Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.
Investigating the relationship between two approaches to verbal information processing in working memory:

AN EXAMINATION OF THE CONSTRUCT OF WORKING MEMORY COUPLED WITH AN INVESTIGATION OF META-WORKING MEMORY

Submitted in partial fulfilment for the degree of Doctor of Philosophy in Psychology at Massey University by...

Llewelyn A. Richards-Ward
Department of Psychology
Massey University
Palmerston North
New Zealand

- 1996 -
ABSTRACT

Working memory is a process whereby persons can preserve information for a short time while concurrently engaging in other cognitive operations. The literature describes two approaches to working memory. The first approach (Baddeley, 1986) can be described as a complete model of working memory. However the second approach is not as clearly a distinct model, although its history, literature, application, simulation and operational definitions can arguably allow one to describe it as a separate model or strand of working memory for the present purposes. Rather, what will be termed the "quantitative/process model" deals only with verbal information and is far less complete than Baddeley’s model in other domains. A central issue is thus how these two models relate with respect to how they handle verbal information. Baddeley (1986) delineated working memory as a set of interconnected components consisting of a Central Executive, a Phonological Loop, and a Visuo-Spatial Sketch-Pad. In this dissertation, this is termed the qualitative/structural model of working memory. Daneman and Carpenter (1980, 1983) delineated working memory as a process involving both a traditional span component and a concurrent operation. This approach, which will be referred to as the quantitative/process model of working memory, has been presumed to involve the Central Executive of the qualitative/structural model of working memory. This presumed relationship is scrutinised in the present dissertation in the context of an alternate hypothesis that the quantitative/process model involves more of the phonological loop than has been presumed. Thus, the first issue this dissertation addressed was how these two models or approaches to working memory account for verbal information. The second facet of the present investigation was to examine whether persons were able to report on their meta-memory for working memory.
Seven linked experiments are reported in the present dissertation. Participants for all seven experiments were predominantly students at local tertiary institutions and ranged in age from 16 to 48 years. The experimental conditions were presented as a two-factor within-subjects design in Experiments 1 to 6. The first general factor was word-type varying either across word-length (Experiments 2, 4, and 6) or across phonological similarity (Experiments 1, 3, and 5). The second factor was whether articulatory suppression was used or not (Experiments 1 to 6). In Experiments 1 and 2, stimuli were presented as a complex-span task (sentence plus word), where in Experiments 3 to 6, stimuli were presented as a simple-span task (word only). Experiment 5 also had a between-subjects factor determined by whether words were sampled from a 10 item pool or from a pool without replacement. Experiment 6 had a between-subjects factor determined by the presentation pace of the stimuli (at 1 per second or self-paced). Finally, Experiment 7 directly compared complex-span and simple-span presentations against a second factor of word-type varying across both phonological similarity and word-length (control, phonologically similar, 3-syllable).

In all seven experiments, participants were measured on dependent variables of recall in the correct serial position and recall in any serial position of the words that were presented. From the difference between these two measures of content, an estimate of the loss of order information (order errors) was calculated. A measure of the time each participant spent viewing (for simple-span tasks) or verifying (for complex-span tasks) the stimuli was made to assess processing time. Finally, before each trial, participants made an estimate of how many items they expected to recall in any order (a measure of their online metamemory). In Experiments 5 to 7, a measure of the time each participant took to articulate the pool of words they had
been asked to recall was taken to provide an estimate of their articulation rate.

The main research questions for this set of studies were as follows: (1) that the quantitative/process model of working memory also uses the Phonological Loop, not just the Central Executive, and hence both models of working memory use the same process to preserve visually presented verbal information; (2) that measurement of dimensions of order and processing time, in addition to the dimension of content or capacity, will contribute independent information to the description of working memory function; and (3) that persons are able to monitor and report on their working memory. Data from the present set of studies provide support for these three hypotheses. The present investigation showed that a concurrent operation does not preclude phonological similarity and word-length effects used to define the components of the qualitative/structural model of working memory. Concurrently, dimensions of content and order, but not processing time, were shown to be important in describing working memory. The conclusion from these results is that both models of working memory refer to the same construct and that preservation of verbal information can be better accounted for by a single process. Finally, in all instances persons were accurate in predicting their general working memory performance. The data also show that persons may be able to predict the effect of some parameter changes on their performance.

---

1 The raw data upon which this dissertation was based can be obtained in the first instance from the author at the following address: Llewelyn A. Richards-Ward
c/- Department of Psychology
Massey University
Private Bag 11222
Palmerston North
New Zealand
The results of the present research suggest that verbal information is handled similarly in both models or approaches and tends to falsify that verbal information is retained primarily in the Central Executive in one model and the Phonological Loop in the other. Second, the results suggest that persons do have a degree of meta-working memory. These results are discussed in terms of their implications for how working memory and meta-working memory can be described. Finally, some future directions for research are outlined.
ACKNOWLEDGEMENTS

No undertaking such as studying for a doctoral degree can occur without support and help from many people. However, to list all of those people who have supported me would be impossible. So, firstly I thank my friends who were there when I needed to talk, work colleagues who regularly asked how things were going, casual acquaintances who took the time to listen or offer advice, and those people who took the time to reply to my letters or email notes.

I would also like to thank Massey University for the doctoral scholarship which enabled me to undertake this research and for the Graduate Research Award A93/G/058 which helped cover some of the costs involved. My gratitude is also extended to the Psychology Department who contributed additional monies toward my research costs and to Michael Donnelly who helped me travel the paths of bureaucracy relatively unhindered.

I also thank Dr Ross St George and Dr Julie Bunnell for being my supervisors. They not only provided me with quality academic supervision but were also available to encourage and guide me in negotiating this degree with minimum trauma and maximum challenge. I remain very deeply indebted to them both.

At a more personal level, there are four people whose inspiration and support have, I believe assisted this undertaking greatly. First, I thank Ross St George for his enthusiasm and ability to ask questions. Without questions, research would never begin. Second, I thank Alison St George whose courses in educational psychology inspired me to consider more deeply how people monitor their cognition and helped me develop my own strategies for learning greatly. Third, I thank John Podd for teaching me the necessity of taking small steps in research and of the value of being thorough. Fourth, I thank Julie Bunnell whose teaching first
inspired my interest in cognitive psychology and whose support has enabled me to develop that interest. To all four of you, please do not let the brevity of this acknowledgement of your contributions in any way detract from the appreciation I extend toward you.

Finally, I wish to thank Leigh without whose participation as an (in)volunteer and support as a partner I could never have completed this degree. "A good wife who can find? She is far more precious than jewels. The heart of her husband trusts in her, and he will have no lack of gain" (Proverbs 31:10-11). Diolch yn fawr rwyn dy cariad di Leigh bach!
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>i</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>v</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>vii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>xii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xvi</td>
</tr>
</tbody>
</table>

## Chapter 1: A History of the Short-Term Store and of Working Memory

- What is Memory?: Early Models of Memory                               | 5    |
- The Span Method of Measuring the Capacity of the Short-Term Store     | 6    |
- The Free-Recall Method of Measuring the Capacity of the Short-Term Store | 7    |
- A Comparison of the Short-Term Store Using Either Span or Free-Recall Measurement Techniques | 8    |
- What is the Short-Term Store for?: The Baddeley and Hitch (1974) Investigation of Working Memory | 10   |
- Summary                                                              | 12   |

## Chapter 2: Qualitative/Structural Models of Working Memory

- An Overview of Baddeley's Definition of Working Memory                    | 14   |
- The Qualitative/Structural Model of Working Memory                        | 16   |
  - The Phonological Loop                                                   | 17   |
  - The Visuo-Spatial Sketch-Pad                                             | 32   |
- The Central Executive                                                     | 33   |
- Summary                                                              | 35   |
Chapter 3: Quantitative/Process Models of Working Memory

A Pragmatic Analysis of the Complex-Span Tasks: Do They Perform? .................................................. 38
- Definition of Working Memory .................................................. 40
- Reliability of Complex-span tasks ........................................ 44
- Validity Evidence for the Reading Span task ......................... 45
- Conclusions ........................................................................ 51

A Theoretical Framework for the Quantitative/Process Model of Working Memory ........................................ 51
- Preservation of Content in Working Memory ......................... 52
- Order Information in Working Memory ................................ 53
- Temporal Factors in Working Memory .................................. 54
- Conclusions ........................................................................ 56

Summary .............................................................................. 56

Chapter 4: Subjective On-line Meta-Memory Measures .... 58
- The Theoretical Basis of Meta-Memory ................................. 60
- The Operational Basis of Meta-Memory ............................... 64
- Assumptions of Meta-Memory Research ................................ 67
- Conclusions ........................................................................ 68

Chapter 5: A Rationale for Investigating the two Models of Working Memory .................................................. 69
- Relationships Between the Qualitative/Structural and Quantitative/Process Models of Working Memory .... 73
- The Relationship Between Meta-Memory and Working Memory ................................................................. 79
- Toward an Integration of Theories and Measurement of Verbal Working Memory ........................................ 80

Summary .............................................................................. 81

Chapter 6: General Hypotheses and General Method ....... 83
- General Hypotheses: Three Defining Postulates ................. 83
- Hypotheses at a Theoretical Level ......................................... 84
- General Method .................................................................... 89
- Participants ........................................................................... 89
- Apparatus ............................................................................ 90
- Stimuli .................................................................................. 90
- Design .................................................................................... 93
- Procedure ............................................................................. 95

Experimentation ..................................................................... 83
Chapter 7: Experiments 1 & 2: An Initial Examination of Quantitative/Process, Qualitative/Structural, and Subjective/Objective Factors in a Complex-Span Task

Experiment 1: An Initial Test of the Phonological Similarity Effect in a Complex-Span Task
Method .................................................. 104
Results .................................................... 108
Discussion .............................................. 109

Experiment 2: The Word-length Effect in a Complex-span Task
Method .................................................. 127
Results .................................................... 133
Discussion .............................................. 134

Summary of Experiments 1 and 2 .......................................................... 147

Chapter 8: Experiments 3 & 4: Examination of Quantitative/Process, Qualitative/Structural, and Subjective/Objective Factors in a Simple-Span Task

Experiment 3: The Phonological Similarity Effect in a Simple-Span Task
Method .................................................. 151
Results .................................................... 153
Discussion .............................................. 154

Experiment 4: The Word-length Effect in a Simple-span Task
Method .................................................. 165
Results .................................................... 167
Discussion .............................................. 168

Summary ........................................................................ 176
Utilizing Dimensions of Order and Processing Time in Addition to Content Information ........................................... 176
Meta-memory for Working Memory .............................................. 177
Conclusions ........................................................................ 178

Chapter 9: Replicating the Phonological Similarity and Word-Length Effects in a Simple-Span Task

Experiment 5: A Comparison of Two Stimulus Sampling Methods on the Phonological Similarity Effect
Method .................................................. 180
Results .................................................... 194
Discussion .............................................. 195

Experiment 6: A Comparison of the Effect of Experimenter-Paced Versus Participant-Paced Presentation of Stimuli on Word-length Effects
Method .................................................. 214
Results .................................................... 221
Discussion .............................................. 222
Chapter 10: Experiment 7: The Integration of a Qualitative/Structural Model of Working Memory with a Quantitative/Process Model of Working Memory ........................................ 236
Hypotheses .................................................................. 241
Method ....................................................................... 243
Results ....................................................................... 245
Discussion ..................................................................... 255

Chapter 11: General Discussion ........................................ 262
Pre-conditions for Measurement of Working Memory:
Reliability, Sensitivity, and Bias .................................... 263
Reliability .................................................................... 263
Sensitivity .................................................................... 264
Bias ........................................................................... 265

Postulate 1: The Commonality Between Qualitative/Structural and Quantitative/Process Definitions of Working Memory ........................................... 265
Main Results .................................................................. 267
The Context of The Present Results in the Literature ........... 271
Conclusion .................................................................... 273

Postulate 2: The Utility of Measures of Content, Order and Processing Time in Describing Working Memory ......................................................... 274
Main Results .................................................................. 274
Limits of the results ...................................................... 279
Conclusion .................................................................... 283

Postulate 3: On-line Meta-Memory for Working Memory Content ......................................................... 284
Main Results .................................................................. 284
Conclusion .................................................................... 288

Summary ...................................................................... 289
The Unity of the Construct of Working Memory ................. 283
Implications of the Present Results for Theories of Working Memory .................................................................. 284
Implications of the Present Results for Meta-Memory Research ......................................................... 293

Future Research .......................................................... 296
Conclusion ...................................................................... 299
Appendices ................................................................. 318

Appendix 1: Experimental Stimuli Used in the Present Dissertation .................. 318
Appendix 2: A Signal Detection Analysis of the Sensitivity and Bias of Participants' Responding on the Sentence Verification Task ................. 326
Appendix 3: The General Information Sheet for Experiments 1 to 7 .................. 328
Appendix 4: The Participant Consent Sheet for Experiments 1 to 7 .................. 329
Appendix 5: F-values and errors terms for Experiment 7 .............................. 330
LIST OF TABLES

Table 1. A comparison of the span and free-recall methods of measuring STS capacity ......................... 9

Table 2. A selective review of working memory definitions used by researchers using a quantitative and process oriented correlational approach to aging and working memory ........................................ 39

Table 3. Reliability coefficients for various operationalisations of a storage plus processing models of working memory. ......................................................... 44

Table 4. Reported correlations between the Daneman and Carpenter (1980) Reading Span task (or a variant) and other measures of working memory or of memory span alone. ........................................ 45

Table 5. A summary of the experimental conditions used in the present dissertation. Conditions vary across phonological similarity, word-length, articulatory suppression, task-type, pool-type, and pacing ........................................................................ 91

Table 6. A summary of the two week test-retest reliability of the complex-span task for phonologically similar and dissimilar words with and without articulatory suppression in Experiment 1. Test-retest reliability was calculated using the Pearson product-moment coefficient ........................................................................ 111

Table 7. Mean (SD) recall of phonologically similar or phonologically dissimilar words either in the correct serial position or in any serial position for both the control and articulatory suppression conditions in Experiment 1. Note that recall is out of three for either correct or muddled verification conditions and out of 6 for the total verification and pre-estimates columns (N = 21). ........................................................................ 116

Table 8. Mean (SD) order errors for phonologically similar or phonologically dissimilar words for both the control and articulatory suppression conditions in Experiment 1. Order errors are out of 3 for the correct and muddled conditions, and out of 6 overall (N = 21) ........................................................... 117

Table 9. Mean (SD) verification times (ms) for phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions in Experiment 1 (N = 21) ........................................................................ 119
Table 10. Mean (SD) pre-estimates of recall in any serial position for phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions in Experiment 1 (N = 21) ........................................ 120

Table 11. A summary of the two week test-retest reliability of the complex-span task for 1 and 2-syllable words with and without articulatory suppression in Experiment 2. Test-retest reliabilities were moderate to high in all conditions and were calculated using the Pearson product-moment coefficient ........................................ 135

Table 12. Mean (SD) recall of 1-syllable or 2-syllable words either in the correct serial position or in any serial position for both the control and articulatory suppression conditions in Experiment 2. Note that recall is out of three for either correct or muddled verification conditions and out of 6 for the total verification and pre-estimates columns (N = 21). ........................................ 137

Table 13. Mean (SD) order errors for 1-syllable and 2-syllable words for both the control and articulatory suppression conditions in Experiment 2. Order errors are out of 3 for the correct and muddled conditions, and out of 6 overall (N = 21) ........................................................................ 139

Table 14. Mean (SD) verification times (ms) for 1-syllable and 2-syllable words for both the control and articulatory suppression conditions in Experiment 2 (N = 21) ........................................ 140

Table 15. Mean (SD) pre-estimates of recall in any serial position for 1-syllable and 2-syllable words for both the control and articulatory suppression conditions in Experiment 2 (N = 21) .......................... 141

Table 16. Mean (SD) recall of phonologically similar or phonologically dissimilar words either in the correct serial position or in any serial position for both the control and articulatory suppression conditions in Experiment 3 (N = 20) ........................................ 155

Table 17. Mean (SD) order errors for phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions in Experiment 3 (N = 20) ........................................ 157

Table 18. Mean (SD) viewing times (ms) for phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions in Experiment 3 (N = 18). ........................................ 159
Table 19. Mean (SD) pre-estimates of recall in any serial position for phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions in Experiment 3 (N = 18) ........................................ 159

Table 20. Mean (SD) recall of 1-syllable or 2-syllable words either in the correct serial position or in any serial position for both the control and articulatory suppression conditions in Experiment 4 (N = 19). ........................................ 168

Table 21. Mean (SD) order errors for 1-syllable and 2-syllable words for both the control and articulatory suppression conditions in Experiment 4 (N = 19) ........................................... 170

Table 22. Mean (SD) viewing times (ms) for 1-syllable and 2-syllable words for both the control and articulatory suppression conditions in Experiment 4 (N = 17) ........................................... 171

Table 23. Mean (SD) pre-estimates of recall in any serial position for 1-syllable and 2-syllable words for both the control and articulatory suppression conditions in Experiment 4 (N = 18) ........................................ 172

Table 24. Mean (SD) recall of phonologically similar or phonologically dissimilar words either in the correct serial position or in any serial position for both the control and articulatory suppression conditions and across pool-type in Experiment 5 (N = 34) ........................................ 199

Table 25. Articulation rate (SD) for phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions and across pool-type in Experiment 5 (N = 34) ........... 201

Table 26. The proportion of variability accounted for in the Fixed-pool condition using the natural logarithm of each of the content measures regressed against the natural logarithm of articulation rate with F-values, significance, and mean square errors of the residual terms evaluating the fit of the regression coefficient .......... 202

Table 27. Mean (SD) order errors for phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions and across pool-type in Experiment 5 (N = 34) ........................................ 204

Table 28 Mean (SD) viewing times (ms) for both phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions and across pool-type in Experiment 5 (N = 34) ................. 207
Table 29. Mean pre-estimates (SD) for both phonologically similar and phonologically dissimilar words for both the control and articulatory suppression conditions and across pool-type in Experiment 5 (N = 33) ........................................208

Table 30. Mean (SD) recall of 1-syllable or 3-syllable words either in the correct serial position or in any serial position for both the control and articulatory suppression conditions across experimenter and participant-paced presentations in Experiment 6 (N = 34). .........................223

Table 31. Articulation rate (SD) for 1-syllable or 3-syllable words for both the control and articulatory suppression conditions and across pacing conditions in Experiment 6 (N = 34) ........................................226

Table 32. Mean (SD) order errors for 1-syllable and 3-syllable words for both the control and articulatory suppression conditions and across the pacing conditions in Experiment 6 (N = 34). ...............226

Table 33. Mean (SD) viewing time (ms) for both 1-syllable and 3-syllable words for both the control and articulatory suppression conditions and across pacing conditions in Experiment 6 (N = 34) ........................................228

Table 34. Mean (SD) pre-estimates of recall in any serial position for both 1-syllable and 3-syllable words for both the control and articulatory suppression conditions and across pacing conditions in Experiment 6 (N = 33) ........................................229

Table 35. A summary of the domains of previous experiments in the present research. ........................................237

Table 36. Mean (SD) recall of control, phonologically similar, and 3-syllable words either in the correct serial position or in any serial position by task-type (simple or complex) for Experiment 7 (N = 32). ........................................246

Table 37. Mean (SD) order errors by task-type (simple or complex) and stimulus-type (control, phonologically similar, 3-syllable; N = 32) for Experiment 7 ........................................250

Table 38. Mean (SD) viewing and verification time (ms) by task-type (simple or complex) and stimulus-type (control, phonologically similar, 3-syllable; N = 32) for Experiment 7 ........................................252

Table 39. Mean (SD) pre-estimates by task-type (simple or complex), and stimulus-type (control, phonologically similar, 3-syllable; N = 32) for Experiment 7 ........................................254
Figure 1. A model of working memory showing the Central Executive, the Phonological Loop, and the Visuo-Spatial Sketch-Pad. ........................................ 16

Figure 2. Salthouse's (1992) model of the relationship between storage and operations in working memory. .................................................. 43

Figure 3. A flowchart showing some aspects of the logic behind the development of the present studies in relation to Postulate 1. ........................................ 87

Figure 4. Recall in the correct serial position by phonological similarity, articulatory suppression, and verification conditions for Experiment 1. .................. 112

Figure 5. Recall in any serial position by phonological similarity, articulatory suppression, and verification conditions for Experiment 1. ...................... 115

Figure 6. Recall in the correct serial position by word-length, articulatory suppression, and verification conditions for Experiment 2. .................................. 136

Figure 7. Recall in the correct serial position and recall in any serial position by word-length and articulatory suppression conditions in Experiment 3. .................................. 156

Figure 8. Recall in the correct serial position and recall in any serial position by word-length and articulatory suppression conditions in Experiment 4. .................................. 169

Figure 9. Recall in the correct serial position by phonological similarity, articulatory suppression, and pool-type conditions in Experiment 5. .................... 196

Figure 10. Recall in any serial position by phonological similarity, articulatory suppression, and pool-type conditions in Experiment 5. .................. 198

Figure 11. A comparison of the two measures of content in Experiment 5 with each other............................................... 200

Figure 12. Item transpositions for phonologically similar and phonologically dissimilar words in Experiment 5. ...................................... 206

Figure 13. Recall in the correct serial position by word length, articulatory suppression, and pacing conditions in Experiment 6. .............................. 225

Figure 14. Item transpositions for 1- and 3-syllable words in Experiment 6................................................................. 227
Figure 15. Recall for Experiment 7 showing the comparison between simple-span and complex-span tasks for each stimulus-type. ........................................... 248

Figure 16. The natural logarithm of viewing times of each stimulus plotted against recall in the correct serial position for each task-type and for each stimulus-type. ................................................................. 253

Figure 17. A regression of mean recall in any serial position against mean pre-estimates for each condition in Experiments 1 to 7. ......................................................... 285

Figure 18. The qualitative/structural and quantitative/process models of working memory .......... 292