Task-set control and procedural working memory

Submitted by Félice Maria van ‘t Wout to the University of Exeter
as a thesis for the degree of
Doctor of Philosophy in Psychology
in May 2012

The thesis is available for Library use on the understanding that it is copyright material
and that no quotation from the thesis may be published without proper
acknowledgement.

I certify that all material in this thesis which is not my own work has been identified and
that no material has previously been submitted and approved for the award of a degree
by this or any other University.

Signature:……………………………………………………………...
Abstract

Flexible and goal-driven behaviour requires a process by which the appropriate task-set is selected and maintained in a privileged state of activation. This process can be conceptualised as loading a task-set into a procedural working memory (PWM) buffer. Task switching experiments, which exercise this process, reveal “switch costs”: increased reaction times and error rates when the task changes, compared to when it repeats. The process of loading a task-set into PWM may be one source of these costs. The switch cost is reduced with preparation, suggesting that at least some of the processes involved in a successful change of task can be achieved in advance of the stimulus.

The aim of this thesis was to investigate the properties of PWM, and its contribution to task-set control. One account of PWM distinguishes between the level at which recently exercised (but currently irrelevant) task-sets are represented, and the level at which only the currently relevant task-set is maintained in a most active state. To distinguish between these levels of representation, and to assess the extent to which the process of getting a task-set into a most-active state (loading it into the PWM buffer) is subject to a capacity limit at each level, the experiments varied the number of tasks participants switched among (Experiments 1 and 2), and the complexity of individual task-sets (Experiments 3-6) in a task-cueing paradigm.

In Experiments 1 and 2, participants switched among three or five tasks, in separate sessions. There was no effect of the number of tasks on the switch cost, or its reduction with preparation, provided that recency and frequency of task usage were matched. When recency and frequency were not matched, there appeared to be a larger switch cost with five tasks at a short preparation interval, suggesting that the time consumed by getting a task-set into a most active state is influenced by its recency and frequency of usage, not the number of alternatives per se.

However, Experiment 3 showed that the time required to select an S-R mapping within a task-set does increase as a function of the number of alternatives (even when stimulus frequency and recency are matched), suggesting that representation of the most active task-set in a PWM buffer is subject to a strict capacity limit. Experiments 4-6 further investigated the capacity limit of this PWM buffer, and found that task-set preparation was more effective for task-sets that are less complex (i.e. specified by fewer S-R rules). These findings suggest that only very few S-R rules can be maintained in a most active state in the PWM buffer.
Finally, Experiments 7-9 investigated whether S-R rules are represented phonologically for task-set maintenance and preparation, by manipulating the phonological properties of the stimulus terms. But task-cueing performance was not affected by the name length (Experiment 7) or phonological similarity (Experiments 8 and 9) of the stimulus terms. These results suggest that phonological representations of S-R rules do not make a functional contribution to task-set control, possibly because the rules are compiled into a non-linguistic PWM.

The results of these experiments are discussed in terms of a procedural working memory which is separate from declarative working memory, and distinguishes between two levels of task-set control: the level of task-sets, which are maintained in a capacity unlimited state of representation, and the level at which the currently relevant task-set is maintained in a most-active but highly capacity limited state of representation.
Acknowledgements

Firstly, thanks go to Stephen Monsell, my first supervisor. I have happy memories of our animated discussions about procedural working memory. I would also like to thank my second supervisor, Aureliu Lavric, for his encouragement and expert advice.

Thanks also to my good friends and fellow (former) PhD students – particularly Heike Elchlepp, Charlotte Forrest and Tobias Stevens. There is nothing like a swim in the sea or a trip to the pub with good friends to make you forget that you just spent a week collecting data in a windowless cubicle.

During the third year of my PhD I also spent two very fun and productive weeks in Klaus Oberauer’s lab in Zurich: I would like to thank Klaus and his group for welcoming me into their lab, and Miriam Gade and her lovely family for welcoming me into their home.

Lastly, I would like to thank my parents, who always encouraged me to do whatever made me happy; and Peter Lown, my almost-husband, for everything.

The research was supported by a studentship from the Economic and Social Research Council.
Index

Chapter 1: General Introduction........................................................................................................19
  1.1 Task-set control......................................................................................................................... 20
      1.1.1 Task switching paradigms ................................................................................................. 20
      1.1.2 Theories of the switch cost ............................................................................................... 22
      1.1.3 Task switching phenomena ............................................................................................. 22
      1.1.4 What does task-set reconfiguration exist of? ................................................................. 28
  1.2 Procedural working memory..................................................................................................... 31
      1.2.1 Retrieving a task-set into the capacity-limited component of PWM ......................... 36
      1.2.2 Selecting a stimulus-response mapping within the capacity-limited component of PWM ...................................................................................................................... 37
      1.2.3 The representation of S-R rules ....................................................................................... 40
      1.2.4 Overview of thesis ............................................................................................................ 43

Chapter 2: Is it harder to switch among a larger set of tasks? ..................................................45
  Abstract........................................................................................................................................... 45
  Introduction .................................................................................................................................. 46
  Experiment 1 .................................................................................................................................. 51
      Method...................................................................................................................................... 52
      Results and Discussion ............................................................................................................. 55
  Experiment 2 .................................................................................................................................. 62
      Method...................................................................................................................................... 63
      Results and Discussion ............................................................................................................. 65
  General Discussion ...................................................................................................................... 72

Chapter 3: The contribution of stimulus recency and frequency to Hick’s law ..................77
  Introduction .................................................................................................................................. 77
  Experiment 3 .................................................................................................................................. 81
      Method...................................................................................................................................... 81
      Results ...................................................................................................................................... 83
List of Figures

**Figure 1.1** Oberauer’s model of working memory…………………………………………………………….33

**Figure 2.1** Examples of stimuli used in Experiment 1…………………………………………………….52

**Figure 2.2** Mean correct RTs (top) and % error (bottom) data in Experiment 1 with three and five tasks, on switch and repeat trials, as a function of CSI; plotted separately for probe task trials (left) and all task trials (right)………………………………………………………………………………56

**Figure 2.3** Mean correct RTs (top) and % error (bottom) data in Experiment 1 with three and five tasks, on long and short CSI trials, as a function of lag; plotted separately for probe task trials (left) and all task trials (right)………………………………………………………………………………58

**Figure 2.4** Mean correct RTs (top) and % error (bottom) data in Experiment 1 with three and five tasks, on switch and repeat trials, as a function of response congruence.60

**Figure 2.5** Mean correct RTs (top) and % error (bottom) data in Experiment 2 with three and five tasks, on switch and repeat trials, as a function of CSI; plotted separately for probe task trials (left) and all task trials (right)………………………………………………………………………………66

**Figure 2.6** Mean correct RTs (top) and % error (bottom) data in Experiment 2 with three and five tasks, in long and short CSI trials, as a function of lag; plotted separately for probe task trials (left) and all task trials (right)………………………………………………………………………………68

**Figure 2.7** Mean correct RTs (top) and % error (bottom) data in Experiment 2 with three and five tasks, on switch and repeat trials, as a function of response congruence.70

**Figure 3.1** Stimuli used in Experiment 3………………………………………………………………..82

**Figure 3.2** Trial matrix displaying the frequency of all transition types in the 6 S-R condition (left) and the 4 S-R condition (right) in Experiment 3, with the probe transitions highlighted in bold………………………………………………………………………………………………82

**Figure 3.3** Mean correct RT (top) and % error (bottom) data in Experiment 3, for 6 S-R and 4 S-R trials, plotted as a function of probe/nonprobe stimuli (left), and as a function of practice (right)………………………………………………………………………………………………85

**Figure 3.4** Mean correct RT (left) and % error (right) data in Experiment 3, for 6 S-R and 4 S-R trials, plotted separately for probe/nonprobe stimuli as a function of lag…..86

**Figure 3.5** Percentiles for probe stimuli and nonprobe stimuli in Experiment 3, in the 6 S-R and 4 S-R conditions………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………..
Figure 4.2 Mean correct RTs (top) and % error (bottom) data in Experiment 4, plotted separately as a function of switch/repeat (left) and congruency (right).................99

Figure 4.3 RT switch cost (ms) in the 3-choice and 2-choice conditions in Experiment 4, for fast (average of 10th-40th percentile) and for slow responses (average of 60th-90th percentile), as a function of CSI.................................................................101

Figure 4.4 Examples of stimuli used in Experiments 5 and 6. In each experiment, half of the participants switched between the country and shape tasks in the category-rule condition and between the animal and symbol tasks in the arbitrary-rule condition, and vice versa for the other half of participants.................................................................105

Figure 4.5 RTs and errors in Experiment 5 for switch and repeat trials (left) and congruent and incongruent trials (right), plotted separately for the category-rule and the arbitrary-rule condition, as a function of CSI.................................................................107

Figure 4.6 RTs and errors in Experiment 5 for repeat trials plotted as a function of position in run..................................................................................................................109

Figure 4.7 RTs and errors in Experiment 5 for now relevant value switch (vs) and now relevant value repeat (vr) trials as a function of task switch/task repeat.............111

Figure 4.8 RTs and errors in Experiment 6 as a function of switch/repeat, arbitrary-/category-rule and CSI plotted separately for incongruent (left) and congruent (right) trials..................................................................................................................115

Figure 4.9 RTs and errors in Experiment 6 for repeat trials plotted as a function of position in run..................................................................................................................117

Figure 4.10 RTs and errors in Experiment 6 for now relevant value switch (vs) and now relevant value repeat (vr) trials as a function of task switch/task repeat........117

Figure 4.11 RT switch cost (ms) in Experiment 6 in the arbitrary- and category-rule conditions, for fast (average of 10th-40th percentile) and for slow responses (average of 60th-90th percentile), as a function of CSI.................................................................118

Figure 5.1 Example trial sequence and stimuli for Experiment 7...............132

Figure 5.2 Mean correct RTs and error data for Experiment 7. A RTs and errors for the one- and three-syllable stimulus names as a function of switch/repeat and CSI. B Single task practice data. C Word-length effects (WLE) plotted for switch and repeat trials, by CSI (100 ms or 1300 ms), as a function of block number.................................134

Figure 5.3 List completion times in centiseconds (cs) for mono and trisyllable stimulus names, in the overt condition (participants cycled through list once) and the covert condition (participants cycled through list four times) in Experiment 7a.................138
Figure 5.4 The stimulus sets used for Experiment 8 (dissimilar set in blue: Q, J, R and F; similar set in red: B, D, T and P), arranged to provide illustrations of stimulus pairs..........................140

Figure 5.5 Mean correct RTs and error data for Experiment 8. A RTs and errors for the similar and dissimilar stimulus names as a function of switch/repeat and CSI. B Single task practice data. C Phonological similarity effects (PSE) plotted for switch and repeat trials, by CSI (100 ms or 1300 ms), as a function of block number.........................141

Figure 5.6 Mean correct RTs and errors for the “common” stimulus in Experiment 8.................................................................143

Figure 5.7 Examples of stimuli used in Experiment 9 (left) assigned to participants for whom the picture stimuli are similar, and the letter stimuli dissimilar, and (right) vice versa.................................................................148

Figure 5.8 Mean correct RTs and error data for Experiment 9. A RTs and errors for the similar and dissimilar stimulus names as a function of switch/repeat and CSI. B Single task practice data. C Phonological similarity effects (PSE) plotted for switch and repeat trials, by CSI (100 ms or 1300 ms), as a function of block number.........................149
List of Tables

**Table 2.1** Tasks, task-cues and response assignments for the 2 sets of stimuli (creatures and trees) used in Experiment 1..........................52

**Table 2.2** Mean correct RTs (ms), with the % error data between brackets, for the different conditions in Experiment 1..........................56

**Table 2.3** All 32 word stimuli used in Experiment 2 and their respective classifications along the 5 task dimensions......................................................64

**Table 2.4** Mean correct RTs (ms), with the % error data between brackets, for the different conditions in Experiment 2. ........................................66

**Table 2.5** Differences between the 5-task and 3-task switch costs in ms (% errors between brackets) for the following trial types: probe trials following probe trials (PP), probe trials following all trials (AP) and all trials following all trials (AA). * = p < 0.05. .................................................................71

**Table 4.1** Switch costs (ms) for the arbitrary- and category-rule conditions (and the difference between them) in Experiment 5 as a function of CSI and congruency (* = p < 0.05). .................................................................111

**Table 4.2** Switch costs (ms) for the arbitrary- and category-rule conditions (and the difference between them) in Experiment 6 as a function of CSI and congruency (* = p < 0.05). .................................................................115

**Table 5.1** Monosyllabic and threesyllabic words (and normative naming latencies) descriptive of pictures used in Experiment 7)........................................131

**Table 5.2** Pictures used in Experiment 9 and their normative naming latencies.......148
Declaration

The research reported in this thesis was carried out at the University of Exeter between October 2008 and May 2012, and was supervised by Prof. Stephen Monsell and Dr. Aureliu Lavric.

This dissertation has not been submitted, in whole or in part, for any other degree, diploma or qualification at any university. Chapters 2 and 5 are articles that will be submitted to scientific journals. Chapter 2 will be submitted to Journal of Experimental Psychology: Human Perception and Performance by van ‘t Wout, F., Monsell, S., and Lavric, A. I conducted the experiments, wrote the first draft and prepared the figures and tables. My co-authors have edited the manuscript. Chapter 5 will be submitted to Journal of Experimental Psychology: Learning, Memory and Cognition. I conducted the experiments, wrote the first draft and prepared the figures and tables. My co-authors have edited the manuscript.

Two second year interns, Beth Whiteman and Michael Clayton, kindly helped to collect the data for Experiment 6.

Félice van ‘t Wout
Exeter, May 2012.