task.

In addition, RM scores correlated weakly with the Percentage Opt score (participants who scored greater than 75) and with the total number of items completed. The first correlation (which is negative) shows that the strategic participants (in terms of completing a similar number of items from each subtask) also recalled more words after a delay. This relationship may connote successful rule learning, and yet no significant correlations between RM and rule breaks existed. Alternatively, the correlation may indicate planning on the participants' behalf, a set of processes weakly connected to RM (Burgess et al., 2000). Once more however, the Percentage Opt score cannot be separated from plan-following, an intentionality measure. All of these possibilities are supported by Burgess and colleagues cognitive analysis; it requires a more fine-grained scoring system (including a planning measure) to delineate between them.

The relationship between the number of subtask items completed and RM is slightly more complex. Burgess et al., (2000) did not consider this rough measure of speed. It was included in the present experiment following Law et al., (2004) who reported differential performance on this measure between their experimental groups. Perhaps this relationship is mediated by rule-learning, with participants' who learnt the rules less efficiently (i.e. poorer RM) taking longer in order to check the rules during the test.

### Hypothesis 3: Raven's Matrices and AMT

It was predicted that Raven's scores would correlate with the strategy scores of the AMT because participants who scored highly on the strategy scores had successfully planned and plan-followed. Burgess and colleagues (2000) found that planning processes were linked to the DLPFC and neuroimaging studies support this (e.g. Unterrainer et al., 2004). DLPFC is an area also associated with general fluid intelligence (Duncan et al., 1995; Prabhakaran et al., 1997; Gray et al., 2003). These data only partly supported this hypothesis. Raven's scores did correlate with the total number of switches. This measure may convey a level of planning but also denotes intentionality processes, as described above (see Burgess et al., 2000). The two strategy scores showed a slight inconsistency. Raven's scores did not negatively correlate with rule breaks, a score that partially depicts the planning involved in organising a permissible subtask order. However, participants' Raven's scores were weakly (approached significance) related to Percentage Opt scores (after excluding the participants who scored less than seven on the rule recall test). The Percentage Opt score is the measure most representative of strategy.

The Raven's score also positively correlated with the number of correct slides reported in the PM task. Whereas the other measures may be indicating shared variance with planning processes – clearly, this measure is a straightforward PM score. Several studies have reported significant correlations between nonverbal reasoning and PM (Cockburn & Smith, 1991; Maylor, 1996; Groot et al., 2002; Salthouse et al., 2004). Indeed, Salthouse et al., (2004) reported that correlations between PM, fluid intelligence and speed of processing were as high as between PM and executive measures (primarily fluency tests). However, researchers have not discussed this relationship in detail. Christoff & Gabrieli also discuss evidence for a role of rostral PFC in nonverbal reasoning tasks, and they attribute this to the need for internally-generated information. The work of Kleigel and colleagues (see Chapter 2, section 2.7.1.) has suggested that PM is partly comprised by planning processes (the extent of which depends on the exact task) and thus it may be this planning link that once more accounts for the relationship. Alternatively, the relationship may stem from the shared variance relating to working memory processes. DLPFC is associated with both working memory and Raven's (Prabhakaran, 1997; Duncan et al., 2000) and working memory has a role in PM tasks (Cherry & LeCompte, 1999). Clearly, the present study cannot provide further evidence regarding the correct interpretation of these results and future studies with

the AMT must tackle this issue by including a purer measure of planning (see Burgess et al., 2000 for an example).

#### Hypothesis 4: Relation to Real-Life Outcome Measures

Participants' scores on the AMT did not correlate with the measures of academic qualifications, which were based on a national points system for UK qualifications. There was a significant correlation between one AMT measure and life satisfaction and significant correlations between the scores on the time management questionnaire and measures of the AMT, and similarly with hobbies listed. Although this was exploratory element of study, it was predicted there would be some relation to real life outcomes because of clinical and lesion evidence. The ecological validity of these types of tests lead to the expectation that the processes used in multitasking reflect those recruited for everyday life tasks (Burgess , 2000).

For instance, achieving success in examinations is likely to make demands on multitasking processes including planning, RM and PM. It was therefore hypothesised that performance on a multitasking test may correlate with success on these examinations (as defined by qualification points). However, the hypothesis was not supported here. This can be explained by numerous extraneous variables that contribute to examination performance (e.g. motivation) that this study was unable to control. In addition, the sample used in this study was narrow. Participants had similar academic qualifications because all of the undergraduates were recruited from the same University, which demands certain qualification levels for entrance. With limited variance in the sample significant correlations are less probable.

Indeed, within the life satisfaction and time management measures there was more variance in participants' scores and significant correlations were revealed. Predictions were based on previous multitasking studies and stated that there would be positive correlations between these measures and AMT measures (e.g. Levine et al, 1998). Interestingly, the measure of whether participants completed the PM slide task during the interruption task correlated with life satisfaction. This could be considered a key measure of self-regulatory behaviours since it requires many self-initiated responses and the maintenance of many subgoals (e.g. cope with interruption task, remember to initiate PM intentions, decide on satisfactory

response to interruption task). This is rather tentative evidence that tasks which load heavily on self-initiated processes may be useful in relation to predicting real life satisfaction. Since everyday life is littered with open-ended tasks and decisions, life satisfaction may be indicative of success in completing these 'life tasks'. There are, of course, many variables not considered here that contribute to life satisfaction (e.g. Diener et al., 2003), consequently the finding of a significant relationship is very promising and is certainly a path for future research.

The time management questionnaire is a good reflection of everyday life planning and organisation and the self-regulatory processes involved in these appear to be partially captured by the AMT, as demonstrated by the significant correlations. The AMT and other multitasking measures may therefore provide an objective assessment of participants' time management and planning abilities. Undoubtedly there would be useful applications for this, including within an organisational setting such as predicting job success in workplaces that require a great deal of time management (or indeed in Ph.D.s!) These data suggests further investigation into the relationship of AMT scores and real life outcomes in more depth is warranted, specifically life satisfaction and time management, perhaps utilising more sophisticated methodological techniques such as factor analysis. Of course, because of the correlational nature of this study it is only possible to extrapolate from the clinical data that these processes are responsible for successful everyday life tasks, rather than another group of processes mediating both. For example, Duncan et al., (1995; 2000; 2001; 2005) would argue that processes that comprise 'g' are actually all that are being measured. This argument is set out below.

### *5.3.9.3. Alternative Explanations of Self-Regulation Processes*

Part of the rationale of this experiment is based on the argument that there is fractionation of PFC function, and thus dissociations between cognitive processes (multiple process theories, see Burgess and Simons, 2005). Areas of the rostral PFC appear to be involved in successful performance of multitasking tests (Levine et al., 1998), and are presumed to be the neural basis of self-regulatory processes. Conversely, the DLPFC is recruited in the Raven's task and other relational reasoning tasks (Prabhakaran et al., 1997). For this reason



and from the clinical studies, it was expected that there would be relative independence between these measures, with tests of IQ missing an important group of processes. However, in contrast to predictions there was evidence of correlations between Raven's (representing IQ) and the AMT. The first explanation for this was described above – which suggested there is a role for DLPFC processes or more properly, planning processes, in multitasking tests. Another possibility is that the fractionation theory of PFC and executive function is erroneous.

An alternative account of PFC function is posited by Duncan (e.g. Duncan, 2001) and discussed in Chapter 1 briefly. Duncan suggests that the PFC acts in a more unified manner to control different types of goal directed behaviour in any task. The ability of the PFC to do this is reflected in an individual's 'g' (or general intelligence) score. For example, Duncan et al., (1995) showed that frontal patients who exhibited everyday planning and organisational skills and showed impaired behaviour on multitasking tests also showed impoverished performance on a fluid intelligence test, or a high 'g' test. Moreover, Duncan et al., (1996) reported that 'goal neglect' in the healthy population is related to low 'g'. In their conception, 'g' reflects the action control functions of an individual's PFC. As described above, there is some evidence for participants exhibiting goal neglect in this study, presumably because the test was loading on these 'g' processes very heavily. Certainly, the AMT is high on the three factors that Duncan et al., (1996) argue load heavily on 'g' processes: novelty, weak feedback (i.e. low environmental support) and multiple concurrent requirements. Moreover, there were positive correlations between the Raven's (a high 'g' task) and AMT scores. To investigate the possibility that the AMT is simply measuring 'g', I analysed only participants who scored 8 or more on the Raven's (high 'g' score) and 27 out of 40 of them attempted all 6 subtasks (67.5%). In addition, 15 out of the 32 (46.9%) participants who scored 6 or less on the Raven's (low 'g' score) attempted all 6 subtasks. Clearly, participants 'g' score cannot be the whole explanation.

#### **5.4. Summary & Limitations**

Data from the AMT has indicated that even within the healthy brain population there can be degree of perseveration (for example, not completing all the subtasks and inappropriate

allocation of time), which may lie on a continuum with patients' performances. This is an interesting result and adds to the multitasking data from the clinical studies, as well as contributes to our understanding of self-regulatory processes in the healthy population. However, there are several limitations to the present experiment. Firstly, the study is correlational, so conclusions about causality must be drawn with caution. The exclusion of an experimental control group was purposeful in order to generate a large enough sample size for the correlations, but future studies with the AMT will require experimental manipulations to characterize the processes involved more fully. Moreover, the different approach by participants to the same test is both a strength of the test (as described above), but also a weakness. This is because it is difficult to describe the cognitive processes contributing to this test's performance when each participant can be doing something quite different, for instance, the degree each participant plans or switches subtasks. This argument is considered further in the next experiment.

## 5.5. Experiment 8

### 5.5.1. Introduction

A key measure from the AMT was the number of subtasks participants attempted and, related to this, the number of self-initiated task switches. Participants showed a range of scores on these measures (range of 0-10). Indeed, the crucial element of these types of tests is that they are ill-structured and are tackled idiosyncratically. Differences in the degree of planning, in the number of task-switches and the order and duration of subtasks performed are expected. For instance, some participants may switch tasks too often or persevere on the same tasks and not initiate switching to new tasks (e.g. Worthington, 1999, Manly et al., 2002; Alderman et al., 2003; Kleigal et al., 2004). That participants have almost total control of the manner in which they perform the task in this way distinguishes it from paradigms such as task-switching & dual-tasking (Burgess et al., 2000). As previously discussed, this gives the tests high ecological validity (Wilson et al., 1998; Burgess et al., in press). However, it makes it difficult to breakdown the cognitive components involved since demands on cognitive control processes can differ so. For example, there are differences within the same test (e.g. participants making more or fewer subtask switches) and there are differences between the ill-structured tests too, even between multitasking tests. For example, Burgess et al., (2000) describes the Greenwich Test as having fewer task-switches but with more rules to follow, compared to the Six Elements. This differentially affects the load on executive processes such as those involved in voluntary task-switching and PM processes. Moreover, the research by Levine et al., (1998; 2000) has emphasised the processes involved in strategy application over PM and task-switching processes. For example, Levine et al. (1998, 2000) relate deficits in strategy in their clinical groups to failures of inhibiting established responses, error correction and flexibility. Attempting to bring these different approaches together could be a fruitful area for research. Specifically, trying to understand how the differences between the demands of the multitasking tests affects other aspects of performance may help elucidate the cognitive mechanisms involved. As Law et al., (2004) acknowledge few experiments have manipulated variables within these tests to investigate '*what factors might constrain or impair successful multitasking performance*' (p. 285). The present study begins this process

by considering how the frequency of self-initiated subtask switching affects performance on other multitasking measures, such as strategy.

Relating these ideas to the healthy population and real life behaviours, researchers in the human-computer interaction field have investigated workers' behaviours in order to determine the most effective interfaces. Czerwinski et al., (2004) completed a diary study of managers' behaviours in the workplace. They reported participants switching tasks frequently, with 40% of these task switches being self-initiated. The authors concluded that *'the key findings gleaned from our diary study, as well as explicit comments from participants, shaped our pursuit of designs for interface tools that might better assist users with task switching'* (p. 180). Gonzalez et al., (2004) also performed a field study with information workers: analysts, software developers and managers. They found that the employees spent an average of three minutes on an event (task) before another event was initiated, with participants interrupting themselves as often as they were interrupted. These data show the frequency of self-initiated task switching in the everyday workplace. Thus, understanding the effect of this variable on multitasking performance in the healthy population is crucial for real life application.

#### *5.5.1.2. Self-Initiated Task-switching*

As described, the number of subtask switches produced during these multitasking tests is a possible source of variance in performance between the participants and a possible source of impairment in patients. To what extent does the number of self-initiated task-switches affect performance on the other elements of multitasking? In real life, it is asking the question: does the number of switches between tasks we make (e.g. emailing, writing, phone calls etc) affect our overall performance? Is it better to move frequently between tasks, or does infrequent subtask switching lead to better performance?

Evaluating theoretical positions on the effect of frequent subtask switches on multitasking performance is rather complex. The requirement to switch between these subtasks in multitasking tests draws on executive control processes for both the PM element of the task (to remember the intention, interrupt the ongoing task and carry it out) and for the switch between the subtasks (the reconfiguration of task set/inhibition of the old task set, see

Chapter 3). Drawing from the task-switching literature, the expectation would be that frequent subtask-switchers would absorb more cognitive resources for this process (Rogers & Monsell, 1995) and show impoverished performance on other elements of the test compared to infrequent task-switchers. Recall that the voluntary task-switching literature would also predict this outcome since self-initiated task switches produce similar switch costs to the ongoing task (Arrington et al., 2004, see Chapter 3, section 3.5). However, there are differences between the voluntary task-switches in that paradigm and the self-initiated task-switches generated in multitasking tests. As Burgess et al. (2000) describes the typical task-switching experiments '*do not involve the deferral of task execution over lengthy periods of time (switches typically occur with an interval of a few seconds or less)*' (p. 850), unlike the multitasking tests.

An alternative perspective is that the participants who switch between subtasks more frequently may reduce the need for conscious, executive control for remembering the intention to switch between tasks (i.e. the PM element). As the PM responses become more habitual with increased frequency (Einstein et al., 1998) this presumably increases the reliance on automatic processes. Similarly, decreased RIs can produce better PM performance (Brandimonte & Passolunghi, 1994). Reducing the demands on controlled processing may free up resources for the other elements of the test, thus improving performance on other aspects of the test.

In order to test these hypotheses a multitasking test similar to the AMT was employed, but with some modifications, such that the number of self-initiated subtask switches that participants were required to make could be manipulated. Participants were instructed to switch between subtasks every 30 seconds or every 2 min 30 seconds. As they switched subtasks they were asked to write down the letter and number from a slide show at the correct interval. Thus, this instruction manipulated the number of self-initiated subtask switches, but also the RI between PM responses. For this reason, a discussion of the effect of length of RIs on PM performance is relevant and is presented below.

These instructions also remove the need for the individual to plan when to switch between tasks, constraining one element of the multitasking test. Instead, a straightforward time-based PM task was inserted into the multitasking framework. This allows the PM element

of multitasking to be investigated separately from the planning component. This is useful for other reasons too. By constraining the planning demands in the multitasking test it is then possible to inspect correlations with the Raven's scores. Experiment 7 showed that measures of the AMT correlated with Raven's, but it was uncertain whether this reflected the overlap of planning processes or 'g' processes. The correlations between the measures from this multitasking test and Raven's may shed light on this matter.

#### *5.5.1.2. Retention Interval in PM Tasks*

The design of the experiment produced a manipulation of RI within the time-based PM task to switch subtasks (30 seconds vs 2 mins 30 seconds). Hicks, Marsh & Russell (2000) reviewed the literature that manipulated RIs in PM tasks. They predicted that PM should follow the RM forgetting curve, so longer RIs lead to lower PM performance. Support for this was obtained from Brandimonte and Passolunghi (1994) who found decreased PM performance when the RI was increased to 3 minutes (compared to recalling the intentions immediately), a result consistent with RM decay. Subsequent studies that manipulate RIs have produced results that are more mixed. For example, Hicks, Marsh and Russell (2000) found that longer RIs produced better PM performance. However, they also found that an increased number of task switches during the RI improved PM performance. They attributed this to an increase in opportunities for participants to self-remind about the intentions. Nigro and Cicogna (2000) found no effect of length of RI on PM performance. Although the authors reported much longer RIs (i.e. 20 mins, 2 days and 2 weeks), which are lengthier delays and more likely to be affected by extraneous variables. Nevertheless, other reports of RI manipulations have found no increase in PM errors with lengthier delays (Einstein et al., 1992; Guynn et al., 1998; Stones et al., 2001). A potential explanation for the mixed data is the large differences in RIs from 30 seconds to several days (Hicks et al., 2000). According to Hicks and colleagues there is evidence that the critical period of forgetting of intentions follows the RM pattern (see also Einstein et al., 2000). For example, a study by Loftus (1971) study captured this critical window; the study employed RIs of 30-60 seconds and no longer than 3 minutes, but participants showed a significant decline in performance with the longer RI. The present study therefore utilised RIs of 30 seconds and 2 min 30 seconds with this in mind. Hence, it was expected that the longer RI would require greater self-initiated recall than the 30 seconds condition, and so place

greater demands on executive control. As described above, accuracy of subtask switching (i.e. PM performance) was measured by participants reporting the stimuli displayed on the slide show as they switched task (i.e. every 30 seconds or 2 minute 30 seconds). The percentage of correct slides reported acted as a measure of PM accuracy.

### *5.5.1.3. Hypotheses*

The background presented thus far cannot differentiate between two possible hypotheses for the manipulation of subtask switching on frequency. These are presented below:

1a) Improved performance on multitasking in the infrequent task-switch group because of reduced demands on task-switching executive processes.

1b) Improved performance on multitasking in the frequent task-switch group because of reduced executive demands required for remembering the intention to switch.

Several measures of multitasking performance were compared in the two subtask switch frequency groups, but a key measure of multitasking performance is the strategy measure which is discussed in the methods section below. This measure is entirely independent from the number of subtask switches generated and acts as a good indicator of strategy and planning.

### Correlations with other Cognitive Measures

#### Hypothesis 2 and Hypothesis 3:

To understand the relationship of multitasking processes with other cognitive processes the same measures were administered as in experiment 7. The hypothesis regarding the relationship of RM to PM was the same and a replication of findings from the previous experiment was expected. However, by instructing participants when they should switch tasks the planning demands are constrained, since participants no longer have to plan when they should switch between the subtasks. For this reason, lower correlations between the multitasking measures and Raven's were expected than were found in experiment 7. This is

based on the theoretical position that Raven's taps different processes to that of multitasking, but is linked to planning processes (Burgess et al., 2000).

#### Correlations with other Real Life Measures

##### Hypothesis 4:

Finally, the same real life outcome measures were utilised as in experiment 7 in order to explore the relationship of multitasking and these outcomes. These were included in an attempt to replicate the results of experiment 7. In experiment 7, non-significant relationships were found between variables that were theoretically predicted to correlate, thus this experiment also tested these relationships again, ensuring against making a Type 2 error. Thus, the hypotheses for these measures were the same as in experiment 7.

### **5.5.2. Method**

#### Participants & Design

The present group study was conducted with a sample of 94 undergraduate (mean age = 19.12, SD = 1.11) psychology students at University College London. All participants were fluent English speakers. The participants were split randomly into two independent groups: frequent task switchers (N=47) and infrequent task switchers (N=47). In the frequent task-switch group there were 39 females and 8 males, and in the infrequent group 40 females and 7 males. The two groups were tested separately but simultaneously.

#### Materials

##### Advanced Multitasking Test 2 – Materials & Procedure

The general materials and procedure was identical to that described in experiment 7. However, there were some important design modifications to the multitasking test (and thus I shall refer to it as the AMT2). These are laid out below.

#### Modifications to the AMT

1) Participants were given 4 subtasks with two sets of A and B in this version of the AMT (in order for there to be more subtasks to switch between for the manipulation). Three of



the subtasks were identical to those described in experiment 7 above. The extra subtask was as follows:

#### Anagram Solving

Task 4) Anagram Solving - Each A and B set comprised 100 simple word items with certain letters missing e.g. bra\_n. Participants were asked to fill the gaps with a letter that created a real word.

2) Participants were not presented with an interruption task in this test. The subtask switch frequency was the important manipulation here, and its effect on multitasking performance. Adding another task switch (albeit externally-cued) in the form of an interruption task would lead to an overly complex design.

3) The extra instructions for this task were added to the other rules of the AMT (see section 5.4. above). Participants were told when to switch between the subtasks (either at 30 seconds or 2 minutes 30 seconds). The experimenter explained to the participants that a changing display of letters and numbers would be displayed on the large screen at the front of the room (note the same slideshow was used as in experiment 7 except an extra 5 minutes worth of slides were presented, see below). Participants were instructed to write the letter and number down from the slideshow just *before* they switched subtask (i.e. at the 30 seconds or 2 minutes 30 second point).

4) The AMT2 was 20 minutes in length so participants in the 2 minutes 30 seconds group were able to attempt both sets of all 4 subtasks (presuming they spend one 2 minute 30 seconds interval on each set).

5) Finally, participants were told that items with asterisks next to them were worth more points (20 items in every 100 were marked with an asterisk, chosen pseudorandomly with the constraint that they were not consecutive items). This replaced the instruction that earlier items were worth more points. This was necessary because participants could not switch between the subtasks as they wished. This gave a very clear strategy measure and is comparable to measures from other multitasking tests (e.g. Levine et al., 1998), percentage of asterisks items completed out of total items completed).

6) The new cued rule recall test questions for the AMT2 appear in Appendix B. The administration of the free and cued rule recall tasks were identical to experiment 7.

#### General Procedure

Participants completed a series of tests, including the AMT2 in one session. The two groups were tested separately. The tests were completed in the following sequence: immediate word list recall, Raven's matrices, AMT2, delayed word list recall and questionnaires.

#### Measures Derived from the AMT 2

##### RM Component

- Pre test cued rule recall.
- Post test cued rule recall.

##### PM Component

- Total number of slides reported.
- Total number of correct slides reported
- Total percentage of correct slides.
- Total number of correct subtask switches.

##### Other Measures

- Total number of subtasks attempted
- Total number of rule breaks.
- Total items completed.
- Total strategic asterisks completed (out of order).
- Percentage strategic asterisks completed (out of order).

#### Other Cognitive and Real Life Measures

The materials and procedure for the cognitive and real life measures included in this experiment were the identical as those in experiment 7. See section 5.4. above for full details but the measures derived from these tests are listed below.

### Cognitive Measures

- Total immediate word list recall.
- Total delayed word list recall.
- Total Raven's Matrices score.

### Real Life Measures

- Total qualification points.
- Total GSCE points.
- Total A Level/AS Level points.
- Life satisfaction score – summed responses from Diener et al., questionnaire.
- Total score on time management questions.
- Total number of hobbies.

### 5.5.3. Results

Due to six participants filling out the multitasking answer sheet in an inappropriate manner they were excluded from the analyses below. Other participants requested to leave the testing room briefly during the group testing session and thus have missing data from certain tests; this is reported where it arises.

Firstly, analyses were carried out to ensure there were no differences in rule recall between the two independent groups. The mean rule recall scores are displayed in Table 5.6. and show high rule recall scores in both group. Indeed, no statistically significant differences emerged between the two groups in the number of correct rules recalled, either before ( $t=.644$ ,  $df=86$ ,  $p=.521$ ) or after the test ( $t=.803$ ,  $df=86$ ,  $p=.424$ ). It is therefore not plausible that any differences in performance between these groups are due to differences in rule comprehension.

Table 5.6. Descriptive statistics of cued-rule recall scores

	N	Mean	Standard Deviation	Min	Max
<b>Frequent Task-switchers</b>					
Correct cued rule recall pre test (max = 10)	43	<b>9.40</b>	.85	7	10
Correct cued rule recall post test (max =10)	43	<b>9.56</b>	.85	7	10
<b>Infrequent Task-switchers</b>					
Correct cued rule recall pre test (max = 10)	44	<b>9.28</b>	.97	6	10
Correct cued rule recall post test (max =10)	44	<b>9.44</b>	.75	7	10

### 5.5.3.1 The Effect of Frequency of Self-Initiated Task-switches on Multitasking Performance

#### Hypothesis 1

The first goal of the present experiment was to test the effects of subtask switch frequency on multitasking performance. Therefore, analyses comparing the two groups on each measure derived from the AMT2 are reported. The Mann Whitney U test, a non-parametric equivalent of a t-test, were used to compare the two groups scores, unless indicated otherwise. The descriptive statistics for these scores for both groups are displayed in Table 5.7. and Table 5.8.

The first measure considered is the strategy measure, which in this test is operationalised as the percentage of asterisks completed out of sequential order (i.e. deliberately chosen). A Mann Whitney U test found no significant difference between the groups in the percentage of strategic items completed,  $U=892$ ,  $p=.646$ , ( $N=44$  in frequent task switch group,  $N=43$  in infrequent task switch group). Generally, the number of rule breaks (of order) was low amongst all participants in both groups. Two participants committed 2 rule breaks and 5 participants committed 1 rule break in the frequent task switch condition and no participants in the infrequent task switch condition committed a rule break. This still resulted in a significant difference between the two groups, the frequent task switch group made significantly more rule breaks,  $U=814$ ,  $p=.006$ . This is perhaps unsurprising given the increased opportunity to commit a rule break in the frequent task switch condition. The total number of subtask items completed also showed a significant difference between the

groups, with more items performed in the infrequent task-switching condition,  $t=5.58$ ,  $df=86$ ,  $p<.001$ . The intentionality aspects of the test were also considered. The frequent task switching group attempted significantly more subtasks compared to the infrequent task switching group,  $U=857$ ,  $p=.048$ . Six participants did not attempt all subtasks in the infrequent task switch group (13.64%) compared to 1 participant in the frequent task switch group (2.27%). Finally, the infrequent task-switch group reported a higher percentage of correct slides, although this difference only approached significant,  $U=749$ ,  $p=.059$  ( $N=43$  in frequent task switch group,  $N=44$  in infrequent task switch group).

*Table 5.7. Frequent task-switchers – descriptive statistics of AMT2 scores*

	N	Mean	Standard Deviation	Min	Max
Total number of subtasks attempted	44	<b>7.98</b>	.15	7	8
Total rule breaks	44	<b>.20</b>	.51	0	2
Total number of switches during test	44	<b>28.86</b>	8.40	12	41
Total number of times reported slide on switching subtask	44	<b>29.14</b>	8.15	14	40
Total number of times reported correct slide on switching subtask	44	<b>11.34</b>	9.21	1	32
Total percentage of correct slides reported on switching task	44	<b>29.58%</b>	23.66	2.56	82.05
Total number of subtask items completed	44	<b>143.50</b>	35.59	78.00	231
Total number of strategic asterisk items completed (out of order asterisks items)	44	<b>72.18</b>	47.86	0	141
Total percentage of strategic asterisks completed (of total items completed)	44	<b>53.59%</b>	35.54	0	100

Table 5.8. *Infrequent task-switchers – descriptive statistics of AMT2 scores*

	N	Mean	Standard Deviation	Min	Max
Total number of subtasks attempted	44	<b>7.80</b>	.59	5	8
Total rule breaks	44	<b>0</b>	0	0	0
Total number of switches during test	44	<b>6.91</b>	.56	4	8
Total number of times reported slide on switching subtask	44	<b>6.68</b>	.96	3	3
Total number of times reported correct slide on switching subtask	44	<b>2.98</b>	2.27	0	7
Total percentage of correct slides reported on switching subtask	44	<b>42.53%</b>	32.38	0	100
Total number of subtask items completed	44	<b>193.91</b>	48.18	96	358
Total number of strategic asterisk items completed (out of order asterisks items)	44	<b>97.36</b>	58.26	0	160
Total percentage of strategic asterisks completed (of total items completed)	44	<b>52.52%</b>	33.09	0	100

### 5.5.3.2. *Relation to Other Cognitive Measures*

#### Hypothesis 2 and 3

The next set of analyses followed the same procedure as experiment 7, correlations between AMT2 scores and the other cognitive measures were calculated. Where there was no significant group difference between AMT2 measures the data was collapsed across both groups and correlations were calculated including all participants to increase power. The correlations reported are two-tailed Spearman's Rho. As Table 5.9. shows significant correlations were found between the RM measures and the percentage of correct slides reported, but not with the strategy score. No significant correlations emerged between Raven's Matrices scores and the percentage of correct slides reported or the strategy score.

Table 5.9. Correlation coefficients between AMT2 measures and cognitive variables – collapsed across 2 groups †

	Immediate word list recall	Delayed word list recall	Raven's
Total percentage of correct slides reported on switching task	.391 P<.000** N=86	.209 p=.055^ N=85	.102 p>.05 N=86
Total percentage of strategic asterisks completed (out of total items completed)	.143 p>.05 N=85	.105 p>.05 N=84	-.016 p>.05 N=85

^ Correlation approaches significance at 0.05 level (two-tailed).

\*\* Correlation is significant at 0.01 level (two-tailed).

† Calculating the same correlations but excluding participants who scored less than seven on the pre-cued rule recall (as in experiment 7) does not change the pattern of results. This is the case with all the correlations reported below.

Where significant differences between the two groups did exist in the AMT2 measures correlations between these AMT2 measures and the cognitive measures were calculated separately for each group. Table 5.10. below displays these correlation coefficients, which showed no significant relationships. Participants in the infrequent task switch condition committed no rule breaks, thus, no correlations were calculated. Similarly, only one participant did not attempt all 8 subtasks in the frequent task switch group, thus no correlations were calculated with this measure in this group.

Table 5.10. Correlation coefficients between AMT2 measures and cognitive variables – separate groups

	Immediate word list recall	Delayed word list recall	Raven's
<b>Frequent Task switch Group</b>			
Total number of subtask items completed	-.038 p>.05 N=43	.090 p>.05 N=42	.007 p>.05 N=42
Total Rule breaks	-.067 p>.05 N=43	-.104 p>.05 N=42	.208 p>.05 N=42
<b>Infrequent Task switch Group</b>			
Total subtasks attempted	.226 p>.05 N=43	.247 p<.05 N=43	.052 p>.05 N=44
Total number of subtask items completed	.126 p>.05 N=43	.168 p>.05 N=43	.052 p>.05 N=44

### 5.5.5.3. Relation to Real-Life Outcome Measures

To understand the relationship between the real life measures and the AMT2, the same approach was taken as above with correlations between these two sets of variables. Where there were no significant differences between the two groups the correlations were calculated with all the participants, otherwise they were calculated for each group. Participants without the relevant U.K. qualifications were excluded from the correlations in order to have a standardised means of measuring academic achievements, leaving 75 participants included in analyses.

#### Qualification scores:

##### Academic Measures

- 1) Total qualification points (A levels, AS levels, GCSEs, half GCSEs or O-levels).
- 2) Total A and AS level points
- 3) Total GCSE and half GCSE points.

The correlation coefficients are shown in Table 5.11. and 5.12. There were significant correlations between several of the academic measures and the AMT2 measures,



specifically the percentage of correct slides reported correlating with total qualification points and almost with A Level scores. All the academic measures correlated positively with the number of items completed in the infrequent task-switching group, suggesting a speed measure is useful from these multitasking tests.

*Table 5.11. Correlation coefficients between academic measures and AMT2 measures – collapsed across 2 groups*

N = 75	Total qualification points	Total A and AS Level points	Total GCSE points
Total percentage of correct slides reported on switching task	.226 p=.051 <sup>^</sup>	.216 p=.063 <sup>^</sup>	.119 p>.05
Total percentage of strategic asterisks completed (out of total items completed)	.069 p>.05	.045 p>.05	.189 p>.05

<sup>^</sup>Correlation approaches significance at 0.05 level (two-tailed).

*Table 5.12. Correlation coefficients between academic measures and the AMT2 measures – separate groups*

	Total qualification points	Total A and AS Level points	Total GCSE points
<b>Frequent Task switch Group (N=35)</b>			
Total number of subtask items completed	-.075 p>.05	-.102 p>.05	.089 p>.05
Total Rule breaks	.159 p>.05	.118 p>.05	.182 p>.05
<b>Infrequent Task switch Group (N=40)</b>			
Total subtasks attempted	.329 p=.038*	.338 .033*	.098 p>.05
Total number of subtask items completed	.466 .002**	.436 .005**	.398 p=.011*

\* Correlation is significant at 0.05 level (two-tailed).

\*\* Correlation is significant at 0.01 level (two-tailed).

#### Life Satisfaction scores

There were no significant correlations between the collapsed scores (percentage of correct slides reported, percentage of strategic asterisks completed) and the life satisfaction measures. Similarly, there were no significant correlations between two of the AMT2 measures (total items completed and total rule breaks) and the life satisfaction measures in

either of the separate groups. However, in the Infrequent task switch group the number of subtasks attempted correlated positively with life satisfaction (correlation coefficient = .315,  $p=.04^*$ ,  $N=43$ ).

#### Time Management and Hobbies and Interests Questionnaire

Table 5.13. displays the correlation coefficients between the AMT2 measures and the time management questionnaire. There were no significant correlations between the strategy score and the correct percentage of slides reported (i.e. the collapsed scores) and the time management questionnaire. Similarly, no AMT2 score correlated with the hobbies and interests measure. Significant correlations emerged between the total number of subtasks completed and time management abilities in the infrequent task switch group. A negative correlation between number of subtask items completed and time management was found in the frequent task switch group.

*Table 5.13. Correlation coefficients between real life measures and AMT2 measures – collapsed across 2 groups*

	Time Management	Hobbies and Interests Listed
<b>Frequent Task switch Group</b>		
Total number of subtask items completed	-.332 $p=.028^*$ $N=44$	.025 $p>.05$ $N=42$
Total Rule breaks	.099 $p>.05$ $N=44$	-.046 $p>.05$ $N=42$
<b>Infrequent Task switch Group</b>		
Total subtasks attempted	.273 $p=.073^{\wedge}$ $N=44$	.045 $p>.05$ $N=43$
Total number of subtask items completed	-.044 $p>.05$ $N=44$	.017 $p>.05$ $N=43$

$\wedge$  Correlation approaches significance at 0.05 level (two-tailed).

\* Correlation is significant at 0.05 level (two-tailed).

## 5.5.4. Discussion

### 5.5.4.1. *Effect of Self-Initiated Task-Switch Frequency - Hypothesis 1*

Two hypotheses were offered for the manipulation of subtask switch frequency. These were as follows:

- 1a) Improved performance on multitasking in the infrequent task-switch group because of reduced demands on task-switching executive processes.
- 1b) Improved performance on multitasking in the frequent task-switch group because of reduced executive demands in the PM task.

This experiment was designed to assess the effect of frequency of subtask switch on other elements of multitasking performance. Multitasking is considered componential (e.g. Burgess et al., 2000; Kleigel et al., 2000) and although different groups of researchers have assessed the cognitive mechanisms for each component (e.g. Levine et al., 1998; Burgess et al., 2000), the effect of one component on the others has been largely neglected. Indeed, because of inconsistency between multitasking studies in the measures reported, it is difficult to assess this effect. The entire range of measures from the AMT2 was included to understand the impact of subtask switching frequency on each component of multitasking. Each measure will therefore be considered in turn.

A key comparison measure between these two groups was the number of strategic items completed by participants (Law et al., 2004). For instance, previously SAD patients have demonstrated impoverished performance on this measure (Levine et al., 1998). This score was devised by calculating the percentage of items with strategic asterisks completed, as a percentage of total items completed. There were no significant differences between the frequent and infrequent task switch groups (53.38% in frequent group vs 52.52% in infrequent group). This suggests that the number of subtask switches generated may not affect strategic multitasking performance; there is some independence in processing. Consequently, it is plausible that individuals with SAD are not necessarily impaired because of the executive demands created by frequent subtask switches (i.e. task switching processes) or because of high executive demands from the PM element of the task (the infrequent task switch group). From correlational data with executive function tests, Levine

et al., (1998) argue strategic responding requires three types of executive processes: error correction or monitoring, inhibition of an established response method and flexibility. These processes are not specifically associated with voluntary task-switching (e.g. Arrington & Logan, 2004, 2005) and indeed lends weight to the argument made by Arrington & Logan (2005) that inhibition is not required for self-initiated task-switching (and the switch costs are attributable to active reconfiguration processes, see Chapter 3, section 3.2.).

Overall, a relatively low percentage of strategic items were completed in both groups. Again, this suggests that this multitasking test is of the correct sensitivity for use with the healthy population. Results are certainly comparable with Law et al., (2004), who used a similar but not equivalent multitasking test (with an interruption). Their population of undergraduates completed 49.6% (SD=15.3%) of higher scoring items. As discussed in experiment 7, this could also be characterised as evidence for 'goal neglect' (Duncan et al., 1996) or a knowing-doing dissociation (Levine et al., 1998). This proposal is strengthened if just the participants who scored 10/10 in pre and post cued rule recall tests are considered (there was a specific question regarding the value of items). The mean percentage of asterisks completed in this subgroup was still only 59.4% (SD=31.98, N=43), certainly suggesting a 'knowing-doing dissociation' within the healthy population. Duncan et al., (1996) have described this before, and attributed the phenomenon to low 'g', or inefficient executive control functioning in the prefrontal cortex (Duncan et al., 1995, 1996). It is thus worth considering only the participants who scored 8 or above on the Raven's task (i.e. high 'g' scorers), as per the procedure of experiment 7. The mean percentage of asterisks completed within this group was still only 52.98%, SD = 33.96, N=73 (and indeed with a more rigorous cut off point of 10 or above on Raven's the percentage reduces further to only 49.97%, SD=34.33, N=36). Again, this is incompatible with Duncan and colleague's theory, since they would predict goal neglect occurring only within low 'g' participants. This is certainly an interesting field of enquiry for future studies, and perhaps a good starting place would be to give post-interview questionnaires to participants after completion of the test, as Levine et al., (1998; 2000) did to ensure participants knew about the possible strategy. Including a measure of planning could also filter out the suggestion that participants were not aware of the most efficient strategy because participants may include it as part of their plan.

Other aspects of multitasking performance were affected by frequency of self-initiated task switching, specifically, the number of items completed, the number of rule breaks and PM performance. On these measures, the infrequent task switch group fared better. Participants in this group performed more items overall, with fewer rule breaks (which were essentially order rule breaks) and reported more slides correctly (though this was not statistically different between the groups). Thus, more generally hypothesis 1a is supported; there is improved multitasking performance in the infrequent task-switch group because of reduced demands on task-switching executive processes. This was especially true for the number of items completed by each group, in which the cost of frequent task switches certainly seems to outweigh the benefit of reducing the PM load. This is perhaps unsurprising; the infrequent task switch group switched subtasks on average 29 times, compared to infrequent task switch group of approximately 7. The data is certainly consistent with the voluntary task-switching literature. However, the practicalities involved in the actual subtask switching (i.e. shuffling of papers) are also quite likely to lead to the completion of fewer task items. Thus, this study requires replication with a computerised version such that the actual task of switching is very easy and non time-consuming (see below).

Generally, an increased number of self-initiated task switches did interfere somewhat with PM performance, with the infrequent task group showing increased accuracy for switching at the correct time. Clearly, the frequent group generated more task switches and thus there were more opportunities to miss the correct slide. However, given the accuracy of previous participants in TB PM tasks such as this (e.g. experiment 1), this task should produce relatively accurate performance. This result is in contrast to results from experiments 1 to 4 in which externally-cued task switching showed independence from PM processes. This supports the notion of PM as a self-initiated task switch. Although the participants performed numerically better on the PM slide task in the infrequent task switch group, this group did have a higher proportion of participants who did not attempt all the subtasks once (6 out of 44 compared to 1 out of 44 in frequent task switch group). However, this should probably be considered a planning failure, rather than a PM failure. The infrequent task switch condition required increased planning to be able to attempt all 8 subtasks (and not break rules) because of so few switches. Nevertheless, arguably this need for planning did

not outweigh the cost of frequent task switches for most of the infrequent task switch participants.

The application of these results to real life is feasible since these types of ill-structured tests have high ecological validity. The overall picture would suggest that fewer self-initiated subtask switches in a multitasking situation, such as within the workplace, produces better overall performance. This is true at least in terms of speed of performance (number of items) and for remembering to carry out intentions (correct slides reported and rule-following). The strategy score is comparatively more artificial in nature, however, it arguably represents something such as goal prioritising, a process seemingly independent of the number of task switches. Thus, instead of developing computer interfaces that are intended to aid with self-initiated task-switching (Czerwinski et al., 2004), maybe operating systems should be designed that actually prevent people switching between tasks (or ‘applications’) and encourage lengthier stays with one endeavour!

#### *5.5.4.2. Correlations with other Cognitive Measures*

##### Hypothesis 2

As predicted, there were significant correlations between the RM measures and the AMT2 measures. Specifically, the RM scores correlated with the PM measure but not with the strategy measure (total percentage of items completed that were worth more). This is in line with the hypotheses that RM is necessary for PM (Burgess & Shallice, 1997) and replicates the results of experiment 7. Scores from the word list recalls did not correlate with the strategy score. This is different to experiment 7 in which RM also correlated weakly with the strategy score (percentage opt) and the number of subtask items completed. This could be because the percentage opt score in experiment 7 also represents remembering to switch between the subtasks after the correct amount of allocated time has elapsed, and thus partly representing PM efficiency – requiring RM processes. The strategy score in the AMT2 may represent a purer measure of strategy application processes, which include flexibility, inhibition of usual responses and error monitoring (Levine et al., 1998).

In this experiment, a self-initiated element of the multitasking was constrained: the subtask switching frequency. Consequently, the demand on planning processes was reduced (e.g. to plan how to allocate time between subtasks) whilst the demands on PM processes remained the same (to switch between subtasks). Thus, the expectation was that there would be only low (if any) correlations between AMT2 measures and Raven's matrices score (compared to experiment 7 at least). This hypothesis was supported. There were no significant correlations between Raven's and any of the multitasking measures. This provides supports for Burgess and colleagues' (2000) theory that the planning component of multitasking is related to IQ measures, possibly because they share some processing and/or recruit similar PFC areas. Future experiments could test this hypothesis further perhaps by increasing the planning load in the multitasking tests, for example, increasing the number of rules regarding subtask order and then comparing these measures to Raven's scores. Alternatively, participants' IQs could be manipulated as the independent variable and planning scores from the multitasking tests compared between the groups. It is possible, of course, that only nonverbal reasoning IQ correlates with planning, because of some common mechanism (such as working memory), and thus, future studies should include other IQ measures (e.g. verbal IQ) and other cognitive tests (e.g. working memory tests) to examine this relationship in more depth.

#### *5.5.4.3. Correlations with Real Life Measures*

##### **Hypothesis 3**

In contrast to experiment 7, there were correlations between the AMT2 measures and the academic measures. I hypothesised that achieving success in these types of examinations is likely to make demands on multitasking processes e.g. planning, RM and PM, the latter of which are not necessarily related to IQ. The total percentage of correct slides reported correlated positively with total qualification points and approached significance with A-levels. This is despite the absence of correlations between the Raven's (IQ) and these AMT 2 measures. This hints at the possibility that the AMT2 is measuring processes different to a standard test of IQ, but which may still be related to important real life indicators such as examinations. Given the multiple correlations, these are quite weak correlation coefficients and so should be considered cautiously; nevertheless it seems an important area to pursue in

future studies. The number of subtask items completed correlated with academic measures more convincingly, however, in the infrequent task switch group. Hunt (1978) relates speed of information processing to verbal intelligence, as does Kline (1991) and Salthouse (2005) to general intelligence, which may explain this relationship; this issue is discussed further in Chapter 6, section 6.4.3. Participants in the frequent task switch group did not exhibit such a relationship, perhaps because of the more limited range of scores within this group (range =153 compared to 262 in the infrequent task switch group). In other words, the very short intervals during which participants were able to complete the subtask items may have prevented individual differences from emerging fully.

#### Hypothesis 4

There was only one small correlation between the number of subtasks attempted and life satisfaction in the infrequent task switch condition. There were also small correlations between the total subtasks attempted, number of items completed and time management scores. This again is only weak support for the hypothesis that multitasking tests tap processes necessary for successful everyday life tasks (Burgess et al., 2000). However, it is certainly interesting that the measures correlating with time management strategies possess a good deal of face validity (e.g. number of subtasks attempted).

Undoubtedly, many extraneous variables in life satisfaction are also relevant that were not considered in this study and certainly larger samples and range of measures are required in future studies. For example, measures which separate out different elements of life satisfaction or everyday life success and difficulties. For example, Chan (2001) has argued that the DEX (Dysexecutive Syndrome Questionnaire) can be used with a non-clinical sample. His study with the DEX showed a healthy population reporting a range of mild dysexecutive-like behaviours. A factor analysis found five factors within the DEX responses – inhibition, intentionality, knowing-doing dissociation, in-resistance and social regulation (replicating Burgess et al., 1998). Each factor showed a distinct pattern of correlation with other executive functions tests e.g. intentionality factor (relating to everyday planning, decision-making and goal-following) correlated with planning, rule regulation and mental flexibility – with the author arguing this factor relates heavily to goal-directed behaviour. This study provides evidence for the fractionation of executive function among the non-clinical sample, which the results from the study reported here



also support, considering the different pattern of cognitive and real life correlations. Another study found no relationships between the DEX and a multitasking test (Alderman et al., 2003) in their healthy control population, but this might be due to their overall high performance on the MET-SV. This study and experiment 7 have produced a wider range of scores in multitasking in the healthy population, thus future studies might want to also administer the DEX to ascertain if the tests are useful for identifying real life difficulties.

Turning to the time management correlations, a positive relationship emerged between the number of subtasks attempted and time management in the infrequent task switch condition, although it did not quite reach significance. Here it is reasonable to assume that the number of subtasks attempted also represents an ability to plan, and this is reflected in the time management score too. A second significant correlation is reported between the time management score and an AMT2 measure, but in this case a negative relationship with the number of items completed in the frequent task switch group. Participants who reported themselves as better time managers completed fewer items. A possible link between these two measures is time estimation. Francis-Smyth & Robertson (1999) report that their participants who perceived themselves as effective time-managers (self-report questionnaires) tended to underestimate the amount of time passed (as measured by a separate test), they believed time to be passing more quickly than it was. The authors attributed this primarily to '*over-zealous monitoring of time and attention to the cognitive timer*' (p. 345). From an attentional model perspective of time estimation (see Chapter 3) increased attention to time monitoring leads to less attentional resources for performing the concurrent tasks (e.g. Thomas & Weaver, 1975; Zakay & Block, 1997). Applying these results here suggests that the effective time managers of the present experiment worked slower because more of their attention was dedicated to time monitoring. Future research could test this hypothesis by including RTs and error rates of the subtasks as dependent variables. Future research may also want to consider more general personality factors, such as conscientiousness, which may affect time management and multitasking performance, as well as contribute to the real life outcome measures (e.g. Calabresi & Cohen, 1968; Adamson & Covic, 2004). These data certainly suggests that further research of everyday time management strategies and multitasking performance is warranted. Indeed, these multitasking tests (or modifications of) might prove useful as occupational tests because not only do they correlate with reports of time management strategies but as cited they can

also have independence *'from the potentially biasing effects of general intellectual ability, familiarity with the environment and gender'* (Alderman et al., 2003, p. 40). Further study might investigate if there are gender differences in performance of the AMT, as is suggested by popular culture, since the samples used here were heavily biased in favour of females. Certainly, evidence indicates that women participate in multitasking in everyday life more frequently (e.g. Michelson & Tipper, 2003). Other limitations of experiments 7 and 8 and future research suggestions are considered further in Chapter 6, section 6.5. within the General Discussion. It is to this Chapter I now turn.

## **Chapter 6**

### ***General Discussion***

#### ***6.1. General Aims and Hypotheses Reviewed***

The set of experiments presented in this thesis aimed to investigate the cognitive control of internally-guided behaviours. As reviewed in Chapters 1 and 2, previous studies provide evidence that behaviour may be mediated by different regions of the PFC according to the degree of environmental constraint afforded by the tasks. The experiments examined behavioural evidence for this dissociation by investigating two types of tasks that depend heavily on endogenous control, PM and multitasking. In this final Chapter, I will briefly review the aims and the findings of the eight experiments presented and examine the specific and broader theoretical interpretations of these data, plus their implications and potential application. Additionally, I will evaluate the methodological limitations of these experiments and offer some proposals for future research that may help delineate between proposed theoretical possibilities.

#### ***6.2. Summary of Chapter 3 - Experiments 1 – 4***

The first empirical Chapter aimed to investigate the cognitive control of internally-guided behaviours by combining the externally-cued task switching paradigm with the PM paradigm. At the beginning of the Chapter evidence for separable processes involved in rapid, externally-cued task-switching and self-initiated PM task-switching was discussed. This evidence stems firstly from neuropsychological data, such as the SAD patients of Burgess et al., (2000) and SRD patients (e.g. Levine et al., 1998), who appear to have few deficits in tasks that are externally-constrained compared to internally-cued tasks (and task switches). Secondly, behavioural studies from the voluntary task-switching paradigm (e.g. Arrington & Logan, 2005) appear to show different sources of switch costs for voluntary versus externally-cued task switches, implying different cognitive processes. Finally, neuroimaging evidence (e.g. Dreher et al., 2002) has demonstrated different neural mediation of cognitive control according to the degree of predictability, and thus endogenous control, of the task switch. To test this hypothesis an additive factors design was employed, with the basic design kept the same across all four experiments. Participants

performed one block of addition only and subtraction only, each block with and without PM instructions. In addition, they each performed two blocks of switching between addition and subtraction (ABAB), with and without PM instructions. Additive results were predicted based on the hypothesis that these two task-switching procedures draw on different executive resources.

In these four experiments the PM task was conceptualised as a self-initiated task switch and thus an externally-cued PM control condition was added to the basic PM paradigm. This was achieved by instructing participants to remember to move between two sets of ongoing task stimuli as the PM task. During the non-PM blocks, the computer automatically generated the equivalent procedure, but without the volition, by moving the participants between the two sets of stimuli automatically. This allowed for a comparison of the ongoing task RTs during the PM and non-PM blocks, before and after the side switch. This proved to be an effective means of investigating the effects of the self-initiated PM task switch, revealing significant RT differences in the PM and non-PM blocks. Consequently, these RT differences were discussed in terms of theoretical models of PM processing requirements.

In experiments 1 to 4, this combination of the PM paradigm and the task-switching paradigm was employed, as described above. The first experiment included a clock in the display and the second experiment included a 'revealable' clock in order for participants to be able to execute the PM intention at the correct time interval. The third experiment did not present a clock in order to increase demands on self-initiated processes. Previous studies in the literature have failed to compare task-switching and TB PM (e.g. Marsh et al., 2002). More generally, previous studies have not measured the effects to the ongoing task of maintaining and executing TB PM intentions, a methodology used by Smith (2003) who obtained ongoing task performance decrements with the addition of an EB PM task. The final experiment in this Chapter used a EB PM task procedure.

Generally, the results were as predicted, with main effects of task-switching on ongoing task RTs and main effects of PM, but no significant interactions. The robust task-switching effect was replicated, with participants showing significantly slower RTs when alternating between addition and subtraction, than doing either just addition or just subtraction.

Somewhat surprisingly though, in experiments 1 and 2 the effect of adding the PM intentions was in the opposite direction to that predicted and demonstrated by Smith (2003). Participants showed faster ongoing task RTs when they also had to remember to carry out the PM intention to switch sides, compared to the blocks in which the computer generated this side switch automatically (i.e. no-PM blocks). This effect occurred regardless of whether the participant was carrying out a 'pure' task block, or a task-alternating block. In experiments 3 and 4, participants demonstrated slower RTs during the PM conditions, replicating Smith (2003). Both of these findings are discussed in more detail below.

In what I hope will be a useful tool for TB PM research in the future, the data was also analysed in terms of change in cognitive processing requirements across the RIs in experiments 1 to 3. Thus, the retention intervals were split into three time bands and compared the mean ongoing task RTs in each of these time bands in the PM and no-PM blocks. Interestingly, a broad pattern became apparent, with participants slowing as they approached a PM task and recovering faster from the side switch compared to the equivalent side switch in the no PM conditions. The possible processing implications of this are also discussed in depth below.

### **6.2.1. The Relationship Between Task-switching and Prospective Memory**

The outcome of these four experiments is in line with the original hypothesis that there would be additive effects of PM and task-switching and no interaction. In all four experiments participants performed slower in the task-alternating blocks, replicating the standard task-switching effect (e.g. Jersild, 1927; Allport et al., 1994; Rogers & Monsell, 1995). However, during the PM blocks the RTs were either faster or slower than the non-PM blocks, this is discussed further below. PM performance was not affected by the task-switching factor; participants were performing at ceiling on this dependent measure. The additive effects are attributed to the differences in the degree of external cueing guiding the two types of behaviour since this is consistent with the hypothesis that cognitive control over internally-guided, open-ended tasks may be mediated by different frontal regions to externally-constrained tasks, as proposed in the General Introduction.

Differential processing in task-switching according to the degree of external cueing is consistent with Arrington & Logan (2005) who reported that voluntary task switches produced a smaller switch cost than matched, explicitly-cued task switches. Moreover, in an experiment that controlled for cue encoding processes, they found that the explicitly-cued procedure did not show reduced switch costs with increasing preparation time, whereas the voluntary task switch costs did diminish with increased preparation. Thus, the authors maintained that the environmentally-cued version may involve processes that resolve the interference from priming effects, rather than reconfiguration of the task-set, which may be responsible for the voluntary switch cost. This could explain the lack of interaction between the paradigms.

These data are also consistent with the Gateway hypothesis (see Chapter 1, section 1.3.2.). According to this hypothesis, the PM task switches require processes (supported by the rostral PFC) that enable the modulation of attention between SOT (the ongoing task) and SIT (the intentions). In contrast, the externally-cued task switches do not require such processes because participants can just allow their behaviour to be ‘captured’ by the external cues and stimuli (see Waszak, 2003; Pollmann, 2004), there is no need to bias attention between SOT and SIT. Potential explanations of the cause of the slowing prior to a PM task switch are discussed in detail below, but a prediction from the Gateway hypothesis might be that the involvement of processes in biasing attention towards SIT could produce the slower ongoing task RTs in the PM conditions (e.g. see Burgess et al., 2001). This fits with these data. However, according to this reasoning, presumably the processes involved in the biasing back to focusing on SOT (i.e. the ongoing task) should also produce some slowing (and thus produce a U-shaped pattern of RTs in the RI) – but this was not the case. Participants showed faster ongoing task responding after switching back to the ongoing task in the TB PM conditions (i.e. at the beginning of the RI). Gilbert et al., (2005) provide support for the argument that the switch back to SOT should produce slowing too. They report that switching from internally-based to externally-based versions of the same task produced larger switch costs to RTs than switching from externally-based to internally-based versions. In other words, the internal-external switch does have an impact on RTs. However, this effect was modulated by the type of ongoing task the participants were performing, thus until more is known about how this variable affects internal/external switching costs it is difficult to draw a conclusion on this matter. Thus,

future research could manipulate the ongoing task. In addition, it may be worth analysing RTs in finer-grained time intervals than 10 seconds as the slowing after the switch from the PM task, back to the ongoing task, may be short-lived, in which case an averaging artefact may have occurred in these data.

### **6.2.2. The Effects of the Prospective Memory Task on Ongoing Task Performance**

I will first discuss the pattern of RT data in experiments 3 and 4 that are in line with the hypotheses, before discussing the RT data of experiments 1 and 2. The overall ongoing task slowing demonstrated in experiments 3 and 4 is a finding consistent with the PM literature. Smith (2003) has demonstrated a cost to the ongoing task during EB conditions, compared to control conditions. The author suggested this is compatible with the 'preparatory attentional and memory processes' (PAM) theory in which participants are also strategically monitoring for the cue whilst performing the ongoing task and this can explain the ongoing task slowing. The author also predicted this outcome in a mathematical model of the PAM theory (Smith & Bayen, 2004). Strategic monitoring for the cue can explain the outcome of experiment 4, in which the intention was connected to an environmental cue in the ongoing task stimuli. However, in experiment 3 the slowing cannot be attributed to monitoring for the cue, but perhaps to monitoring time and time estimation processes. This is the first study to demonstrate a cost to the ongoing task in TB PM. The data obtained from experiment 6 supports this notion that the significant slowing in experiments 3 and 4 are consequences of separate processes, since there was no extra interference to the ongoing task when EB and TB PM were combined.

Another possibility, borrowed from the task-switching literature, is that bottom up processes may account for the performance decrements in the ongoing task during PM conditions, at least in the EB PM experiment. These stimulus-driven interference theories have previously not been applied to theoretical considerations of PM processes. Switches between the PM response and the ongoing task may generate stimulus-driven costs to the subsequent trials. For instance, Allport et al., (1994) attribute switch costs to task-set inertia, a consequence of residual activation of the competing task-set or inhibition of the current task-set (see Chapter 3, section 3.2.). Indeed, Waszak et al., (2003) provided empirical evidence that *'stimulus-elicited priming from a prior, competing task can indeed*

*have very large interference effects on the speed of response to the same stimuli, following a shift of task, and that these effects can be very long-lasting.*' (p. 399). Stimulus-task bindings are formed from performing a task-set that are represented as memory traces, and may be automatically retrieved on presentation of the same, or similar, stimuli and the resolution of the competition this causes between task-sets comprises the RT costs.

Within the EB PM paradigm the same stimuli usually afford both tasks (e.g. Einstein & McDaniel, 1995) thus two potential sources of interference arise: interference to the ongoing task due to the PM response (i.e. task switch) and interference in switching to the PM response caused by priming from the ongoing task responses. The latter is difficult to evaluate because of the lack of data regarding the RTs of the PM responses, and valid comparison RTs (such as the baseline RT of the PM task). In experiments 1 to 4 the PM response does not require any computation, unlike in the ongoing task (it is simply to press a different button rather than perform a sum), making the PM responses faster and meaningless for the analysis required to assess this argument. In assessing the former (interference to the ongoing task after the PM task switch) it is worth considering predictions from a computational model of task-switching. Gilbert & Shallice (2002) demonstrated through modelling that asymmetric task switches arise when two tasks make different demands on endogenous control. The PM response requires a great deal of endogenous control, it is entirely internally-driven. According to Gilbert & Shallice's model therefore this would produce smaller task switch costs when the participant makes the PM response, compared to when switching back to the ongoing task. However, they also include the factor of pathway strength within this model (i.e. the strength of the stimulus-response network), which also modulates the switch cost. As such, no prediction can easily be conceived regarding PM task switch costs until further modelling techniques are employed.

Task-set priming is certainly a potential variable affecting ongoing task performance and worthy of further research to resolve the issue. To investigate the effect of task-set inertia or other bottom-up processes during PM conditions researchers could compare ongoing task performance, when the stimuli affords both the ongoing task and the PM task, to ongoing task performance when the stimuli cannot afford both. For example, the ongoing task could be addition but the EB cue to make the PM response could be embedded in the pattern of



the background screen (see Park et al., 1997 for a similar methodology). Univalent stimuli can reduce priming or task-set inertia effects (Waszak et al., 2003) and thus the relative slowing of the ongoing task could be measured.

Experiments 1 and 2 showed a facilitation effect to RTs during the PM blocks. The hypothesis derived from these results associated the external clock to a 'deadline' effect, such that participants speeded up because of the psychological pressure of the time. Evidence suggests that an interruption task can have such an effect (e.g. Speier et al., 1999; Zijlstra et al., 1999). This proposed effect was not replicated in the TB with clock PM blocks in experiment 5. Thus, the effect was attributed to the slower responding after the side switch in the non-PM conditions.

### **6.2.3. Explaining the Pattern of RT Data Across the Retention Interval in Experiments 1- 6**

The slowing before a self-initiated TB task switch (i.e. the PM response) could represent several possibilities. Firstly, there is the simple notion that the participants are monitoring the time more frequently as they approach the correct time to make the switch. Cicogna et al., (2005) argue that time monitoring *'occurs as an additional task with respect to the ongoing activity'* (p. 222). As such, this time monitoring might lead to the ongoing task RT patterns found in these RIs (due to divided attention). Alternatively, the slower RTs found in these studies could be a consequence of eye movements and/or clock orientated motor movements. The pattern of clock checking in experiment 2 is consistent with the proposed strategic time monitoring model of Ceci & Bronfenbrenner (1985). The slowing before the switch then is consistent with their concept of the 'scallop' phase, during which the participants increase clock-checking and are thus dividing their attention. However, the data reveal faster ongoing task RTs after the PM responses. This is inconsistent with the time monitoring explanation of the pre-switch slowing since clock checking is increased in this period (the 'calibration' phase).

Several other lines of evidence are inconsistent with the pre-PM response slowing simply reflecting increased time monitoring. Consider the experiments that did not include a clock on the display (experiments 3 and 5). Analyses demonstrated slowing prior to the PM response despite the absent clock. With the 'revealable' clock in experiment 2, the same

pattern of data was found despite removing the trial before and after a clock check from the analyses. This eliminates eye and motor movements as an explanation, at least for these experiments. There is no reason to assume the slowing has the same basis in all of the PM experiments, (or indeed within the same experiment) but, given their similarity, they are likely to share some properties. Moreover, if time monitoring explains the slowing across the RI, there is no reason why trials immediately following a side switch in the first 3 experiments should be slower in the externally-cued condition. Presumably after just making a PM response, participants do not need to check the clock, thus speed of responding might be equivalent to the externally-cued condition. Of course, experiments 5 and 6 did not include the externally-cued PM switch equivalent so some of the explanations described below may only apply to experiments 1 to 4.

A different account of this pre-PM response slowing then which can perhaps account for these data better, is the notion of preparatory pre-task switch control processes. For instance, a distinction perhaps relevant to these data, and discussed by Waszak and colleagues (2003), is between 'goal-setting' and 'task-readiness' (Fagot, 1994). Goal-setting is a preparatory process which establishes which task is to be executed, these processes act to bias *'the possible stable states to which the system is able to settle'* (Waszak et al., 2003, p. 401), and thus prepare the participant to execute the correct task. 'Task-readiness', however, is *'the time the system takes to settle to a task-relevant response'* (Waszak et al., 2003, p. 401). Task-readiness can be affected by interference from bottom up processes. Thus, the pre-PM response slowing may be related to these goal-setting processes and can explain the faster recovery from the switch than compared to the externally-cued equivalent side switch, as the system has been biased by the preparatory processes.

A similar account has also been proposed by Monsell and associates (2003) to explain differences between the effects of predictable and unpredictable switches. In predictable task-switching, they argue it is possible to commit entirely to the new task-set after a task switch, if the individual knows they will be repeating that task again. Consequently, there may be a more efficient 'recovery', and after the first trial, the participant is 'ready' to perform the same task again and the RT returns to a normal rate. They relate this task readiness to the possibility that individuals have endogenous control over the levels of

activation and inhibition applied to the task-sets (e.g. Norman & Shallice, 1986; Gilbert & Shallice, 2002). In the externally-generated side switch blocks the participants are slower to recover, perhaps because they are less prepared to commit to 'task-readiness' as the task switches are unpredictable. As Monsell et al., (2003) claim then, there seems to be '*expectation-based modulation of endogenous control input*' (p. 336). In other words, the more predictable the task-switch, the more inhibition and activation is endogenously controlled and the better the performance of the ongoing task following the switch. Since participants have complete control over the task-sets they perform (because they must identify the correct cue or time) in the PM paradigm this is particularly relevant. The voluntary task switch study of Arrington & Logan (2004) also considered the position of the trial after the switch and found that with a longer RSI (i.e. with increased preparation time) the faster the recovery after the switch. This is also consistent with the task-readiness account in which endogenous control can be applied to bias the task-set response prior to the switch and reduce switch costs, if there is ample preparation time.

This is also consistent with Rubenstein et al., (2001) who argue that two active control processes account for the switch cost. The first is goal-shifting and involves deciding the correct production rules to be inserted into working memory, this can be achieved in a preparation period. The second is rule-activation, which is actually the insertion of these rules, and this can only be achieved once the exogenous stimulus has occurred. It could therefore be argued that there is early goal-shifting preparation occurring prior to the PM cue (i.e. time). Recall however, that the trial immediately preceding a task switch is not included in the analyses because of probable eye and motor movements, rendering the RTs meaningless. Thus, the extent to which any of these preparatory processes can proceed *several* trials before the task switch is not discussed in the literature and remains an area for further investigation. Finer-grained analyses of the RIs may improve our understanding of this issue. Perhaps if preparatory processes are occurring prior to the PM task switch then this might be reflected in the RT immediately before the PM response, and it might be in this trial alone that there is shared processing with the task-switching paradigm. As such, all of these hypotheses regarding the potential explanation of the pre-switch slowing and faster recovery in PM task switches remain fairly speculative. Future studies should include this trial before a PM response and perhaps utilise PM task switches that do not include side switches as the intention.

Several other caveats must be made to the discussion above. Applying the task-switching literature is relevant to PM because of the self-initiated task switch inherent in the paradigm. Nevertheless, several differences remain between the two paradigms and therefore mapping the theoretical positions of the task-switching literature onto PM effects must be performed with some caution. Clearly, the major issue is that the task-switching paradigm primarily uses external cues to guide the behaviour of the participants and generate the task switch. All of the theoretical considerations are thus based on externally-guided behaviours, rather than internally-guided behaviours (naturally there is still some endogenous control involved, as described). The four experiments reported here showed no interaction between task-switching and PM processing, as such they are likely to be recruiting separable processes. The explanations above draw on the task-switching hypotheses and therefore may not be appropriate to account for the slowing. This, however, may be resolved by considering that the ABAB procedure used in these experiments provide little preparation time; new stimuli are generated as soon as participants have responded to the previous trial. As such, the preparatory processes described above may not be operating, hence showing no interaction with the PM processes. Alternatively, as Arrington & Logan (2005) contend and as discussed above, this strongly environmentally-cued task-switching methodology may generate switch costs only as a consequence of stimulus-driven interference, rather than executive processes. Or indeed, different types of executive processes may be at play (e.g. inhibition to overcome the bottom up interference in the ABAB procedure, Mayr, 2002). Future research could differentiate between these alternatives by looking for additive or interaction effects in experiments combining PM and other task-switching procedures, such as the explicit-cueing procedure, and manipulating the RSI.

Another caveat is that in experiments 1 to 6 there was not always a reliable pattern of slowing prior to the TB PM switch in all conditions. This may alter the interpretation of the pre-PM response slowing. If preparatory processes were responsible then presumably this pattern of data is expected across all RIs. Two potential explanations follow. Firstly, as elucidated in the discussion of experiment 6, the numbers of participants included in the analyses were low, reducing the power of the experiment to find significant effects. Secondly, there is an account in the task-switching literature that is consistent with the

notion that participants do not always employ preparatory processes prior to a task switch. De Jong (2000) argues that occasionally participants will fail to employ preparatory processes ('intention activation'), perhaps because of goal neglect (De Jong et al., 1999) or mental fatigue (Lorist et al., 2000), which leads to prolonged task switch RTs, even with large RSI's. If this is also true of PM task switches then this could lead to this slightly inconsistent pattern of ongoing task RTs. Lorist et al., (2000) gathered ERP data during their task-switching study and found an enlarged frontal negativity in switch trials, compared to repeat trials. This was argued to reflect the task-set reconfiguration processes, but crucially this wave was less apparent during later trials (2 hours worth of task-switching was endured!) in which mental fatigue had reduced the likelihood of preparation. A similar ERP methodology could be applied during PM tasks to test this 'fail-to-engage' hypothesis.

One final comment regarding these experiments is a characteristic of PM processing that has so far not been touched on. Within the EB PM literature, there are several studies that demonstrate an 'Intention Superiority Effect' (ISE). Participants respond more readily to cues that have are to-be-performed actions associated with them than cues that are just remembered (Goschke & Kuhl, 1993). They attributed this effect to a higher level of activation associated with intentions in order to make their retrieval easier. In the task-switching literature, the pathway strength or level of activation associated with a task-set is also a factor mitigating the switch cost (Gilbert & Shallice, 2002). How then is the ISE interacting with the PM task-switch? This remains an area for future investigation.

### **6.3. Summary of Chapter 4 – Experiments 5 & 6**

#### **6.3.1. Experiment 5**

The aim of experiment 5 was to investigate the effect of the presentation of the clock on performance of the ongoing task in a PM paradigm. In experiments 1 to 3 different patterns of RTs were obtained in PM blocks with a clock, with a revealable clock and without a clock. Neuroimaging evidence also reported different neural mediation of clock and no-clock TB PM, suggesting a possible dissociation of processing according to the nature of the clock presented. Thus, the presence and absence of the clock was hypothesised to differentially affect both the overall RTs to the ongoing task in the PM and no-PM blocks and the pattern of RTs across the retention intervals. In this experiment and experiment 6

however, it was overall accuracy rates of the ongoing task which were affected by the clock manipulation, as opposed to the RTs. Participants were significantly more inaccurate in the TB PM block with no-clock compared to baseline (i.e. no PM intentions) and with a clock. Participants did show the expected change in RTs across the RIs, slowing as they approached the PM response in both clock and no-clock TB PM blocks.

These data were interpreted as the presentation of the clock altering the cognitive processing requirements of the task. With a clock present, the task is increasingly externally-cued and the dependency on self-initiated control processing is reduced, hence improved ongoing task performance. During the no-clock blocks extra processing is required not only in terms of time estimation but also self-initiated retrieval, with increasing cognitive demands for the PM task performance of the ongoing task is diminished.

Previous TB PM studies have rarely required participants to remember an intention without the presentation of a clock (except in neuroimaging, see for e.g. Okuda et al., 2002; 2004). In this sense, the experiments reported here are relatively unique. The original Einstein & McDaniel PM paradigm was designed to mimic the key features of everyday PM tasks in the laboratory (as described in Chapter 2, section 2.3.) and arguably by removing a clock the ecological validity of this paradigm is reduced. After all, everyday life is littered with clocks and timing devices, such as computers and mobile telephones. By removing the clock perhaps then the fundamental nature of a PM task is changed and this change is a step away from real life PM tasks, and thus, a step away from being applicable. Below I outline three arguments in defence of the methodological technique employed here:

- 1) The crucial point is that removing the clock helped demonstrate that clocks can act as an external cue, and that the degree to which they do so appears to lie along a continuum according to their presentation in laboratory paradigms. This forces open the methodological issue associated with TB PM studies and should be addressed in future studies. The application of these experiments then is partly to improve our lab paradigms, the theoretical applications are discussed in detail below.

- 2) In real life TB PM tasks a degree of time estimation may be required, from seconds to hours. The pulse and step distinction may be relevant here (see Chapter 2, section 2.5.).

'Step' intentions that must be realised within a certain window of time (e.g. tomorrow afternoon) may incur a differential dependency on time estimation than pulse intentions, in which accurate time monitoring is required. As there are few TB PM studies that address this distinction, this remains a hypothesis to be tested. The time estimation literature distinguishes between various time intervals, and Lewis & Miall (2003) argue it is probable that interval judgements of different lengths recruit different cognitive systems. How this interacts with fulfilling TB PM intentions is also another avenue for future TB PM research.

3) The neuroimaging evidence showed a dissociation of neural activity in clock and no-clock versions. An aim of these experiments was to replicate this finding behaviourally. In pursuit of this goal, it was necessary to remove the clock entirely.

Future studies could proceed with researching the presentation of the clock by comparing 'revealable' clocks with a constantly available clock, or indeed manipulating the type of revealable clock (such as a clock physically behind participants and one that is revealed by a key press). This could establish if this factor, which has not been controlled for in previous studies, may explain inconsistent data such as the ageing studies (see Chapter 2, section 2.6.). In addition, it would yield data to test the hierarchy theory posited in Chapter 3, and revisited below.

Finally, the involvement of time estimation processes in the no-clock PM blocks complicates conclusions regarding the self-initiated retrieval processes involved. This is not particular to this set of experiments however. Previous TB PM studies have not often discussed the contribution of these processes (one exception is Cicogna et al., 2005). Time estimation processes are likely to be employed even with a clock available, especially in methodologies in which the clock needs to be revealed. The experiments in this thesis suggest that the measurement of these processes may be obtained from ongoing task performance rather than PM performance, a dependent variable lacking in previous TB PM research (e.g. Cicogna et al., 2005; Cook et al., 2005). The extent to which increased internal time estimation produces better or worse PM performance remains to be seen (these experiments show no effect on PM performance, but the participants were performing at ceiling). Extrapolating from the time estimation literature, in which

numerous studies have shown the requirement of attention and memory processes for time perception (e.g. Pouthas & Perbal, 2004), PM performance during no-clock conditions might be expected to decline as dependency on strategic retrieval increases. Thus, any individual differences in the use of time estimation within TB PM studies is a factor worthy of consideration, in the same way that individual differences in general allocation of attention or effort is (e.g. Kliegel et al., 2004; Marsh et al., 2005). Some participants may clock check less because they rely on their internal clock. As the interactions between time estimation, retrieval and PM performance are delineated the importance of these individual differences may become apparent.

One means of dissociating time estimation from retrieval processes may be to use a factorial design to cross an easy TB PM intention (that reduces demands on self-initiated retrieval) and a difficult TB PM cue with presenting a clock and no clock. Perhaps the easy condition could include regular reminders about the intention whereas the difficult condition does not; meaning participants must rely on self-initiated retrieval. A main effect of clock presentation and PM difficulty might be expected (with poorer ongoing task performance in the no-clock and difficult conditions) but no interaction – showing the relative effects of time estimation and self-initiated retrieval processes.

### **6.3.2. Experiment 6**

Experiment 6 compared TB PM without a clock and EB PM tasks in order to test the hierarchy theory outlined in Chapter 4, which stipulates that TB PM without a clock requires more cognitive resources than EB PM because of the demands on time estimation and self-initiated retrieval. A second aim was to determine the degree of interference, and thus shared processing, these two types of PM tasks produce in a combined condition, after a neuroimaging study suggested they may be mediated by different neural bases (Okuda et al., 2002). Finally, the experiment also considered the pattern of ongoing task performance across the TB PM RIs, as in the previous experiments and discussed above. A similar methodological paradigm was used as in experiment 5 but several PM conditions were incorporated into the design for comparison with the mixed PM task condition. These were as follows: a baseline condition, single intention TB and EB and dual intention TB and EB.



Previous research investigating the effects of mixing PM tasks had not included this full range of comparison conditions (e.g. Cicogna et al., 2005; Cook et al., 2005).

Analyses revealed significantly poorer ongoing task performance (lower accuracy) in the TB conditions than the EB conditions, supporting the hypothesis derived from the hierarchy theory. In addition, the findings revealed no significant differences in ongoing task performance between the single and dual intention conditions of the same PM task type, in line with predictions and previous research (Cicogna et al., 2005). Interference between processing in the mixed intention condition did not produce significant detriments to ongoing task performance compared to the other conditions, although there was a hint of increased inaccuracy in the mixed intention condition. Generally, performance of the ongoing task was equivalent in the mixed intention condition and the TB conditions. Cicogna and colleagues also reported a similar outcome, with PM performance of the main TB PM task showing a slight, but non-significant reduction when an interpolated EB PM task was added within the RI. Cook et al., found a significant decrease in TB PM performance when participants were also maintaining an EB intention and the authors provided two potential explanations for this: interference between strategic cue and time monitoring or changes in attention allocation such that the TB intention loses out. Strategic monitoring was not evident in any of the EB PM conditions of experiment 6 (as there was no difference in ongoing task performance in the EB PM and baseline conditions), which could explain the lack of interference in the mixed intention condition. Arguably, this indirectly supports the first explanation offered by Cook and colleagues for their interference effect. This highlights the methodological benefit of also measuring ongoing task performance as an indicator of strategic processing.

However, the explanation that cue and time monitoring share some processing resources is also consistent with the Gateway hypothesis. According to the hypothesis, interference between strategic time and cue monitoring may occur because in both cases rostro-lateral BA10 is required to either switch between attention to the ongoing task and to bias attention to internal ruminations (i.e. EB PM) or simply bias attention towards SIT (i.e. TB PM). Clearly further research is required to test this prediction, for instance, applying neuroimaging to experiments that manipulate the degree of strategic processing required within the EB and TB tasks.

In addition, as discussed in Chapter 4, adding TB PM intentions, without providing a clock, to an EB PM paradigm could provide an expedient framework for assessing the degree of attentional resources required for the EB PM task. The more resources that are used for non-temporal processing (e.g. strategic processes for the EB PM task) then the shorter the retention intervals should be between TB PM responses (Brown, 1997; Coull et al., 2004; Zakay & Block, 2004), thus allowing the degree of conscious control to be assessed between different EB PM manipulations (e.g. specific vs categorical cue). Future research may then be able to address this issue of whether strategic monitoring for the cue and time monitoring do require shared mechanisms.

Turning to some methodological issues regarding experiment 6, firstly, it is worth considering the counterbalancing procedure employed. In the mixed PM condition, half the participants were given short RIs for the EB PM task (with cues appearing approximately every 30 seconds) and long RIs for the TB PM task (with the instruction to make a TB PM response every 2 minutes). The other half of the participants received the opposite instructions, with short RIs for the TB PM responses and long RIs for the EB PM cues. With so many conditions already in the experiment, counterbalancing the EB and TB PM instructions in this manner seemed the most effective means of controlling this variable. Nevertheless, given the lack of empirical data regarding changes in time estimation strategies across different RI lengths in TB PM, future research could include both versions as separate conditions (i.e. participants carry out both versions). It may also be pertinent to consider if any time estimation processes are recruited to carry out the EB PM task when the cues appear at relatively regular intervals (as they did in these experiment, although the cues were staggered according to chance so it is difficult to assess this in this experiment). This raises the question of to what extent participants change their cue monitoring strategy over the course of the RI because they gain a sense of the time intervals between the cues? Perhaps, as with TB PM, cue monitoring gradually becomes more substantial across the RI as participants gradually become expectant of the cue. (Although in experiments where the EB cue may only appear once or twice (e.g. Cook et al., 2005) this is unlikely to be a strategy the participants use). Again, future research could address this issue, for instance by manipulating the regularity of the appearance of the EB PM cues. Post experimental

interview with participants may also provide some information on this, a technique Cicogna et al., (2005) used to establish attention allocation in their dual intention conditions.

Another methodological consideration with regards to experiment 6 is the use of overlapping RIs in the dual intention TB conditions. Participants were requested to remember to press a specific key every 30 seconds (PM 1 response), and every 2 minutes remember to press a different key instead (PM 2 response). Consequently, the design of this condition may have imposed an extra memory task; participants may have chosen to keep an ongoing mental track of the number of PM 1 responses they had made to facilitate their PM 2 responding. In other words, participants are aware that every 4<sup>th</sup> PM 1 response should actually be a PM 2 response. Thus, decreased accuracy in this condition may have resulted from maintaining an online count of PM 1 responses. This does not undermine the central tenet that the TB condition without a clock requires increased internal control because this process of monitoring PM 1 responses is still under endogenous control. Furthermore, Cicogna et al., (2005) demonstrated, in their dual TB intention conditions, that participants exhibited diminished performance of the interpolated TB task when the correct execution time of this interpolated task was closer to the execution time of the main PM task. This was attributed to the attentional overload generated from the requirement to start a new internal timer (as the interpolated task was added within the delay of the main task). In experiment 6, participants only required one internal timer (since 30 seconds and 2 minutes overlap) – thus the prediction would be that with non-overlapping RIs ongoing task performance would still deteriorate further.

### **6.3.3. Evaluation of the Hierarchy Theory**

The outcomes of experiments 1 to 6 pointed toward a new theoretical position regarding the dependence on self-initiated processing in different types of PM tasks. TB PM with a clock and possibly with a revealable clock require less endogenous control than EB PM and TB PM without a clock. Previously it has been assumed that TB PM must rely on self-initiated processes more than EB tasks (see Chapter 1, section 2.5.). I thus proposed a new ‘hierarchy’ theory of PM tasks in which the dependence on self-initiated processing changes according to the degree of environmental cueing in the framework, rather than simply the type of PM task (i.e. TB or EB).

At this stage, definite claims cannot be made regarding PM performance associated with these different types of PM tasks. PM performance was close to ceiling in all 6 PM experiments reported in this thesis and all effects related to ongoing task performance. Future research could manipulate the parameters of the PM task to make them more difficult (see McDaniel & Einstein, 2000) and assess any PM performance decrements after manipulating the presentation of the clock. Based on the EB PM research, increasing cue saliency (i.e. presenting a clock throughout the experiment) will increase PM performance and vice versa (e.g. Ellis & Milne, 1996; Cohen et al., 2003). Although, it is of course possible that a clock in constant view could reduce its saliency because of desensitisation.

A theory must be assessed on its usefulness and implications for everyday PM. The hierarchy theory would suggest that TB PM tasks in everyday life may be executed more successfully if an individual has access to a clock, either throughout the day, or at regular intervals. Conversely, TB PM tasks in which an individual does not have access to a clock are more likely to be forgotten or are more likely to affect performance of the ongoing task if they must rehearse the intention regularly. This rests on the presumption that the clock will act as a cue for the TB intention however, and in everyday life this may not be the case. Clocks in everyday life are unlikely to be as salient as in these experiments. Although participants in Sellen et al.'s (1997) naturalistic study did report in a post-experimental interview that clocks (and seeing or hearing things relating to time), did act as an external cue for their TB intentions. Indeed, the conclusions of their study fit perfectly with the hierarchy theory. The authors argue that two mechanisms are responsible for the remembering of intentions, one mechanism prompts from the 'outside-in' and the other from the 'inside-out', in other words external and internal prompts. Thus, although they concluded that generally the time task requires more internal control because the passage of time itself was not a salient enough clue; clocks could act as external prompts.

Despite the reports from the participants of Sellen et al., the usefulness of this theory is currently limited to PM tasks performed in this type of lab-based paradigm. Nevertheless, characterising clocks as potential cues is an important development for theorising about the cognitive processes involved in PM, as it questions a fundamental assumption of PM research, that TB PM draws more heavily on self-initiated processes. Indeed, it should encourage PM researchers to develop a multiprocess theory of TB PM, which could

hopefully translate into a useful heuristic for predicting PM success in everyday life and in clinical populations.

#### **6.4. Summary of Chapter 5 - Experiments 7 & 8**

The final experiments presented in this thesis attempted to explore individual differences in self-regulatory skills. Ill-structured tests, such as multitasking tests, have shown to be useful in the neuropsychological literature as measures of organisation and endogenous control (Shallice & Burgess, 1991; Levine et al., 1998; Burgess et al., 2000). These tests are thought to tap a relatively discrete subset of executive processes that are recruited for open-ended, internally-driven situations, and thus may not be utilized in IQ or traditional executive function tests. Using these tests within the healthy population has rarely been considered in previous research (except Law et al., 2004). In experiment 7, therefore, an Advanced Multitasking Test (AMT) was developed for use with healthy volunteers in order to assess individual differences in this subset of processes. Performance was also compared on scores from this test with other cognitive measures to observe if this dissociation holds true in a non-brain damaged population. Finally, the relationship of these processes and real-life measures, such as time management and life satisfaction, was explored, with the rationale that these processes are crucial to everyday life (Burgess, 2000).

##### **6.4.1. Experiment 7**

The basic features of the AMT were kept similar to previous multitasking tests, such as the Greenwich test (Burgess et al., 2000). However, two new demands were added to the basic design – an interruption task and an extra PM slide task. These increased the load on self-regulatory processes so the test was suitable for healthy participants, whilst maintaining ecological validity. Several performance outcomes were noted from the use of the AMT. Firstly, participants showed a wide range of performances on a variety of measures from the AMT. Secondly, a high proportion of participants demonstrated ‘goal neglect’; they failed to execute basic task demands such as attempting all the subtasks. Thirdly, the interruption task disrupted performance of the additional, continuous PM slide task and finally performance was relatively low (compared to other experiments in this thesis) on the continuous PM slide task. The other set of findings from this experiment (correlation analyses) are discussed below.

Arguably, this range of performances assures the usefulness of this test in the healthy population. Moreover, it may be an effective test for investigating goal neglect in the healthy population. One current theory relating to this apparent dissociation of knowledge from action emphasises the importance of 'g' (Duncan, 2001), but the results of experiment 7 did not suggest that participants with lower Raven's scores were more likely to fail to attempt all subtasks. Of course, this does not imply that low 'g' is not a factor in producing goal neglect in other types of task (see Duncan et al., 1997) but in this task it may be related to PM failure (perhaps as a result of the high load on PM). It would be interesting if future research could manipulate the load on PM in order to establish the 'critical point' of PM, that is, a point at which the high PM load prevents participants from performing other goals. Speculatively, this critical point might represent a situation in which there is attentional overload on the processes responsible for internally-driven behaviours. This could have direct implications for occupational settings in which employees endure a high degree of multitasking and self-initiated switching. Indeed, Hudson et al (2004) entitled their study of manager's daily activities: 'I'd be overwhelmed, but it's just one more thing to do' to reflect the feelings of their participants. Cognitive modelling may also help elucidate the cognitive mechanisms generating this goal neglect. Researchers have designed a cognitive architecture of human multitasking based on the ACT-R model of cognition (Anderson et al., 2004) that have demonstrated their usefulness in accounting for internally-driven multitasking behaviour and modelling everyday life tasks, such as driving (e.g. Kushleyeva et al., 2004; Salvucci, 2004). Successful cognitive models can simulate errors and other behaviours (such as when to switch tasks e.g. Kushleyeva et al., 2004) and thus may be able to simulate this 'critical point', if one exists.

Law et al., (2004) reported no effect of an interruption task on the performance of the multitasking test, but they may have not included scores that could reveal the disruptions. Participants in experiment 7 seemed to show poor PM performance during the interruption task. I argued that this fits with the previous research, which contends that interruptions interfere with PM (e.g. McDaniel et al., 2004). However, this interpretation must be considered with caution because there was no control (without an interruption) condition with which to compare PM performance. Indeed, the lack of experimental control groups does restrict the conclusions that can be drawn from this study, this is addressed to some

degree by experiment 8. In addition, the precise timing of an interruption will mitigate its disruptiveness (e.g. Monk et al., 2002; Adamczyk & Bailey, 2004). Interruptions that occur between subtask boundaries (i.e. as the participants moves from one subtask to the next), or during other periods of reduced mental workload, are less disruptive than those which occur during a subtask is being completed (e.g. Iqbal et al., 2005). In this group testing procedure, the precise timing of the interruption was not controlled; hence, individual participants were doubtlessly at disparate points of subtask performance. This may have hidden or worsened the disruptive effects of the interruption task, thus future studies must individually test participants on the AMT and perhaps change from inserting the interruption task at an absolute point, to a relative point that matches participants' subtask status (e.g. as they switch between two subtasks).

#### **6.4.2. Experiment 8**

The objective of Experiment 8 was to manipulate the degree of self-initiated subtask switching present in the AMT in order to understand the impact of this variable on performance. Thus, this experiment aimed to begin the procedure of pinning down the variables that affect multitasking performance. Self-initiated task-switching was considered first because of its apparent cost to ongoing task performance between switches (experiments 1 to 3 of this thesis, and Arrington & Logan, 2004). This manipulation also produced a constraint on the planning required by participants, a variable which I was unable to measure in experiment 7. Predictions regarding the impact of self-initiated switching on multitasking performance were somewhat challenging because of the potential interaction between self-initiated task-switching processes and PM. However, the results suggested a performance dissociation between task-switching and the strategic (i.e. goal prioritising) elements of this test. This supports the use of these scores as separate and useful measures (although see below) derived from multitasking tests (e.g. number of subtasks attempted and proportion of high value items completed), and presumably reflects a different set of cognitive processes (see Burgess, 2000). Strategy generation and PM are consistent with the separate SAS processes posited by Shallice and Burgess (1996; see Chapter 1, section 1.2.2.), and these multitasking tests are successful means of tapping them. Future neuropsychological research may be able to further elucidate the degree of separation of these elements of multitasking and indeed find specific PFC regions that mediate them (see e.g. Shallice, 2002). For instance, Fletcher et al., (1998) report a

neuroimaging study in which a specific region of the left lateral PFC appeared responsible for generating organising strategies for list recall. Nathaniel-James & Frith (2002) have related this PFC area with ‘sculpting the response space’, a mechanism required to produce top down modulation of responses when environmental triggering of schema is inappropriate. In contrast, as discussed in detail, is the role of rostral PFC in PM processes (Burgess et al., 2001). The relative importance of these processes in successful everyday multitasking, such as in the workplace, requires delineating.

### **6.4.3. Correlations Between The AMT and Cognitive Measures in Experiments 7 & 8**

As described in Chapter 2, section 2.7.1., Kleigel and colleagues (2002) demonstrated that 50% of the performance variation on three phases of their complex PM task (intention formation, intention re-instantiation and intention execution) could be predicted by executive test scores (Tower of London and verbal fluency) in their healthy sample. In contrast, the neuropsychological studies seemed to show a dissociation between traditional executive measures and multitasking performance (e.g. Shallice & Burgess, 1991). Although Levine et al., (1998) report both cognitive profiles, relative standalone SAD and SAD plus general executive impairment. The two multitasking experiments presented here certainly confirm the link between RM and multitasking (Burgess et al., 2000). In experiment 7, RM scores correlated with many of the AMT measures whereas in experiment 8 this was restricted primarily to the PM measure. These correlations probably reflect rule-learning and intention content.

In terms of Raven’s, the results were somewhat mixed. Experiment 7 revealed modest correlations with some of the AMT measures, whereas experiment 8 revealed virtually no correlations with the AMT. This is possibly due to the reduced number of participants in the analyses of experiment 8 (although there were significant correlations between these measures and the real life outcome measures). In addition, there were slight differences in the dependent measures between the two versions of the AMT. This was necessary because of the manipulation required in experiment 8 but does make the interpretation slightly limited. For instance, the removal of the interruption in experiment 8 is likely to have had an impact on the number of items completed and the number of subtasks attempted – thus, perhaps changing their relationship with Raven’s. Another potential explanation relates to



the degree of planning required in the two versions of the AMT. There is a common neural area (DLPFC) associated with Raven's (e.g. Prabhakaran et al., 1997, although also see Christoff & Gabrieli, 2001) and the planning component of the multitasking tests (Burgess et al., 2000). Since the AMT2 constrained the planning demands (because participants were told when to switch subtasks) maybe this can explain the lack of associations between these measures in experiment 8. Including a planning measure in future studies with the AMT could determine the validity of this explanation. However, the evidence would suggest that the Raven's correlations are probably linked to planning, rather than PM. Future research should use experimental designs with the AMT (such as manipulating the planning required) alongside correlational designs, since the latter reduce the causal conclusions that can be drawn.

Another missing source of information, besides a planning measure, is an indicator of speed of processing. Salthouse (2005) analysed the relationship between a range of cognitive tasks and executive tests, such as the WCST and Stroop. Using an analytical model methodology the author concluded, from two separate data sets, that many of the target variables (i.e. the executive test measures) are actually closely related to reasoning and perceptual speed. Multitasking tests were not included in the Salthouse study and, at least in experiment 8, the AMTs do not seem to be simply reasoning (i.e. Raven's), nevertheless a speed of processing account of the individual differences cannot be ruled out. Other executive tests can be highly influenced by speed of processing (e.g. Self-ordered pointing test, Bryan & Luszcz, 2001), although this has been explained in terms of its shared variance with 'g', in which case a speed test may have just exhibited the same pattern of correlations as Raven's. The exact role of speed of processing in PM or multitasking is uncertain (e.g. Kleigel et al., 2004), thus, future studies should include such a speed measure in order to resolve this issue.

Two other methodological issues have become apparent from using multitasking tests. Firstly, that the scores from the tests are potentially measuring a variety of cognitive processes (as acknowledged by Burgess et al., 2000) and secondly, that there is inconsistency in the measures presented by researchers, making interpretation difficult. Consider the Percentage Opt score from the AMT in experiment 7. This score represents the degree of accordance with the optimal strategy (to gain maximum points from the

subtasks). Participants may have scored poorly because they did not plan, they did not follow the plan, or they did not have the strategic capabilities to devise the optimal strategy. This is also true of the score measuring the number of subtasks participants attempted. Unfortunately, due to time limitations, it was not possible to include a measure of participants' planning before they began the AMT, this would have aided in distinguishing the reason for poor performance on this measure. Future research that utilises the AMT should include a planning measure. However, the Percentage Opt score also does not take into consideration that participants may prefer a particular subtask, or that they may find one subtask easier to complete, and thus spend longer on that subtask. If the score is affected by these factors then it is not necessarily measuring any of the aforementioned processes. This is a common feature of multitasking tests (e.g. Burgess et al., 2000, scored participants for spending less than 200 seconds on each subtask) but is improved by measuring strategy using the proportion of items completed that are worth more points, as in experiment 8. However, the criticism that participants may just prefer one type of subtask and thus spend a disproportionate amount of time on it can still be levelled at this type of scoring system.

The second methodological issue also relates to the measures that researchers devise and report in these multitasking tests. For instance, in the work of Kliegel and colleagues (see Chapter 2, section 2.7.1.), the authors conceived of a measure of overall task performance on their complex PM task by subtracting the number of rule breaks from the number of subtasks attempted. In their measure of overall task performance, Burgess et al., (2000) included these scores but they also awarded points for strategic allocation of time (as described above). As discussed in Chapter 5, section 5.2., Law and colleagues (2004) only reported two measures from their multitasking test (proportion of items worth more points completed, total number of items completed). These differences complicate cross studies comparisons. For instance, as described above, experiment 7 suggested a disruptive effect of the interruption on the PM measures of the AMT, but this was not measured by Law and colleagues. Perhaps as these more ecologically-valid tests are developed a taxonomy of scores can be agreed based on behavioural dissociations, neuropsychological dissociations and neuroimaging data.

#### **6.4.4. Correlations Between The AMT and Real-life Measures in Experiments 7 & 8**

These two experiments have only scratched the surface of the relationship between multitasking and real life outcomes. The initial rationale for these hypotheses were based on clinical data showing correlations between performance on multitasking tests and everyday life problems (e.g. Burgess et al., 1998; Knight et al., 2002). From this data, I extrapolated the types of real life outcomes that performance on these tests might correlate with in the healthy population. There were hints of significant correlations between AMT performance and life satisfaction and everyday time management in experiment 7. There was some replication of these relationships in experiment 8, although the correlations remained weak (and in some cases inconsistent between the two experimental groups). Experiment 8 also produced significant correlations between the AMT2 and the academic qualifications (which were not related to 'g'). Despite the somewhat mixed results, future studies should pursue the goal of relating executive ill-structured tasks to real life outcomes in the healthy population as there is certainly intimation in these early studies that they may provide useful indicators. Everyday life is full of open-ended tasks requiring endogenous control and the AMT may prove to be a useful representation of this (see Burgess et al., submitted).

Of course, a serious limitation with these experiments was the use of self-report questionnaires for measures of real life outcomes. Time management and organisational capabilities might be better assessed by using 'other' ratings, perhaps from employees or friends and families, as with the DEX questionnaire (Wilson et al., 1996). Moreover, future research could include validated time management questionnaires (such as Macan et al., 1990), which also have subscales that can provide more information on specific elements of time management (e.g. goal setting versus perceived control of time). Similarly, although these multitasking tests have higher ecological validity than traditional executive functioning tests, they remain somewhat artificial, especially the subtasks employed. Finding a task that is truly novel (and thus tapping executive function) and yet shares features of everyday life tasks is difficult but will no doubt prove to be a rewarding exercise (see Burgess et al., submitted). Future research investigating the relationship of these tests with real life outcomes could develop methodologies along the lines of more real life

multitasking. For instance, Stone et al., (2001) developed a paradigm based on air traffic control procedures that produced more realistic multitasking scenarios.

## **6.5. Cognitive Control of Internally-guided Behaviours**

### **6.5.1. Broader Implications and Conceptual Considerations**

At the broadest level, the experiments presented in this thesis support the theoretical position that there are multiple executive processes rather than single process theories (see Burgess & Simons, 2005 for review). Independent processes appear to be recruited for task-switching and PM and there is some evidence for a behavioural dissociation between multitasking processes and other complex tasks. It is difficult to reconcile these results with a single system/construct theory (e.g. Duncan, 1995; see Chapter 1, section 1.2.2.) of executive control. A capacity-limited, general-purpose executive mechanism would presumably share processing resources in the PM and task-switching experiments and produce interference.

Cohen and colleagues (e.g. 1998; see Chapter 1, section 1.2.2.) have suggested that the PFC maintains context representations which bias lower-level processes to control behaviour. This same mechanism, of maintaining task context and using this to provide top down support, produces several different functions including working memory, inhibition and attention. However, the lack of interference between PM and task-switching suggests that this theoretical framework requires elaboration. Studies with the Continuous Performance Task (CPT) – a test of sustained attention and vigilance – have supplied the empirical evidence for this theory (e.g. Braver & Cohen, 2001, Braver & Bongiolatti, 2002) and neuroimaging studies have placed this context representation mechanism within DLPFC, rather than the PFC in its entirety (Braver et al., 2002). The CPT requires little internal guidance in terms of initiating responses (all the cues are presented), suggesting this context representation model might be more suitable for describing the role of executive processes in externally-constrained tasks. This position is consistent with the absence of rostral PFC activity in the imaging studies.

In terms of the cognitive control of PM, a ubiquitous internally-driven behaviour, it is evident that processing demands alter according to the degree of environmental support,

even in TB PM. Experiments 5 and 6 cannot directly address the question of fractionation of executive processes however. The realisation of intentions within the environmentally-cued conditions of these experiments may be achieved automatically, at least the retrieval of the intentions (i.e. with little executive control). As such, it is not possible to argue that different executive mechanisms are mediating these versions of the tasks (i.e. clock or no-clock and TB and EB), but both experiments do highlight the importance of this external cueing variable in cognitive tasks. Future neuropsychological studies on patients with focal frontal lesions can act as a crucial tool in dissociating executive processes involved in PM compared to other executively demanding tasks.

As discussed in Chapter 1, distinguishing between tasks according to the degree of environmental cueing is common in the executive function literature (e.g. Shallice & Burgess, 1991). The basic proposition of the action control theory of Norman & Shallice (1986) is that two different mechanisms implement schemas according to whether the behaviour required is routine or novel. In novel situations, endogenous control is required (via the SAS) to decide or plan the correct schema, using the cues from the environment is simply not enough. Given the hierarchal nature of this theory and the evidence regarding the possible role of rostral PFC (See Chapter 1, section 1.3.) these data seems consistent with different processing mechanisms according to the degree of self-initiated demands involved. Passingham (1993) proposed an analogous dissociation in relation to action control. Passingham contends that the medial premotor cortex area makes a larger contribution to self-initiated actions and the lateral premotor cortex mediates externally-cued action selection. Of course, few behaviours are either fully stimulus-driven or fully self-initiated and part of the task of cognitive psychology and cognitive neuroscience is to understand their interaction (see Pashler et al., 2001).

Other interpretations of the dissociation between task-switching and PM processes should be acknowledged. Firstly, as mentioned above, theories of executive function often distinguish between the control of routine and non-routine (novel) behaviours (e.g. Stuss & Alexander, 2000; Cooper, 2002). Arguably, task-switching and PM may be qualitatively different regarding this variable and this can explain the independent control of each. For instance, Pollmann (2004) claims that: *'task-switching...experiments are characterised by a clear rule-guided association between stimulus and response'* (p. 273). Conversely, PM

may be characterised as requiring relatively novel responses to the stimuli (although in real life it is a common task). To avoid this criticism, the PM responses were deliberately set to be more frequent than in other PM studies and a repeated measures design was employed. Furthermore, there is evidence that even routine tasks require executive control processes (e.g. Schwartz et al., 1991; see also Cooper, 2002).

As discussed, the ABAB task-switching paradigm and PM have been characterised as variations of task-switches along an internal/external continuum. This distinction is common in the literature; for instance, Brown & Marsden (1988) discuss Parkinson disease patients as an example of a group who show impairments in task-switching only when there are no external cues. However, a second possible reinterpretation of these findings is based on a view presented by Rogers et al., (1998). They discuss the difficulty of this conceptual distinction, arguing that internal and external cues cannot be separated from the continuum of 'cue strength': '*...any task cue presented in close temporal and spatial proximity to a stimulus will naturally have a greater impact on the subject's actual performance than the inevitably weaker task cues that might be held internally, say, in working memory*'. (Rogers et al., 1998, p. 817). No doubt there are differences in cue strength between internal and external cues. However, this perhaps just emphasises the need for internal control or the difficulty of cognitive control in initiating task-switches in the absence of external cues. Moreover, experiments using external cues do not control for cue strength. For instance, in the task-switching literature whether or not an addition cue (i.e. +) is weaker or stronger than a subtraction cue (i.e. -) is not discussed (although more recent task-switching paradigms include a cue-stimulus learning procedure, e.g. Logan & Bundesen, 2003). Separating cue strength from the internal/external continuum seems a difficult task to achieve empirically. For example, it seems rather challenging to make an internal cue stronger, if strength is defined by temporal and spatial proximity (and proximal to what exactly?). As such, cue strength may be more efficiently considered an element of the internal/external continuum, rather than separate from it.

A good example of this stems from the PM literature with research involving implementation intentions. Implementation intentions are effective in increasing the likelihood that participants will execute an intention. They are verbalised IF-THEN plans (if situation y arises, then I will initiate goal-directed behaviour z) which are thought to

mediate their effects by increasing the accessibility of the cue and strengthening the link between the cue and the response (Gollwitzer & Brandstatter, 1997; Sheeran & Orbell, 1999). As such, they are reducing the dependency on conscious, controlled processing to realise the intention and instead allow behaviour to be initiated by automatic processes triggered by the environmental context. This emphasises the potential clinical applications of dissociating between externally-cued and internally-generated behaviours. By building in a rich environmental structure into tasks and daily routines, patients with SAD or SRD (and dysexecutive syndrome more generally) may benefit in their everyday organisation skills (e.g. Levine et al., 2000).

### **6.5.2. Future Directions**

Several specific suggestions for future research have been presented throughout this Chapter, but it is perhaps important to summarise and extend a few of these ideas in this final section.

Firstly, neuropsychological studies with patients with frontal lobe damage are of crucial importance in the further testing of the endogenous/exogenous control dissociation. Testing patients with specific focal lesions on the tasks presented in experiments 1-4 would reveal possible neural dissociations in function along this continuum. Gilbert and colleagues have recently presented one such patient (with rostral PFC damage) with the test used in their neuroimaging study of SIT and SOT attention switching (see Gilbert et al., 2005). The patient was able to complete all tasks successfully except when it was necessary to inhibit environmental cues that were acting as distractors, suggesting some impairment in this ability to switch (Gilbert, 2006). Other clinical disorders may also be of relevance. For instance, post traumatic stress disorder entails the unwanted intrusions of internally-generated memories of a stressing event. Neural studies of this disorder suggest some involvement of the PFC and especially the medial and orbital PFC (Bremner, 1999; 2002). From the evidence discussed in this thesis, it seems possible that an impairment of executive processes involved in endogenous control could generate these symptoms. Burgess et al., (2005) also implicate the Gateway Hypothesis in schizophrenia because of the potential deficit in differentiating between one's thoughts and experiences (i.e. hallucinations). Also somewhat speculatively, there may be a link between obsessive-compulsive disorder and these different executive control processes. The perseveration these patients can exhibit may again be a manifestation of poor endogenous control.

Secondly, in terms of PM, there seem several fruitful avenues for research. Clearly, further empirical investigations of the hierarchy theory are necessary as described, including naturalistic studies with clocks. The impact of TB intentions on the performance of 'ongoing' workplace tasks seems necessary to be able to relate the findings of this thesis to everyday life. Similarly, understanding the effects of the length of the RI on the use of time estimation processes would also be informative for application to everyday life. An interdisciplinary approach with psychologists studying temporal cognition would therefore be productive. Researching other parameters that change the cognitive processing involved in TB PM is also of interest. For instance, perhaps the saliency of the time point at which to carry out the intention is a useful manipulation. If a more salient time point (perhaps 5.12pm instead of 5pm) becomes a stronger external cue and this increases the likelihood of remembering that intention, then this has direct application in everyday life.

Finally, tests that are more 'real-life' are coming to the forefront of cognitive neuroscience and neuropsychology (e.g. Channon et al., 2001; Burgess et al., submitted) because of their value as clinical tests, as well as the importance of 'cognitive ethology' (Kingstone et al., 2005). Future research could develop the AMT further to produce an increasingly more ecologically valid and useful test. For instance, instead of the PM slide task in which participants must remember to check the slides frequently, a task in which participants must just check something once or twice may be more realistic (see Manly et al., 2002, for example). Alternatively, healthy participants could even be taken 'shopping' as in the original MET. Another interesting way of investigating the relationship of ill-structured tests to real life outcomes might be to compare performance of populations of healthy participants, according to their position in an occupational setting (such as managers and senior-managers) on the AMT and other standard neuropsychological tests. There are also other ill-structured tests available, such as the Iowa 'gambling' test produced by Bechara and colleagues (2000), which may also show correlations with real life outcomes and are not yet well developed for the healthy population.

Patients tested on the original multitasking tests can break social rules when executing these tests (e.g. Alderman et al., 2003), as well as show general disorganisation. Thus, it is possible there is a link between multitasking performance and social cognition (see



Channon & Crawford, 1999; Burgess et al., 2000). Intuitively, social cognition is likely to make demands on internally-generated information (such as mentalising), and thus it may be valuable to include measures of social cognition in future research with the healthy population. Neuropsychological tests with these and other executive function tests may yield further evidence of dissociations between cognitive processes.

# References

- Adamczyk, P. D. & Bailey, B. P. (2004). If Not Now When? The Effects of Interruptions at Various Moments within Task Execution. In *Proceedings of Computer Human Interaction*. 271-278.
- Adamson, B. J. & Covic, T. (2004). Teaching Time and Organizational Management Skills to First Year Health Science Students: does training make a difference? *Journal of Further and Higher Education*, 28, 261-276.
- Alderman, N., Burgess, P. W., Knight, C., & Henman, C. (2003). Ecological validity of a simplified version of the multiple errands shopping test. *J Int.Neuropsychol.Soc*, 9, 31-44.
- Allport, A., Styles, E. A., & Hsieh, S. L. (1994). Shifting Intentional Set - Exploring the Dynamic Control of Tasks. *Attention and Performance Xv*, 15, 421-452.
- Allport, A. & Wylie, G. (2000). 'Task-switching', stimulus-response bindings, and negative priming. In S.Monsell & J. Driver (Eds.), *Attention and performance XVIII: Control of cognitive processes* (pp. 35-70). Cambridge, M.A.: MIT Press.
- Altmann, E. M. & Trafton, J. G. (2002). Memory for goals: an activation-based model. *Cognitive Science*, 26, 39-83.
- Anderson, J. R. (1983). *The Architecture of Cognition*. Harvard University Press.
- Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. (2004). An integrated theory of the mind. *Psychol.Rev.*, 111, 1036-1060.
- Anderson, S. W., Damasio, H., Jones, R. D., & Tranel, D. (1991). Wisconsin Card Sorting Test performance as a measure of frontal lobe damage. *J Clin.Exp.Neuropsychol.*, 13, 909-922.
- Anderson, S. W., Damasio, H., Tranel, D., & Damasio, A. R. (2000). Long-term sequelae of prefrontal cortex damage acquired in early childhood. *Dev.Neuropsychol.*, 18, 281-296.

- Anderson, V. (1998). Assessing Executive Functions in Children: Biological, Psychological, and Developmental Considerations. *Neuropsychological Rehabilitation*, 8, 319-349.
- Anderson, V., Levin, H. S., & Jacobs, R. (2002). Executive functions after frontal lobe injury: A developmental perspective. In D.T.Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 504-527). London: Oxford University Press.
- Arbuthnott, K. & Frank, J. (2000). Executive control in set switching: Residual switch cost and task-set inhibition. *Canadian Journal of Experimental Psychology-Revue Canadienne de Psychologie Experimentale*, 54, 33-41.
- Arrington, C. M. & Logan, G. D. (2004). The cost of a voluntary task switch. *Psychol Sci*, 15, 610-615.
- Arrington, C. M. & Logan, G. D. (2005). Voluntary task switching: chasing the elusive homunculus. *J Exp.Psychol Learn.Mem.Cogn*, 31, 683-702.
- Baddeley, A. & Della, S. S. (1996). Working memory and executive control. *Philos Trans R Soc Lond B Biol Sci*, 351, 1397-1403.
- Baddeley, A. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology*, 49, 5-28.
- Baddeley, A., Della Sala, S., Gray, C., Papagno, C., & Spinnler, H. (1997). Testing central executive functioning with a pencil-and-paper test. In P.M.Rabbitt (Ed.), *Methodology of Frontal and Executive Function* (pp. 61-80). Hove: Psychology Press.
- Banich, M. T., Milham, M. P., Atchley, R. A., Cohen, N. J., Webb, A., Wszalek, T. et al. (2000). Prefrontal regions play a predominant role in imposing an attentional 'set': evidence from fMRI. *Brain Res Cogn Brain Res*, 10, 1-9.
- Baron-Cohen, S., Ring, H., Moriarty, J., Schmitz, B., Costa, D., & Ell, P. (1994). Recognition of mental state terms. Clinical findings in children with autism and a functional neuroimaging study of normal adults. *Br.J Psychiatry*, 165, 640-649.

- Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*, 7.
- Bechara, A., Damasio, H., Tranel, D., & Anderson, S. W. (1998). Dissociation Of working memory from decision making within the human prefrontal cortex. *J Neurosci*, *18*, 428-437.
- Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cereb.Cortex*, *10*, 295-307.
- Bechara, A., Tranel, D., & Damasio, H. (2000). Characterization of the decision-making deficit of patients with ventromedial prefrontal cortex lesions. *Brain*, *123 (Pt 11)*, 2189-2202.
- Bench, C. J., Frith, C. D., Grasby, P. M., Friston, K. J., Paulesu, E., Frackowiak, R. S. et al. (1993). Investigations of the functional anatomy of attention using the Stroop test. *Neuropsychologia*, *31*, 907-922.
- Berger, A., Henik, A., & Rafal, R. (2005). Competition between endogenous and exogenous orientating of visual attention. *Journal of Experimental Psychology: General*, *134*, 207-234.
- Berman, K. F., Ostrem, J. L., Randolph, C., Gold, J., Goldberg, T. E., Coppola, R. et al. (1995). Physiological activation of a cortical network during performance of the Wisconsin Card Sorting Test: a positron emission tomography study. *Neuropsychologia*, *33*, 1027-1046.
- Berthoz, S., Artiges, E., Van De Moortele, P. F., Poline, J. B., Rouquette, S., Consoli, S. M. et al. (2002). Effect of impaired recognition and expression of emotions on frontocingulate cortices: an fMRI study of men with alexithymia. *Am.J Psychiatry*, *159*, 961-967.
- Bisiacchi, P. S., Sgaramella, T. M., & Farinello, C. (1998). Planning strategies and control mechanisms: Evidence from closed head injury and aging. *Brain and Cognition*, *37*, 113-116.

- Blair, R. J. (2004). The roles of orbital frontal cortex in the modulation of antisocial behavior. *Brain Cogn*, 55, 198-208.
- Block, R. A. & Zakay, D. (1997). Prospective and retrospective duration judgments: A meta-analytic review. *Psychonomic Bulletin & Review*, 4, 184-197.
- Brandimonte, M., Ferrante, D., Feresin, C., & Delbello, R. (2001). Dissociating prospective memory processes from vigilance processes. *Psicologica*, 22, 97-113.
- Brandimonte, M. A. & Passolunghi, M. C. (1994). The Effect of Cue-Familiarity, Cue-Distinctiveness, and Retention Interval on Prospective Remembering. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology*, 47, 565-587.
- Braver, T. S., Barch, D. M., & Cohen, J. D. (1999). Cognition and control in schizophrenia: a computational model of dopamine and prefrontal function. *Biol.Psychiatry*, 46, 312-328.
- Braver, T. S. & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neurosci Biobehav.Rev.*, 26, 809-817.
- Braver, T. S. & Bongiolatti, S. R. (2002). The role of frontopolar cortex in subgoal processing during working memory. *Neuroimage*, 15, 523-536.
- Bremner, J. D. (1999). Alterations in brain structure and function associated with post-traumatic stress disorder. *Semin Clin Neuropsychiatry*, 4, 249-255.
- Bremner, J. D. (2002). Neuroimaging studies in post-traumatic stress disorder. *Current Psychiatry Report*, 4, 254-263.
- Brown, R. G. & Marsden, C. D. (1988). An investigation of the phenomenon of "set" in Parkinson's disease. *Mov Disord.*, 3, 152-161.
- Bryan, J. & Luszcz, M. A. (2001). Adult age differences in self-ordered pointing task performance: contributions from working memory, executive function and speed of information processing. *J.Clin.Exp.Neuropsychol.*, 23, 608-619.
- Burgess, P. W. & Shallice, T. (1996). Response suppression, initiation and strategy use following frontal lobe lesions. *Neuropsychologia*, 34, 263-272.

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

Burgess, P. W. & 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: Psychology Press.

Burgess, P. W., Alderman, N., Evans, J., Emslie, H., & Wilson, B. A. (1998). The ecological validity of tests of executive function. *J Int.Neuropsychol.Soc*, 4, 547-558.

Burgess, P. W. & McNeil, J. E. (1999). Content-specific confabulation. *Cortex*, 35, 163-182.

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

Burgess, P. W. (2000). Strategy application disorder: the role of the frontal lobes in human multitasking. *Psychological Research*, 63, 279-288.

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* ( Cambridge, MA: The MIT Press.

Burgess, P. W., Quayle, A., & Frith, C. D. (2001). Brain regions involved in prospective memory as determined by positron emission tomography. *Neuropsychologia*, 39, 545-555.

Burgess, P. W. & Robertson, I. H. (2002). Principles of the Rehabilitation of Frontal Lobe Function. In D.T.Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 557-571). London: Oxford University Press.

Burgess, P. W., Scott, S. K., & Frith, C. D. (2003). The role of the rostral frontal cortex (area 10) in prospective memory: a lateral versus medial dissociation. *Neuropsychologia*, 41, 906-918.

Burgess, P. W. & Simons, J. S. (2005). Theories of frontal lobe executive function: Clinical applications. In P.W.Halligan & D. T. Wade (Eds.), *Effectiveness of Rehabilitation for Cognitive Deficits* (pp. 211-231). Oxford: Oxford University Press.

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). London: Psychology Press.

Burgess, P. W., Simons, J. S., Dumontheil, I., & Gilbert, S. J. (2005). The gateway hypothesis of rostral PFC function. In J.Duncan, L. H. Phillips, & P. McLeod (Eds.), *Measuring the Mind: Speed, Control, and Age* (pp. 217-248). Oxford: Oxford University Press.

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. The case for the development and use of "ecologically valid" measures of executive function in basic and applied cognitive neuroscience. *Journal of the International Neuropsychological Society*, (in press).

Burgess, P. W., Gilbert, S. J., Okuda, J., & Simons, J. S. (2006). Rostral prefrontal brain regions (area 10): A gateway between inner thought and the external world? In W.Prinz & N. Sebanz (Eds.), *Disorders of Volition*. ( Cambridge, M.A.: MIT Press.

Calabresi, R. & Cohen, J. (1968). Personality and time attitudes. *Journal of Abnormal Psychology*, 73, 431-439.

Carlesimo, G. A., Casadio, P., & Caltagirone, C. (2004). Prospective and retrospective components in the memory for actions to be performed in patients with severe closed-head injury. *Journal of the International Neuropsychological Society*, 10, 679-688.

Ceci, S. J. & Bronfenbrenner, U. (1985). Dont Forget to Take the Cupcakes Out of the Oven - Prospective Memory, Strategic Time-Monitoring, and Context. *Child Development*, 56, 152-164.

Chan, R. C. (2001). Dysexecutive symptoms among a non-clinical sample: A study with the use of the Dysexecutive Questionnaire. *Br.J Psychol*, 92 Part 3, 551-565.

- Channon, S. & Crawford, S. (1999). Problem-solving in real-life-type situations: the effects of anterior and posterior lesions on performance. *Neuropsychologia*, *37*, 757-770.
- Channon, S., Charman, T., Heap, J., Crawford, S., & Rios, P. (2001). Real-life-type problem-solving in Asperger's syndrome. *J Autism Dev. Disord.*, *31*, 461-469.
- Chen, Y. C., Thaler, D., Nixon, P. D., Stern, C. E., & Passingham, R. E. (1995). The Functions of the Medial Premotor Cortex .2. the Timing and Selection of Learned Movements. *Experimental Brain Research*, *102*, 461-473.
- Cherry, K. E. & LeCompte, D. C. (1999). Age and individual differences influence prospective memory. *Psychology and Aging*, *14*, 60-76.
- Cherry, K. E., Martin, R. C., Simmons-D'Gerolamo, S. S., Pinkston, J. B., Griffing, A., & Gouvier, W. D. (2001). Prospective remembering in younger and older adults: role of the prospective cue. *Memory*, *9*, 177-193.
- Christoff, K. & Gabrieli, J. D. E. (2000). The frontopolar cortex and human cognition: Evidence for a rostrocaudal hierarchical organization within the human prefrontal cortex. *Psychobiology*, *28*, 168-186.
- Christoff, K., Ream, J. M., Geddes, L. P., & Gabrieli, J. D. (2003). Evaluating self-generated information: anterior prefrontal contributions to human cognition. *Behav. Neurosci.*, *117*, 1161-1168.
- Cicogna, P., Nigro, G., Occhionero, M., & Esposito, M. J. (2005). Time-based prospective remembering: Interference and facilitation in a dual task. *European Journal of Cognitive Psychology*, *17*, 221-240.
- Cockburn, J. & Smith, P. T. (1991). The Relative Influence of Intelligence and Age on Everyday Memory. *Journals of Gerontology*, *46*, 31-36.
- Cockburn, J. (1995). Task interruption in prospective memory: a frontal lobe function? *Cortex*, *31*, 87-97.



- Cockburn, J. (1996). Failure of prospective memory after acquired brain damage: preliminary investigation and suggestions for future directions. *J Clin. Exp. Neuropsychol.*, *18*, 304-309.
- Cohen, A. L., Dixon, R. A., Lindsay, D. S., & Masson, M. E. (2003). The effect of perceptual distinctiveness on the prospective and retrospective components of prospective memory in young and old adults. *Can. J Exp. Psychol*, *57*, 274-289.
- Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: a parallel distributed processing account of the Stroop effect. *Psychol.Rev.*, *97*, 332.
- Cohen, J. D. & Servan-Schreiber, D. (1992). Context, cortex and dopamine: a connectionist approach to behavior and biology in schizophrenia. *Psychol.Rev.*, *99*, 45.
- Cohen, J. D. (2000). The role of prefrontal cortex, anterior cingulate and locus coeruleus in cognitive control and the regulation of behavior. *Journal of Cognitive Neuroscience*, *13*.
- Collette, F., Van Der, L. M., Laureys, S., Delfiore, G., Degueldre, C., Luxen, A. et al. (2005). Exploring the unity and diversity of the neural substrates of executive functioning. *Hum. Brain Mapp.*, *25*, 409-423.
- Cook, G. I., Marsh, R. L., & Hicks, J. L. (2005). Associating a time-based prospective memory task with an expected context can improve or impair intention completion. *Applied Cognitive Psychology*, *19*, 345-360.
- Cooper, R. & Shallice, T. (2000). Contention scheduling and the control of routine activities. *Cognitive Neuropsychology*, *17*, 297-338.
- Cooper, R. (2002). Order and disorder in everyday action: the roles of contention scheduling and supervisory attention. *Neurocase*, *8*, 61-79.
- Craik, F. I. M. (1986). A Functional Account of Age Differences in Memory. In F.Klix & H. Hagendorf (Eds.), *Human Memory and Cognitive Capabilities, Mechanisms and Performances* (pp. 409-422). Amsterdam: Elsevier.

- Craik, F. I. M. & McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 13, 474-479.
- Craik, F. I. M. & Kerr, S. A. (1996). Prospective memory, aging, and lapses of intention. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective Memory: Theory and Applications* (pp. 227-237). New Jersey: Erlbaum.
- Craik, F. I. M. & Grady, C. L. (2002). Aging, Memory and Frontal Lobe Functioning. In D. T. Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 528-540). Oxford: Oxford University Press.
- Crepeau, 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.
- Crepeau, F., Scherzer, B. P., Belleville, S., & Desmarais, G. (1997). A qualitative analysis of central executive disorders in a real-life work situation. *Neuropsychological Rehabilitation*, 7, 147-165.
- Czerwinski, M., Horvitz, M., & Wilhite, S. (2004). A diary study of task switching and interruptions. In *Conference on Human Factors in Computing Systems* (pp. 175-182).
- D'Ydewalle & Brunfaut, E. (1996). Are older subjects necessarily worse in prospective memory tasks? In M. Georgas, E. Manthouli, E. Besevegis, & A. Kokkevi (Eds.), *Contemporary psychology in Europe: Theory, research and applications* (pp. 161-172). Gottingen, Germany: Hogrefe & Huber.
- D'Ydewalle, G., Luwel, K., & Brunfaut, E. (1999). The importance of on-going concurrent activities as a function of age in time- and event-based prospective memory. *European Journal of Cognitive Psychology*, 11, 219-237.
- D'Ydewalle, G., Bouckaert, D., & Brunfaut, E. (2001). Age-related differences and complexity of ongoing activities in time- and event-based prospective memory. *Am. J Psychol*, 114, 411-423.

- Dagher, A., Owen, A. M., Boecker, H., & Brooks, D. J. (1999). Mapping the network for planning: a correlational PET activation study with the Tower of London task. *Brain*, *122*, 1973-1987.
- Damasio, A. R., Tranel, D., & Damasio, H. (1990). Individuals with sociopathic behavior caused by frontal damage fail to respond autonomically to social stimuli. *Behav Brain Res*, *41*, 81-94.
- Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philos Trans R Soc Lond B Biol Sci*, *351*, 1413-1420.
- Daum, I., Schugens, M. M., Spieker, S., Poser, U., Schonle, P. W., & Birbaumer, N. (1995). Memory and Skill Acquisition in Parkinsons-Disease and Frontal-Lobe Dysfunction. *Cortex*, *31*, 413-432.
- De Jong, R. (2000). An intention-activation account of residual switch costs. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 357-376). Cambridge, M.A.: MIT Press.
- De Jong, R. & Berendsen, E. C. R. (1999). Goal neglect and inhibitory limitations: Dissociable causes of interference effects in conflict situations. *Acta Psychologica*, *101*, 379-394.
- Dias, R., Robbins, T. W., & Roberts, A. C. (1996). Dissociation in prefrontal cortex of affective and attentional shifts. *Nature*, *380*, 69.
- Dieber M.P., Passingham R.E., Colebatch J.G., Friston K.J., Nixon P.D., & Frackowiak R.S. (1991). Cortical areas and the selection of movement: a study with positron emission tomography. *Experimental Brain Research*, *84*, 393-402.
- Dieber, M. P., Honda, M., Ibanez, V., Sadato, N., & Hallett, M. (1999). Mesial motor areas in self-initiated versus externally triggered movements examined with fMRI: Effect of movement type and rate. *Journal of Neurophysiology*, *81*, 3065-3077.
- Diener, E., Emmons, R. A., Larsen, R. J., & Griffin, S. (1985). The Satisfaction With Life Scale. *J.Pers.Assess.*, *49*, 71-75.

- Diener, E., Oishi, S., & Lucas, R. E. (2003). Personality, culture, and subjective well-being: emotional and cognitive evaluations of life. *Annu.Rev.Psychol.*, *54*, 403-425.
- Dobbs, A. R. & Rule, B. G. (1987). Prospective memory and self-reports of memory abilities in older adults. *Canadian Journal of Psychology*, *41*, 209-221.
- Dobbs, A. R. & Reeves, M. B. (1996). Prospective memory: More than memory. In M.A.Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective Memory: Theory and Applications* (pp. 199-225). Hillsdale, N.J.: Erlbaum.
- Dove, A., Pollmann, S., Schubert, T., Wiggins, C. J., & von Cramon, D. Y. (2000). Prefrontal cortex activation in task switching: an event-related fMRI study. *Cognitive Brain Research*, *9*, 103-109.
- Dreher, J. C., Koechlin, E., Ali, S. O., & Grafman, J. (2002). The roles of timing and task order during task switching. *Neuroimage*, *17*, 95-109.
- Dreisbach, G., Haider, H., & Kluwe, R. H. (2002). Preparatory processes in the task-switching paradigm: Evidence from the use of probability cues. *Journal of Experimental Psychology-Learning Memory and Cognition*, *28*, 468-483.
- Duncan, J. (1986). Disorganization of behaviour after frontal lobe damage. *Cogn.Neuropsychol.*, *3*, 271.
- Duncan, J., Burgess, P., & Emslie, H. (1995). Fluid intelligence after frontal lobe lesions. *Neuropsychologia*, *33*, 261-268.
- Duncan, J., Emslie, H., Williams, P., Johnson, R., & Freer, C. (1996). Intelligence and the frontal lobe: the organization of goal-directed behavior. *Cogn.Psychol.*, *30*, 257.
- Duncan, J., Johnson, R., Swales, M., & Freer, C. (1997). Frontal lobe deficits after head injury: Unity and diversity of function. *Cognitive Neuropsychology*, *14*, 713-741.
- Duncan, J. & Owen, A. M. (2000). Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends Neurosci.*

- Duncan, J., Seltz, R. J., Kolodny, J., Bor, D., Herzog, H., Ahmed, A. et al. (2000). A neural basis for general intelligence. *Am.J Ophthalmol.*, 130, 687.
- Duncan, J. (2001). An adaptive coding model of neural function in prefrontal cortex. *Nat Rev.Neurosci*, 2, 820-829.
- Duncan, J. (2005). Frontal lobe function and general intelligence: why it matters. *Cortex*, 41, 215-217.
- Edwards, M. B. & Gronlund, S. D. (1998). Task interruption and its effects on memory. *Memory.*, 6, 665-687.
- Egly, R., Rafal, R. D., & Henik, A. (1992). Reflexive and Voluntary Orienting in Detection and Discrimination Tasks. *Bulletin of the Psychonomic Society*, 30, 469.
- Einstein, G. O. & McDaniel, M. A. (1990). Normal Aging and Prospective Memory. *Journal of Experimental Psychology-Learning Memory and Cognition*, 16, 717-726.
- Einstein, G. O., Holland, L. J., McDaniel, M. A., & Guynn, M. J. (1992). Age-Related Deficits in Prospective Memory - the Influence of Task Complexity. *Psychology and Aging*, 7, 471-478.
- Einstein, G. O., Richardson, S. L., Guynn, M. J., Cunfer, A. R., & McDaniel, M. A. (1995). Aging and Prospective Memory - Examining the Influences of Self-Initiated Retrieval-Processes. *Journal of Experimental Psychology-Learning Memory and Cognition*, 21, 996-1007.
- Einstein, G. O. & McDaniel, M. A. (1996). Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings. In *Prospective Memory: Theory and Applications* (pp. 115-141). Hillsdale, N.J.: Erlbaum.
- Einstein, G. O., Smith, R. E., McDaniel, M. A., & Shaw, P. (1997). Aging and prospective memory: The influence of increased task demands at encoding and retrieval. *Psychology and Aging*, 12, 479-488.

Einstein, G. O., McDaniel, M. A., Smith, R. E., & Shaw, P. (1998). Habitual prospective memory and aging: Remembering intentions and forgetting actions. *Psychological Science, 9*, 284-288.

Einstein, G. O., McDaniel, M. A., Manzi, M., Cochran, B., & Baker, M. (2000). Prospective memory and aging: Forgetting intentions over short delays. *Psychology and Aging, 15*, 671-683.

Einstein, G. O., McDaniel, M. A., Williford, C. L., Pagan, J. L., & Dismukes, R. K. (2003). Forgetting of intentions in demanding situations is rapid. *Journal of Experimental Psychology-Applied, 9*, 147-162.

Einstein, G. O. & McDaniel, M. A. (2005). Evidence for spontaneous retrieval processes in prospective memory. In (pp. 19).

Ellis, J. & Milne, A. (1996). Retrieval cue specificity and the realization of delayed intentions. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology, 49*, 862-887.

Ellis, J., Kvavilashvili, L., & Milne, A. (1999). Experimental tests of prospective remembering: the influence of cue-event frequency on performance. *Br.J Psychol, 90 (Pt 1)*, 9-23.

Ellis, J. & Kvavilashvili, L. (2000). Prospective memory in 2000: Past, present, and future directions. *Applied Cognitive Psychology, 14*, S1-S9.

Emerson, M. J. & Miyake, A. (2003). The role of inner speech in task switching: A dual-task investigation. *Journal of Memory and Language, 48*, 148-168.

Eslinger, P. J. & Damasio, A. R. (1985). Severe disturbance of higher cognition after bilateral frontal lobe ablation: patient EVR. *Neurology, 35*, 1731-1741.

Eslinger, P. J., Grattan, L. M., Damasio, H., & Damasio, A. R. (1992). Developmental consequences of childhood frontal lobe damage. *Arch.Neurol, 49*, 764-769.

Eslinger, P. J. (2002). The anatomic basis of utilisation behaviour: A shift from frontal-parietal to intra-frontal mechanisms. *Cortex, 38*, 379-387.

Fagot, C. (1994). *Chronometric investigation of task switching*. University of California, San Diego..

Faw, B. (2003). Pre-frontal executive committee for perception, working memory, attention, long-term memory, motor control, and thinking: a tutorial review. *Conscious.Cogn*, 12, 83-139.

Fletcher, P. C., Shallice, T., Frith, C. D., Frackowiak, R. S., & Dolan, R. J. (1998). The functional roles of prefrontal cortex in episodic memory. II. Retrieval. *Brain*, 121 ( Pt 7), 1249-1256.

Fletcher, P. C. & Henson, R. N. A. (2001). Frontal lobes and human memory - Insights from functional neuroimaging. *Brain*, 124, 849-881.

Forstmann, B. U., Brass, M., Koch, I., & von Cramon, D. Y. (2005). Internally generated and directly cued task sets: an investigation with fMRI. *Neuropsychologia*, 43, 943-952.

Fortin, S., Godbout, L., & Braun, C. M. (2002). Strategic sequence planning and prospective memory impairments in frontally lesioned head trauma patients performing activities of daily living. *Brain Cogn*, 48, 361-365.

Francis-Smythe, J. A. & Robertson, I. T. (1999). On the relationship between time management and time estimation. *British Journal of Psychology*, 90, 333-347.

Freedman, D. J., Riesenhuber, M., Poggio, T., & Miller, E. K. (2001). Categorical representation of visual stimuli in the primate prefrontal cortex. *Science*, 291, 312-316.

Freedman, M., Black, S., Ebert, P., & Binns, M. (1998). Orbitofrontal function, object alternation and perseveration. *Cereb.Cortex*, 8, 18.

Friston, K. J., Price, C. J., Fletcher, P., Moore, C., Frackowiak, R. S., & Dolan, R. J. (1996). The trouble with cognitive subtraction. *Neuroimage*, 4, 97-104.

Frith, C. D. & Frith, U. (1999). Interacting minds a biological basis. *Science*, 286, 1692.

Fuster, J. M. (1989). *The Prefrontal Cortex*. (vols. 2) New York: Raven.

Fuster, J. M. (1997). *The prefrontal cortex: Anatomy, physiology, and neuropsychology of the frontal lobe*. New York: Lippincott-Raven.

Fuster, J. M. (2002). Frontal lobe and cognitive development. *Journal of Neurocytology*, *31*, 373-385.

Gerloff, C., Richard, J., Hadley, J., Schulman, A. E., Honda, M., & Hallett, M. (1998). Functional coupling and regional activation of human cortical motor areas during simple, internally paced and externally paced finger movements. *Brain*, *121* ( Pt 8), 1513-1531.

Gershberg, F. B. & Shimamura, A. P. (1995). Impaired use of organizational strategies in free recall following frontal lobe damage. *Neuropsychologia*, *33*, 1305-1333.

Gilbert, S. J. & Shallice, T. (2002). Task switching: A PDP model. *Cognitive Psychology*, *44*, 297-337.

Gilbert, S. J., Frith, C. D., & Burgess, P. W. (2005). Involvement of rostral prefrontal cortex in selection between stimulus-oriented and stimulus-independent thought. *Eur.J Neurosci*, *21*, 1423-1431.

Gilbert, S. J., Spengler, S., Simons, J. S., Steele, J. D., Lawrie, S. M., Lawrie, S. M. et al. Functional specialization within rostral prefrontal cortex (area 10): A meta-analysis. *Journal of Cognitive Neuroscience.*, (in press).

Gilbert, S. J. (2006). Neuroimaging investigations of the gateway hypothesis. In *Proceedings of the Experimental Psychology Society London Meeting*.

Gillie, T. & Broadbent, D. (1989). What Makes Interruptions Disruptive - A Study of Length, Similarity, and Complexity. *Psychological Research-Psychologische Forschung*, *50*, 243-250.

Goel, V., Grafman, J., Tajik, J., Gana, S., & Danto, D. (1997). A study of the performance of patients with frontal lobe lesions in a financial planning task. *Brain*, *120* ( Pt 10), 1805-1822.

Goel, V. & Grafman, J. (2000). Role of the right prefrontal cortex in ill-structured planning. *Cogn.Neuropsychol.*, *17*, 415-436.



- Goldberg, E. (2001). *The Executive Brain: Frontal Lobes and the Civilized Mind*. New York: Oxford University Press.
- Goldman-Rakic, P. S. (1987). Handbook of Physiology, Section 1. Higher Functions of the Brain.
- Goldman, R. S., Axelrod, B. N., & Tompkins, L. M. (1992). Effect of Instructional Cues on Schizophrenic-Patients Performance on the Wisconsin Card Sorting Test. *American Journal of Psychiatry*, *149*, 1718-1722.
- Goldstein, L. H., Bernard, S., Fenwick, P. B., Burgess, P. W., & McNeil, J. (1993). Unilateral frontal lobectomy can produce strategy application disorder. *Journal of Neurology, Neurosurgery, and Psychiatry*, *56*, 274-276.
- Gollwitzer, P. M. & Brandstatter, V. (1997). Implementation intentions and effective goal pursuit. *Journal of Personality and Social Psychology*, *73*, 186-199.
- Gollwitzer, P. M. & Schaal, B. (1998). Metacognition in Action: The Importance of Implementation Intentions. *Personality and Social Psychology Review*, *2*, 124-136.
- Gonzalez, V. M. & Mark, G. (2004). "Constant, constant multi-tasking craziness": Managing multiple working spheres. In *Conference on Human Factors in Computer Systems*.
- Goschke, T. & Kuhl, J. (1993). Representation of Intentions - Persisting Activation in Memory. *Journal of Experimental Psychology-Learning Memory and Cognition*, *19*, 1211-1226.
- Gotler, A., Meiran, N., & Tzelgov, J. (2003). Nonintentional task set activation: evidence from implicit task sequence learning. *Psychon.Bull.Rev.*, *10*, 890-896.
- Graf, P. & Uttl, B. (2001). Prospective memory: a new focus for research. *Conscious.Cogn*, *10*, 437-450.
- Grafman, J., Schwab, K., Warden, D., Pridgen, A., Brown, H. R., & Salazar, A. M. (1996). Frontal lobe injuries, violence, and aggression: a report of the Vietnam Head Injury Study. *Neurology*, *46*, 1231-1238.

- Grafman, J. (2002). The structured event complex and the human prefrontal cortex. In D.T.Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 292-310). New York: Oxford University Press.
- Grant, D. A. & Berg, E. A. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card sorting problem. *Journal of Experimental Psychology*, *38*, 404-411.
- Gray, J. R., Chabris, C. F., & Braver, T. S. (2003). Neural mechanisms of general fluid intelligence. *Nat Neurosci*, *6*, 316-322.
- Groot, Y. C., Wilson, B. A., Evans, J., & Watson, P. (2002). Prospective memory functioning in people with and without brain injury. *J Int.Neuropsychol.Soc*, *8*, 645-654.
- Gusnard, D. A., Akbudak, E., Shulman, G. L., & Raichle, M. E. (2001). Medial prefrontal cortex and self-referential mental activity: Relation to a default mode of brain function. *Proceedings of the National Academy of Sciences of the United States of America*, *98*, 4259-4264.
- Guynn, M. J., McDaniel, M. A., & Einstein, G. O. (1998). Prospective memory: When reminders fail. *Memory & Cognition*, *26*, 287-298.
- Guynn, M. J. (2001). Remembering to perform actions: A different type of memory? In M.D.Zimmer, R. L. Cohen, M. D. Guynn, J. Engelkamp, R. Kormi-Nouri, & M. A. Foley (Eds.), *Memory for action: A distinct form of episodic memory?* (pp. 25-48). New York: Oxford University Press.
- Guynn, M. J. (2003). A two-process model of strategic monitoring in event-based prospective memory: Activation/retrieval mode and checking. *International Journal of Psychology*, *38*, 245-256.
- Hannon, R., Adams, P., Harrington, S., FriesDias, C., & Gipson, M. T. (1995). Effects of brain injury and age on prospective memory self-rating and performance. *Rehabilitation Psychology*, *40*, 289-298.

- Harlow J.M. (1868). Recovery after severe injury to the head. *Pub Mass Med Soc*, 2, 327-346.
- Harris, J. E. & Wilkins, A. W. (1982). Remembering to do things: A theoretical framework and an illustrative experiment. *Human Learning*, 1, 123-136.
- Heaton, R. K., Chelune G.J., Talley J.L., Kay G.G., & Curtiss G (1993). *Wisconsin Card Sorting Test Manual*. Odessa, Florida: Psychological Assessment Resources.
- Henry, J. D., MacLeod, M. S., Phillips, L. H., & Crawford, J. R. (2004). A meta-analytic review of prospective memory and aging. *Psychol Aging*, 19, 27-39.
- Henson, R. (2005). What can functional neuroimaging tell the experimental psychologist? *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology*, 58, 193-233.
- Hicks, J. L., Marsh, R. L., & Russell, E. J. (2000). The properties of retention intervals and their affect on retaining prospective memories. *J Exp. Psychol Learn. Mem. Cogn*, 26, 1160-1169.
- Hirst, W. & Volpe, B. T. (1988). Memory strategies with brain damage. *Brain Cogn*, 8, 379-408.
- Hsieh, S. & Liu, L. C. (2005). The nature of switch cost: task set configuration or carry-over effect? *Brain Res Cogn Brain Res*, 22, 165-175.
- Hudson, J. M., Christensen, J., Kellogg, W. A., & Erikson, T. (2002). "I'd Be Overwhelmed, But It's Just One More Thing to Do:" Availability and Interruption in Research Management. In *Conference on Human Factors in Computer Systems* (pp. 97-104).
- Humphreys, G. W. & Price, C. J. (2001). Cognitive neuropsychology and functional brain imaging: implications for functional and anatomical models of cognition. *Acta Psychol (Amst)*, 107, 119-153.
- Hunt, E. (1978). Mechanics of verbal ability. *Psychological Review*, 85, 109-134.

Huppert, F. A., Johnson, T., & Nickson, J. (2000). High prevalence of prospective memory impairment in the elderly and in early-stage dementia: Findings from a population-based study. *Applied Cognitive Psychology, 14*, S63-S81.

Iqbal, S. T., Adamczyk, P. D., Zheng, A. S., & Bailey, B. P. (2005). Towards an Index of Opportunity: Understanding Changes in Mental Workload During Task Execution. In (pp. 311-320).

Jersild, A. (1927). Mental set and shift. *Archives of Psychology, 89*.

Johnson, S. C., Baxter, L. C., Wilder, L. S., Pipe, J. G., Heiserman, J. E., & Prigatano, G. P. (2002). Neural correlates of self-reflection. *Brain, 125*, 1808-1814.

Joseph, R. (1999). Frontal lobe psychopathology: mania, depression, confabulation, catatonia, perseveration, obsessive compulsions, and schizophrenia. *Psychiatry, 62*, 138-172.

Kane, M. J. & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: an individual-differences perspective. *Psychon.Bull.Rev., 9*, 637-671.

Kimberg, D. Y., Aguirre, G. K., & D'Esposito, M. (2000). Modulation of task-related neural activity in task-switching: an fMRI study. *Brain Res.Cogn.Brain Res., 10*, 189-196.

Kingstone, A., Smilek, D., Birmingham, E., Cameron, D., & Bischof, W. F. (2005). Cognitive ethology: giving real life to attention research. In J.Duncan, L. H. Phillips, & P. McLeod (Eds.), *Measuring the Mind: Speed, Control and Age* (pp. 341-357). Oxford: Oxford University Press.

Kinsella, G., Murtagh, D., Landry, A., Homfray, K., Hammond, M., O'Beirne, L. et al. (1996). Everyday memory following traumatic brain injury. *Brain Inj., 10*, 499-507.

Kliegel, M., McDaniel, M. A., & Einstein, G. O. (2000). Plan formation, retention, and execution in prospective memory: A new approach and age-related effects. *Memory & Cognition, 28*, 1041-1049.

- Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2001). Varying the importance of a prospective memory task: differential effects across time- and event-based prospective memory. *Memory, 9*, 1-11.
- Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2002). Complex prospective memory and executive control of working memory: A process model. *Psychologische Beitrage, 44*, 303-318.
- Kliegel, M. & Martin, M. (2003). Prospective memory research: Why is it relevant? *International Journal of Psychology, 38*, 193-194.
- Kliegel, M., Martin, M., & Moor, C. (2003). Prospective memory and ageing: Is task importance relevant? *International Journal of Psychology, 38*, 207-214.
- Kliegel, M., Eschen, A., & Thone-Otto, A. I. (2004). Planning and realization of complex intentions in traumatic brain injury and normal aging. *Brain Cogn, 56*, 43-54.
- Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2004). Importance effects on performance in event-based prospective memory tasks. *Memory, 12*, 553-561.
- Kline, P. (1991). *Intelligence: A Psychometric View*. London: Routledge.
- Knight, C., Alderman, N., & Burgess, P. W. (2002). Development of a simplified version of the multiple errands test for use in hospital settings. *Neuropsychological Rehabilitation, 12*, 231-255.
- Koch, I. (2001). Automatic and intentional activation of task sets. *Journal of Experimental Psychology-Learning Memory and Cognition, 27*, 1474-1486.
- Koch, I. (2003). The role of external cues for endogenous advance reconfiguration in task switching. *Psychon.Bull.Rev., 10*, 488-492.
- Koechlin, E., Basso, G., Pietrini, P., Panzer, S., & Grafman, J. (1999). The role of the anterior prefrontal cortex in human cognition. *Nature, 399*, 148-151.

- Koechlin, E., Corrado, G., Pietrini, P., & Grafman, J. (2000). Dissociating the role of the medial and lateral anterior prefrontal cortex in human planning. *Proceedings of the National Academy of Sciences*, 97, 7651-7656.
- Kopp, U. A. & Thone-Otto, A. I. (2003). Disentangling executive functions and memory processes in event-based prospective remembering after brain damage: A neuropsychological study. *International Journal of Psychology*, 38, 229-235.
- Kray, J. & Lindenberger, U. (2000). Adult age differences in task switching. *Psychol Aging*, 15, 126-147.
- Kushleyeva, Y., Salvucci, D. D., & Lee, F. J. (2005). Deciding when to switch tasks in time-critical multitasking. *Cognitive Systems Research*, 6, 41-49.
- Kvavilashvili, L. (1987). Remembering intention as a distinct form of memory. *British Journal of Psychology*, 78, 507-518.
- Kvavilashvili, L. (1992). Remembering Intentions - A Critical-Review of Existing Experimental Paradigms. *Applied Cognitive Psychology*, 6, 507-524.
- Kvavilashvili, L. & Ellis, J. (1996). Varieties of intention: Some distinctions and classifications. In M.Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective Memory: Theory and Applications* (pp. 23-51). Hillsdale, N.J.: Erlbaum.
- Kvavilashvili, L. (1998). Remembering intentions: Testing a new method of investigation. *Applied Cognitive Psychology*, 12, 533-554.
- Kvavilashvili, L. (2005). Automatic or controlled? Rehearsal and retrieval processes in everyday time- and event-based prospective memory tasks . In (pp. 43).
- Lakein, A. (1973). *How to get control of your time and your life*. New York: New American Library.
- Lauwereyns, J. (1998). Exogenous/endogenous control of space-based/object-based attention: Four types of visual selection? *European Journal of Cognitive Psychology*, 10, 41-74.

- 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 Psychol (Amst)*, *116*, 285-307.
- Lee, A. C., Robbins, T. W., & Owen, A. M. (2000). Episodic memory meets working memory in the frontal lobe: functional neuroimaging studies of encoding and retrieval. *Crit Rev.Neurobiol.*, *14*, 165-197.
- Lepage, M., Ghaffar, O., Nyberg, L., & Tulving, E. (2000). Prefrontal cortex and episodic memory retrieval mode. *Proceedings of the National Academy of Sciences of the United States of America*, *97*, 506-511.
- Levin, H. S., Culhane, K. A., Hartmann, J., Evankovich, K., Mattson, A. J., Harward, H. et al. (1991). Developmental-Changes in Performance on Tests of Purported Frontal-Lobe Functioning. *Developmental Neuropsychology*, *7*, 377-395.
- Levine, B., Stuss, D. T., Milberg, W. P., Alexander, M. P., Schwartz, M., & Macdonald, R. (1998). The effects of focal and diffuse brain damage on strategy application: evidence from focal lesions, traumatic brain injury and normal aging. *J.Int.Neuropsychol.Soc*, *4*, 247-264.
- Levine, B., Freedman, M., Dawson, D., Black, S. E., & Stuss, D. T. (1999). Ventral frontal contribution to self-regulation: convergence of episodic memory and inhibition. *Neurocase*, *5*, 263.
- 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.
- Levine, B., Robertson, I. H., Clare, L., Carter, G., Hong, J., Wilson, B. A. et al. (2000). Rehabilitation of executive functioning: An experimental-clinical validation of Goal Management Training. *Journal of the International Neuropsychological Society*, *6*, 299-312.

- Levine, B., Katz, D. I., Dade, L., & Black, S. E. (2002). Novel Approaches to the Assessment of Frontal Damage and Executive Deficits in Traumatic Brain Injury. In *Principles of Frontal Lobe Function* (pp. 448-465). London: Oxford University Press.
- Levy, R. L. (1977). Relationship of an overt commitment to task compliance in behavior therapy. *Journal of Behavior Therapy and Experimental Psychiatry*, 8, 25-29.
- Levy, R. L., Yamashita, D., & Pow, G. (1979). The relationship of an overt commitment to the frequency and speed of compliance with symptom reporting. *Medical Care*, 17, 281-284.
- Levy, R. L. & Clark, H. (1980). The use of an overt commitment to enhance compliance: a cautionary note. *Journal of Behavior Therapy and Experimental Psychiatry*, 11, 105-107.
- Levy, R. L. & Goldman-Rakic, P. S. (2000). Segregation of working memory functions within the dorsolateral prefrontal cortex. *Experimental Brain Research*, 133, 23-32.
- Lewis, P. A. & Miall, R. C. (2003). Distinct systems for automatic and cognitively controlled time measurement: evidence from neuroimaging. *Current Opinion in Neurobiology*, 13, 250-255.
- Lezak, M. (1995). *Neuropsychological Assessment* . (3rd ed.) New York: Oxford University Press.
- Lhermitte, F. (1983). "Utilization behaviour" and its relation to lesions of the frontal lobes. *Brain*, 106, 237.
- Loftus, E. (1971). Memory for intentions: The effect of presence of a cue and interpolated activity. *Psychonomic Science*, 23, 315-316.
- Logan, G. D. (1985). Executive control of thought and action. *Acta Psychologica*, 60, 193-210.
- Logan, G. D. & Bundesen, C. (2003). Clever homunculus: is there an endogenous act of control in the explicit task-cuing procedure? *J Exp. Psychol Hum. Percept. Perform.*, 29, 575-599.



- Logie, R., Maylor, E., la Sala, S., & Smith, G. (2004). Working memory in event- and time-based prospective memory tasks: Effects of secondary demand and age. *European Journal of Cognitive Psychology, 16*, 441-456.
- Lorist, M. M., Klein, M., Nieuwenhuis, S., de, J. R., Mulder, G., & Meijman, T. F. (2000). Mental fatigue and task control: planning and preparation. *Psychophysiology, 37*, 614-625.
- Macan, T. H., Shahani, C., Dipboye, R. L., & Phillips, A. P. (1990). College-Students Time Management - Correlations with Academic-Performance and Stress. *Journal of Educational Psychology, 82*, 760-768.
- MacDonald, A. W., III, Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288*, 1835-1838.
- Macleod C.M. (1991). Half a century of research on the Stroop effect: an interactive review. *Psychological Bulletin, 109*, 163-193.
- Mandler, G. (1980). Recognizing: The judgment of previous occurrence. *Psychological Review, 87*, 252-271.
- Manly, T., Hawkins, K., Evans, J., Woldt, K., & Robertson, I. H. (2002). Rehabilitation of executive function: facilitation of effective goal management on complex tasks using periodic auditory alerts. *Neuropsychologia, 40*, 271-281.
- Marenco, S., Coppola, R., Daniel, D. G., Zigun, J. R., & Weinberger, D. R. (1993). Regional cerebral blood flow during the Wisconsin Card Sorting Test in normal subjects studied by xenon-133 dynamic SPECT: comparison of absolute values, percent distribution values, and covariance analysis. *Psychiatry Res, 50*, 177-192.
- Marsh, R. L., Hicks, J. L., & Landau, J. D. (1998). An investigation of everyday prospective memory. *Memory & Cognition, 26*, 633-643.
- Marsh, R. L. & Hicks, J. L. (1998). Event-based prospective memory and executive control of working memory. *Journal of Experimental Psychology-Learning Memory and Cognition, 24*, 336-349.

Marsh, R. L., Hicks, J. L., & Bink, M. L. (1998). Activation of completed, uncompleted, and partially completed intentions. *Journal of Experimental Psychology-Learning Memory and Cognition*, 24, 350-361.

Marsh, R. L., Hicks, J. L., & Hancock, T. W. (2000). On the interaction of ongoing cognitive activity and the nature of an event-based intention. *Applied Cognitive Psychology*, 14, S29-S41.

Marsh, R. L., Hicks, J. L., & Watson, V. (2002). The dynamics of intention retrieval and coordination of action in event-based prospective memory. *Journal of Experimental Psychology-Learning Memory and Cognition*, 28, 652-659.

Marsh, R. L., Hicks, J. L., Cook, G. I., Hansen, J. S., & Pallos, A. L. (2003). Interference to ongoing activities covaries with the characteristics of an event-based intention. *Journal of Experimental Psychology-Learning Memory and Cognition*, 29, 861-870.

Marsh, R. L., Hicks, J. L., & Cook, G. I. (2005). On the relationship between effort toward an ongoing task and cue detection in event-based prospective memory. *J Exp. Psychol Learn. Mem. Cogn*, 31, 68-75.

Martin, M. (1986). Aging and patterns of change in everyday memory and cognition. *Human Learning*, 5, 63-74.

Martin, M. & Schumann-Hengsteler, R. (2001). How task demands influence time-based prospective memory performance in young and older adults. *International Journal of Behavioral Development*, 25, 386-391.

Martin, M., Kliegel, M., & McDaniel, M. A. (2003). The involvement of executive functions in prospective memory performance of adults. *International Journal of Psychology*, 38, 195-206.

Mathias, J. L. & Mansfield, K. M. (2005). Prospective and declarative memory problems following moderate and severe traumatic brain injury. *Brain Inj.*, 19, 271-282.

- Mattioli, F., Grassi, F., Perani, D., Cappa, S. F., Miozzo, A., & Fazio, F. (1996). Persistent post-traumatic retrograde amnesia: a neuropsychological and (18F)FDG PET study. *Cortex*, 32, 121-129.
- Maylor, E. A. (1990). Age and Prospective Memory. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology*, 42, 471-493.
- Maylor, E. A. (1996). Age-related impairment in an event-based prospective-memory task. *Psychol.Aging*, 11, 74-78.
- Maylor, E. A., Smith, G., Della, S. S., & Logie, R. H. (2002). Prospective and retrospective memory in normal aging and dementia: an experimental study. *Mem.Cognit.*, 30, 871-884.
- Mayr, U. & Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology-Learning Memory and Cognition*, 26, 1124-1140.
- Mayr, U. & Keele, S. (2000). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General*, 129, 4-26.
- Mayr, U. (2002). Inhibition of action rules. *Psychon.Bull.Rev.*, 9, 93-99.
- McDaniel, M. A. & Einstein, G. O. (1993). The importance of cue familiarity and cue distinctiveness in prospective memory. *Memory*, 1, 23-41.
- McDaniel, M. A., Robinson-Riegler, B., & Einstein, G. O. (1998). Prospective remembering: Perceptually driven or conceptually driven processes? *Memory & Cognition*, 26, 121-134.
- McDaniel, M. A., Glisky, E. L., Rubin, S. R., Guynn, M. J., & Routhieaux, B. C. (1999). Prospective memory: a neuropsychological study. *Neuropsychology*, 13, 103-110.
- McDaniel, M. A. & Einstein, G. O. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Applied Cognitive Psychology*, 14, S127-S144.

- McDaniel, M. A., Guynn, M. J., Einstein, G. O., & Breneiser, J. (2004). Cue-focused and reflexive-associative processes in prospective memory retrieval. *Journal of Experimental Psychology-Learning Memory and Cognition*, *30*, 605-614.
- McDaniel, M. A., Einstein, G. O., Graham, T., & Rall, E. (2004). Delaying execution of intentions: Overcoming the costs of interruptions. *Applied Cognitive Psychology*, *18*, 533-547.
- McFarlane, D. C. & Latorella, K. A. (2002). The scope and importance of human interruption in human-computer interaction design. *Human-Computer Interaction*, *17*, 1-61.
- McFarlane, D. C. (2002). Comparison of four primary methods for coordinating the interruption of people in human-computer interaction. *Human-Computer Interaction*, *17*, 63-139.
- McGann, D., Ellis, J. A., & Milne, A. (2002). Conceptual and perceptual processes in prospective remembering: differential influence of attentional resources. *Mem.Cognit*, *30*, 1021-1032.
- McGann, D., Ellis, J., & Milne, A. (2003). Conceptual and perceptual processing in prospective remembering. *European Journal of Cognitive Psychology*, *15*, 19-41.
- Meacham, J. A. & Leiman, B. (1975). Remembering to perform future actions. In *Proceedings of the Meeting of the American Psychological Association*.
- Meacham, J. A. & Singer, J. (1977). Incentive effects in prospective remembering. *Journal of Psychology*, *97*, 191-197.
- Mecklinger, A., von Cramon, D. Y., Springer, A., & Matthes-von Cramon, G. (1999). Executive control functions in task switching: Evidence from brain injured patients. *Journal of Clinical and Experimental Neuropsychology*, *21*, 606-619.
- Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *J.Exp.Psychol.: Learn.Mem.Cogn.*, *22*, 1423.
- Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology*, *41*, 211-253.

- Meiran, N. (2000). Modeling cognitive control in task-switching. *Psychological Research-Psychologische Forschung*, 63, 234-249.
- Meiran, N., Gotler, A., & Perlman, A. (2001). Old age is associated with a pattern of relatively intact and relatively impaired task-set switching abilities. *J Gerontol.B Psychol Sci Soc Sci*, 56, 88-102.
- Mesulam, M. M. (1986). Frontal cortex and behavior. *Ann.Neurol*, 19, 320-325.
- Meyer D.E., Evans J.E., Lauber E.J., Gmeindl L., Rubinstein J., Junck L. et al. (1998). The role of dorsolateral prefrontal cortex for executive cognitive processes in task switching. *Journal of Cognitive Neuroscience*, 106.
- Meyer, D. E. & Kieras, D. E. (1997). A computational theory of executive cognitive processes and multiple-task performance .1. Basic mechanisms. *Psychological Review*, 104, 3-65.
- Meyer, D. E., Evans, J. E., Lauber, E. J., Gmeindl, L., Rubinstein, J., Junck, L. et al. (1998). The role of dorsolateral prefrontal cortex for executive cognitive processes in task switching. *Journal of Cognitive Neuroscience*, 106.
- Michelson, W. & Teppermen, L. (2003). Focus on Home: What Time-Use Data Can Tell About Caregiving to Adults. *Jounral of Social Issues*, 59, 591-610.
- Milan, E. G., Sanabria, D., Tornay, F., & Gonzalez, A. (2005). Exploring task-set reconfiguration with random task sequences. *Acta Psychol (Amst)*, 118, 319-331.
- Miller, E. K. & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, 24, 167-202.
- Milner, B. (1963). Effects of different brain lesions on card sorting. *Arch.Neurol.*, 9, 90.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognit Psychol*, 41, 49-100.

- Miyata, Y. & Norman, D. A. (1986). Psychological Issues in Support of Multiple Activities. In D.A.Norman & S. W. Draper (Eds.), *User Centered Design*. (pp. 265-284). New Jersey: Erlbaum.
- Monk, C. A., Boehm-Davis, D., & Trafton, J. G. (2002). The attentional costs of interrupting task performance at various stages. In *Human Factors and Ergonomics Society*. (pp. 1824-1828).
- Monsell, S. (1996). Control of mental processes. In V.Bruce (Ed.), *Unsolved mysteries of the mind: tutorial essays in cognition*. (pp. 93-148). Hove: Erlbaum.
- Monsell, S., Yeung, N., & Azuma, R. (2000). Reconfiguration of task-set: Is it easier to switch to the weaker task? *Psychological Research-Psychologische Forschung*, 63, 250-264.
- Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, 7, 134-140.
- Monsell, S., Sumner, P., & Waters, H. (2003). Task-set reconfiguration with predictable and unpredictable task switches. *Memory & Cognition*, 31, 327-342.
- Morrin, K. A., Law, D. J., & Pellegrino, J. W. (1994). Structural Modeling of Information Coordination Abilities - An Evaluation and Extension of the Yee, Hunt, and Pellegrino Model. *Intelligence*, 19, 117-144.
- Moscovitch, M. (1982). A neuropsychological approach to perception and memory in normal and pathological aging. In F.I.M.Craik & S. Trehub (Eds.), *Aging and Cognitive Processes* ( New York: Plenum Press.
- Moscovitch, M. (1994). Cognitive resources and dual-task interference effects at retrieval in normal people: The role of the frontal lobes and medial temporal cortex. *Neuropsychology*, 8, 524-534.
- Moscovitch, M. (1995). Recovered consciousness: a hypothesis concerning modularity and episodic memory. *J Clin.Exp.Neuropsychol.*, 17, 276-290.
- Moscovitch, M. & Melo, B. (1997). Strategic retrieval and the frontal lobes: evidence from confabulation and amnesia. *Neuropsychologia*, 35, 1017-1034.

- Moscovitch, M. & Winocur, G. (2002). The frontal cortex and working-with memory. In D.T.Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 189-209). Oxford: Oxford University Press.
- Nathaniel-James, D. A. & Frith, C. D. (2002). The role of the dorsolateral prefrontal cortex: evidence from the effects of contextual constraint in a sentence completion task. *Neuroimage.*, *16*, 1094-1102.
- Nigro, G. & Cicogna, P. (2000). Does delay affect prospective memory performance? *European Psychologist*, *5*, 228-233.
- Nolde, S. F., Johnson, M. K., & Raye, C. L. (1998). The role of prefrontal cortex during tests of episodic memory. *Trends in Cognitive Sciences*, *2*, 399-406.
- Norman, D. A. & Shallice, T. (1983). Attention to Action - Willed and Automatic-Control of Behavior. *Bulletin of the Psychonomic Society*, *21*, 354.
- Norman, D. A. & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R.J.Davison, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation* (pp. 1-18). New York: Plenum.
- Nyberg, L., McIntosh, A. R., Cabeza, R., Habib, R., Houle, S., & Tulving, E. (1996). General and specific brain regions involved in encoding and retrieval of events: what, where, and when. *Proc.Natl Acad.Sci U.S.A*, *93*, 11280-11285.
- Okuda, J., Fujii, T., Yamadori, A., Kawashima, R., Tsukiura, T., Fukatsu, R. et al. (1998). Participation of the prefrontal cortices in prospective memory: evidence from a PET study in humans. *Neuroscience Letters*, *253*, 127-130.
- Okuda, J., Frith, C. D., & Burgess, P. W. (2004). Organisation of time- and event-based intentions in rostral prefrontal cortex. *Neuroimage*, *22*, S54.
- Otani, H., Landau, J. D., Libkuman, T. M., StLouis, J. P., Kazen, J. K., & Throne, G. W. (1997). Prospective memory and divided attention. *Memory*, *5*, 343-360.

Pardo, J. V., Pardo, P. J., Janer, K. W., & Raichle, M. E. (1990). The anterior cingulate cortex mediates processing selection in the Stroop attentional conflict paradigm. *Proc.Natl Acad.Sci U.S.A*, 87, 256-259.

Park, D. C., Hertzog, C., Kidder, D. P., Morrell, R. W., & Mayhorn, C. B. (1997). Effect of age on event-based and time-based prospective memory. *Psychology and Aging*, 12, 314-327.

Pashler, H., Johnston, J. C., & Ruthruff, E. (2001). Attention and performance. *Annu.Rev.Psychol.*, 52, 629-651.

Passingham, R. E. (1993). *The frontal lobes and voluntary action*. Oxford: Oxford University Press.

Pavot, W., Diener, E., Colvin, C. R., & Sandvik, E. (1991). Further validation of the Satisfaction with Life Scale: evidence for the cross-method convergence of well-being measures. *J.Pers.Assess.*, 57, 149-161.

Perret, E. (1974). Left Frontal Lobe of Man and Suppression of Habitual Responses in Verbal Categorical Behavior. *Neuropsychologia*, 12, 323-330.

Peterson, B. S., Skudlarski, P., Gatenby, J. C., Zhang, H., Anderson, A. W., & Gore, J. C. (1999). An fMRI study of Stroop word-color interference: evidence for cingulate subregions subserving multiple distributed attentional systems. *Biol Psychiatry*, 45, 1237-1258.

Phillips, L. H. (1997). Do 'frontal tests' measure executive function: issues of assessment and evidence from fluency tests. In M.A.Rabbitt (Ed.), *Methodology of frontal and executive functions*. (pp. 191-213). Hove: Psychology Press.

Pollmann, S. (2004). Anterior prefrontal cortex contributions to attention control. *Experimental Psychology*, 51, 270-278.

Poon, L. W. & Schaffer, G. (1982). Prospective memory in young and elderly adults. In Proceeding of the Meeting of the American Psychological Association.



- Posner, M. I. & Snyder, C. R. R. (1975). Attention and cognitive control. In R.L.Solso (Ed.), *Information Processing and Cognition* ( Hillsdale, NJ: Erlbaum.
- Pouthas, V. & Perbal, S. (2004). Time perception depends on accurate clock mechanisms as well as unimpaired attention and memory processes. *Acta Neurobiologiae Experimentalis*, 64, 367-385.
- Prabhakaran, V., Smith, J. A. L., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. E. (1997). Neural substrates of fluid reasoning: An fMRI study of neocortical activation during performance of the Raven's Progressive Matrices Test. *Cognitive Psychology*, 33, 43-63.
- Ramnani, N. & Owen, A. M. (2004). Anterior prefrontal cortex: Insights into function from anatomy and neuroimaging. *Nature Reviews Neuroscience*, 5, 184-194.
- Raven, J. (2000). The Raven's Progressive Matrices: Change and stability over culture and time. *Cognitive Psychology*, 41, 1-48.
- Raven, J. C. (1976). Raven's Advanced Progressive Matrices APM Set 1. Oxford Psychologists Press.
- Reason, J. T. (2006). Lapses of Attention. In R.Pasasuraman, R. Davies, & J. Beatty (Eds.), *Varieties of Attention*. Orlando: Academic Press.
- Reitan, R. M. & Wolfson, D. (1994). A Selective and Critical-Review of Neuropsychological Deficits and the Frontal Lobes. *Neuropsychology Review*, 4, 161-198.
- Reitman, W. R. (1964). Information-processing models in Psychology. *Science*, 144, 1192-1198.
- Robbins, T. W. (1996). Dissociating executive functions of the prefrontal cortex. *Philos Trans R Soc Lond B Biol Sci*, 351, 1463-1470.
- Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). 'Oops!': performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia*, 35, 747.

- Rogers, R. D. & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *J.Exp.Psychol.*, *124*, 207-231.
- Rogers, R. D., Sahakian, B. J., Hodges, J. R., Polkey, C. E., Kennard, C., & Robbins, T. W. (1998). Dissociating executive mechanisms of task control following frontal lobe damage and Parkinson's disease. *Brain*, *121*, 815-842.
- Royall, D. R., Lauterbach, E. C., Cummings, J. L., Reeve, A., Rummans, T. A., Kaufer, D. I. et al. (2002). Executive control function: a review of its promise and challenges for clinical research. A report from the Committee on Research of the American Neuropsychiatric Association. *J Neuropsychiatry Clin.Neurosci*, *14*, 377-405.
- Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *J Exp.Psychol Hum.Percept.Perform.*, *27*, 763-797.
- Ruge, H., Brass, M., Koch, I., Rubin, O., Meiran, N., & von Cramon, D. Y. (2005). Advance preparation and stimulus-induced interference in cued task switching: further insights from BOLD fMRI. *Neuropsychologia*, *43*, 340-355.
- Rugg, M. D., Fletcher, P. C., Chua, P. M., & Dolan, R. J. (1999). The role of the prefrontal cortex in recognition memory and memory for source: an fMRI study. *Neuroimage*, *10*, 520-529.
- Rushworth, M. F., Passingham, R. E., & Nobre, A. C. (2005). Components of attentional set-switching. *Exp.Psychol*, *52*, 83-98.
- Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403-428.
- Salthouse, T. A., Berish, D. E., & Siedlecki, K. L. (2004). Construct validity and age sensitivity of prospective memory. *Mem.Cognit.*, *32*, 1133-1148.
- Salthouse, T. A. (2005). Relations between cognitive abilities and measures of executive functioning. *Neuropsychology.*, *19*, 532-545.
- Salvucci, D. D. (2005). A multitasking general executive for compound continuous tasks. *Cognitive Science*, *29*, 457-492.

Saver, J. L. & Damasio, A. R. (1991). Preserved access and processing of social knowledge in a patient with acquired sociopathy due to ventromedial frontal damage.

*Neuropsychologia*, 29, 1241-1249.

Schmitter-Edgecombe, M. & Wright, M. J. (2004). Event-based prospective memory following severe closed-head injury. *Neuropsychology*, 18, 353-361.

Schneider, W. & Shiffrin, R. M. (1977). Controlled and automatic human information processing: 1. Detection, Search and Attention. *Psychol.Rev.*, 84, 1-66.

Schott, J. M. & Rossor, M. N. (2003). The grasp and other primitive reflexes. *Journal of Neurology, Neurosurgery, and Psychiatry*, 74, 558-560.

Schwartz, M. F., Reed, E. S., Montgomery, M. W., Palmer, C., & Mayer, N. H. (1991). The quantitative description of action disorganisation after brain damage: A case study. *Cognitive Neuropsychology*, 8, 381-414.

Schwartz, M. F., Montgomery, M. W., Buxbaum, L. J., Lee, S. S., Carew, T. G., Coslett, H. B. et al. (1998). Naturalistic action impairment in closed head injury. *Neuropsychology*, 12, 13-28.

Schwartz, M. F., Buxbaum, L. J., Montgomery, M. W., Fitzpatrick-DeSalme, E., Hart, T., Ferraro, M. et al. (1999). Naturalistic action production following right hemisphere stroke. *Neuropsychologia*, 37, 51-66.

Sellen, A. J., Louie, G., Harris, J. E., & Wilkins, A. J. (1997). What brings intentions to mind? An in situ study of prospective memory. *Memory*, 5, 483-507.

Semendeferi, K., Damasio, H., Frank, R., & Van Hoesen, G. W. (1997). The evolution of the frontal lobes: a volumetric analysis based on three-dimensional reconstructions of magnetic resonance scans of human and ape brains. *J Hum.Evol.*, 32, 375-388.

Semendeferi, K., Lu, A., Schenker, N., & Damasio, H. (2002). Humans and great apes share a large frontal cortex. *Nat Neurosci*, 5, 272-276.

Shallice, T. (1982). Specific Impairments of Planning. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences*, 298, 199-209.

Shallice, T. (1988). *Neuropsychology of Mental Structure*. Cambridge: Cambridge University Press.

Shallice, T., Burgess, P. W., Schon, F., & Baxter, D. M. (1989). The origins of utilization behaviour. *Brain*, *112* ( Pt 6), 1587-1598.

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

Shallice, T. (1994). Multiple Levels of Control Processes. In Umiltà, C. & Moscovitch, M. (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 395-420). Cambridge, MA: MIT Press.

Shallice, T. & Burgess, P. (1996). The domain of supervisory processes and temporal organization of behaviour. *Philos Trans R Soc Lond B Biol Sci*, *351*, 1405-1411.

Shallice, T. (2002). Fractionation of the Supervisory System. In D.T.Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 261-277). New York: Oxford University Press.

Sheeran, P. & Orbell, S. (1999). Implementation intentions and repeated behaviour: augmenting the predictive validity of the theory of planned behaviour. *European Journal of Social Psychology*, *29*, 349-369.

Shimamura, A. P. (2002). Memory Retrieval and Executive Control Processes. In D.T.Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 210-220). Oxford: Oxford University Press.

Shum, D., Valentine, M., & Cutmore, T. (1999). Performance of individuals with severe long-term traumatic brain injury on time-, event-, and activity-based prospective memory tasks. *J Clin.Exp.Neuropsychol.*, *21*, 49-58.

Simons, J. S. & Spiers, H. J. (2003). Prefrontal and medial temporal lobe interactions in long-term memory. *Nat.Rev.Neurosci.*, *4*, 637-648.

- Smith, E. E. & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science*, 283, 1657.
- Smith, R. E. (2003). The cost of remembering to remember in event-based prospective memory: Investigating the capacity demands of delayed intention performance. *Journal of Experimental Psychology-Learning Memory and Cognition*, 29, 347-361.
- Smith, R. E. & Bayen, U. J. (2004). A multinomial model of event-based prospective memory. *Journal of Experimental Psychology-Learning Memory and Cognition*, 30, 756-777.
- Sohn, M. H. & Carlson, R. A. (2000). Effects of repetition and foreknowledge in task-set reconfiguration. *Journal of Experimental Psychology-Learning Memory and Cognition*, 26, 1445-1460.
- Sohn, M. H., Ursu, S., Anderson, J. R., Stenger, V. A., & Carter, C. S. (2000). The role of prefrontal cortex and posterior parietal cortex in task switching. *Proceedings of the National Academy of Sciences of the United States of America*, 97, 13448-13453.
- Sohn, M. H. & Anderson, J. R. (2001). Task preparation and task repetition: Two-component model of task switching. *Journal of Experimental Psychology-General*, 130, 764-778.
- Speier, C., Valacich, J. S., & Vessey, I. (1999). The influence of task interruption on individual decision making: An information overload perspective. *Decision Sciences*, 30, 337-360.
- Spikman, J. M., Deelman, B. G., & van Zomeren, A. H. (2000). Executive functioning, attention and frontal lesions in patients with chronic CHI. *J Clin. Exp. Neuropsychol.*, 22, 325-338.
- Sternberg, S. (1969). Discovery of Processing Stages - Extensions of Donders Method. *Acta Psychologica*, 30, 276-315.
- Stone, M., Dismukes, K., & Remington, R. (2001). Prospective memory in dynamic environments: effects of load, delay, and phonological rehearsal. *Memory*, 9, 165-176.

Stone, V. E., Baron-Cohen, S., & Knight, R. T. (1998). Frontal lobe contributions to theory of mind. *J Cogn Neurosci*, *10*, 640-656.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643.

Stuss, D. T. & Benson, D. F. (1986). *The Frontal Lobes*. New York: Raven.

Stuss, D. T., Shallice, T., & Alexander, M. P. (1995). *A multidisciplinary approach to anterior attentional functions*.

Stuss, D. T. & Alexander, M. P. (2000). Executive functions and the frontal lobes: a conceptual view. *Psychol Res*, *63*, 289-298.

Stuss, D. T., Floden, D., Alexander, M. P., Levine, B., & Katz, D. (2001). Stroop performance in focal lesion patients: dissociation of processes and frontal lobe lesion location. *Neuropsychologia*, *39*, 771-786.

Stuss, D. T. & Levine, B. (2002). Adult clinical neuropsychology: lessons from studies of the frontal lobes. *Annu.Rev.Psychol*, *53*, 401-433.

Stuss, D. T. & Knight, R. T. (2002). *Principles of Frontal Lobe Function*. New York: Oxford University Press.

Stuss, D. T., Alexander, M. P., Shallice, T., Picton, T. W., Binns, M. A., Macdonald, R. et al. (2005). Multiple frontal systems controlling response speed. *Neuropsychologia*, *43*, 396-417.

Thaler, D., Chen, Y. C., Nixon, P. D., Stern, C. E., & Passingham, R. E. (1995). The Functions of the Medial Premotor Cortex .1. Simple Learned Movements. *Experimental Brain Research*, *102*, 445-460.

Thomas, E. A. C. & Weaver, W. B. (1975). Cognitive Processing and Time Perception. *Perception & Psychophysics*, *17*, 363-367.

Tilney, F. (1928). *The Brain: From Ape to Man*. New York: Hoeber.

Tornay, F. J. & Milan, E. G. (2001). A more complete task-set reconfiguration in random than in predictable task switch. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology*, 54, 785-803.

Tranel, D. & Damasio, H. (1994). Neuroanatomical correlates of electrodermal skin conductance responses. *Psychophysiology*, 31, 427-438.

Tulving, E. (1983). *Elements of episodic memory*. New York: Oxford University Press.

Unterrainer, J. M., Rahm, B., Kaller, C. P., Ruff, C. C., Spreer, J., Krause, B. J. et al. (2004). When planning fails: individual differences and error-related brain activity in problem solving. *Cereb.Cortex*, 14, 1390-1397.

Uttal, W. R. (2001). *The New Phrenology: The Limits of Localizing Cognitive Processes in the Brain*. Cambridge, M.A.: MIT Press.

van den Berg, S., Aarts, H., Midden, C., & Verplanken, B. (2004). The role of executive processes in prospective memory tasks. *European Journal of Cognitive Psychology*, 16, 511-533.

Vendrell, P., Junque, C., Pujol, J., Jurado, M. A., Molet, J., & Grafman, J. (1995). The role of prefrontal regions in the Stroop task. *Neuropsychologia*, 33, 341-352.

Vogels, W. W., Dekker, M. R., Brouwer, W. H., & de, J. R. (2002). Age-related changes in event-related prospective memory performance: a comparison of four prospective memory tasks. *Brain Cogn*, 49, 341-362.

Volkow, N. D. & Fowler, J. S. (2000). Addiction, a disease of compulsion and drive: involvement of the orbitofrontal cortex. *Cereb.Cortex*, 10, 318-325.

Voncramon, D. Y. & Voncramon, G. M. (1994). Back to Work with A Chronic Dysexecutive Syndrome - (A Case-Report). *Neuropsychological Rehabilitation*, 4, 399-417.

Wager, T. D., Jonides, J., & Reading, S. (2004). Neuroimaging studies of shifting attention: a meta-analysis. *Neuroimage.*, 22, 1679-1693.

- Ward, G., Roberts, M. J., & Phillips, L. H. (2001). Task-switching costs, Stroop-costs, and executive control: A correlational study. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology*, *54*, 491-511.
- Waszak, F., Hommel, B., & Allport, A. (2003). Task-switching and long-term priming: role of episodic stimulus-task bindings in task-shift costs. *Cognit Psychol*, *46*, 361-413.
- Wearden, J. H. (2004). Decision processes in models of timing. *Acta Neurobiologiae Experimentalis*, *64*, 303-317.
- Weidner, R., Pollmann, S., Muller, H. J., & von Cramon, D. Y. (2002). Top-down controlled visual dimension weighting: An event-related fMRI study. *Cerebral Cortex*, *12*, 318-328.
- Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A Normative Developmental-Study of Executive Function - A Window on Prefrontal Function in Children. *Developmental Neuropsychology*, *7*, 131-149.
- West, R. & Craik, F. I. (1999). Age-related decline in prospective memory: the roles of cue accessibility and cue sensitivity. *Psychol Aging*, *14*, 264-272.
- West, R. & Alain, C. (2000). Evidence for the transient nature of a neural system supporting goal-directed action. *Cereb.Cortex*, *10*, 748-752.
- West, R. & Craik, F. I. (2001). Influences on the efficiency of prospective memory in younger and older adults. *Psychol Aging*, *16*, 682-696.
- West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychol Bull.*, *120*, 272-292.
- Whittlesea, B. W. A. & Williams, L. D. (2001). The discrepancy-attribution hypothesis: I. The heuristic basis of feelings of familiarity. *Journal of Experimental Psychology-Learning Memory and Cognition*, *27*, 3-13.
- Whittlesea, B. W. A. & Williams, L. D. (2001). The discrepancy-attribution hypothesis: II. Expectation, uncertainty, surprise, and feelings of familiarity. *Journal of Experimental Psychology-Learning Memory and Cognition*, *27*, 14-33.



- Whyte, J., Polansky, M., Cavallucci, C., Fleming, M., Lhulier, J., & Coslett, H. B. (1996). Inattentive behavior after traumatic brain injury. *J Int.Neuropsychol.Soc*, 2, 274-281.
- Wilkins, A. J. & Baddeley, B. T. (1978). Remembering to recall in everyday life: an approach to absent-mindedness. In M.M.Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical Aspects of Memory* (pp. 27-34). New York: Academic Press.
- Willingham, D. T. & Dunn, E. W. (2003). What neuroimaging and brain localization can do, cannot do and should not do for social psychology. *J Pers.Soc Psychol*, 85, 662-671.
- Wilson, B. A., Alderman, N., Burgess, P. W., Emslie, H. C., & Evans, J. J. (1996). *The Behavioural Assessment of the Dysexecutive Syndrome*. Flempton, Bury St Edmunds: Thames Valley Test Company.
- Wood, R. L. & Rutterford, N. A. (2004). Relationships between measured cognitive ability and reported psychosocial activity after bilateral frontal lobe injury: An 18-year follow-up. *Neuropsychological Rehabilitation*, 14, 329-350.
- Worthington, A. (1999). Dysexecutive paramnesia: Strategic retrieval deficits in retrospective and prospective remembering. *Neurocase*, 5, 47-57.
- Yamadori, A., Okuda, J., Fujii, T., Kawashima, R., Kinomura, S., Ito, M. et al. (1997). Neural correlates of prospective memory: A positron emission tomography study. *Brain and Cognition*, 35, 366-369.
- Zakay, D. (1993). Time estimation methods--do they influence prospective duration estimates? *Perception*, 22, 91-101.
- Zakay, D. & Block, R. A. (1997). Temporal cognition. *Current Directions in Psychological Science*, 6, 12-16.
- Zakay, D. & Block, R. A. (2004). Prospective and retrospective duration judgments: an executive-control perspective. *Acta Neurobiologiae Experimentalis*, 64, 319-328.
- Zeigarnik, B. (1927). Über das Behalten von erledigten und underledigten Handlungen. *Psychologische Forschung*, 9, 1-85.

Zeigarnik, B. (1938). On finished and unfinished tasks. In W.D.Ellis (Ed.), *A source book of Gestalt psychology* (pp. 300-314). New York: Harcourt Brace.

Zijlstra, F. R. H., Roe, R. A., Leonora, A. B., & Krediet, I. (1999). Temporal factors in mental work: Effects of interrupted activities. *Journal of Occupational and Organizational Psychology*, 72, 163-185.

# Appendix A

## Cued Rule Recall from Experiment 7

**Please answer the questions below about the rules of this test.**

1. How many different tasks are there in this test?
2. What rules are there about the order in which to do the tasks?
3. How long do you have for the entire test?
4. How often must you write down the letter and number from the display on the screen in the Time Task?
5. When does the Time Task finish?
6. How often will the letter and number display on the screen change in the Time Task?
7. Within each of the tasks do you score more points for items that you do earlier or later?
8. How many tasks should you try and attempt?
9. How often can you consult the timer?

## **Words presented for list recall tests in Experiment 7 & 8**

1. Dance
2. Tent
3. Ladder
4. Spray
5. Pipe
6. Harvest
7. Cardboard
8. Flame
9. Kite
10. Money
11. Brush
12. Fan
13. Leather
14. Game
15. Document
16. Sponge

**Time Management and Hobbies Questionnaire for Experiments  
7 & 8**

**Please answer the following questions as honestly and accurately as possible.**

1) Do you think carefully about the time management of your academic work, setting specified times aside to complete it?

NEVER 1 - 2 - 3 - 4 - 5 ALWAYS

2) Do you set goals for yourself of things to achieve on a daily basis?

NEVER 1 - 2 - 3 - 4 - 5 ALWAYS

3) Do you set goals for yourself of things to achieve on weekly basis?

NEVER 1 - 2 - 3 - 4 - 5 ALWAYS

4) Do you keep your diary up to date to help you remember events and/or deadlines?

NEVER 1 - 2 - 3 - 4 - 5 ALWAYS

5) Is your day usually planned out in advance?

NEVER 1 - 2 - 3 - 4 - 5 ALWAYS

6) Is your week usually planned out in advance?

NEVER 1 - 2 - 3 - 4 - 5 ALWAYS

7) Do you consider yourself someone with a lot of interests/hobbies?

YES/NO

Please list the hobbies that you do on a regular basis:

## **Academic Qualifications Scoring System for Experiments 7 & 8**

According to the UCAS U.K. Tariff system (2003), A-Levels and AS-Levels are designated the following scores:

### GCE A-Levels Grade

A = 120  
B = 100  
C = 80  
D = 60  
E = 40

### GCE AS-Levels

A = 60  
B = 50  
C = 40  
D = 30  
E = 20

According to the U.K. Government Department of Education Website (2003), GCSEs are designated the following scores:

### GCSE Grade

A\* = 8  
A = 7  
B = 6  
C = 5  
D = 4  
E = 3  
F = 2  
G = 1

### Half GCSE Grade

A\* = 4  
A = 3.5  
B = 3  
C = 2.5  
D = 2  
E = 1.5  
F = 1  
G = 0.5

# Appendix B

## Cued Rule Recall from Experiment 8

**Please answer the questions below about the rules of this test.**

1. How many different tasks are there in this test?
2. What rules are there about the order in which to do the tasks?
3. How long do you have for the entire test?
4. How often must you switch tasks?
5. When do you write down the letter/number on display?
6. How often will the letter/number display on the screen change?
7. Within each of the tasks which items do you score more points for?
8. How many tasks should you try and attempt?
9. How often can you consult the timer?
10. Do you have to do the items in order within each task?

