Understanding Performance on the Search-for-Answer Comprehension Speed Task: Delineating Determinants, Age Effects, and Complex Relations with Cognitive Resources

by

Stuart Warren Swain MacDonald
B.A. Honours, University of Winnipeg, 1996

A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

in the Department of Psychology

We accept this thesis as conforming
to the required standard

[redacted]

Dr. David F. Hultsch, Supervisor (Department of Psychology)

[redacted]

Dr. Esther Strauss, Departmental Member (Department of Psychology)

[redacted]

Dr. Roger A. Dixon, Departmental Member (Department of Psychology)

[redacted]

Dr. Geraldine H. Van Gyn, Outside Member (School of Physical Education)

[redacted]

Dr. Brian Harvey, External Examiner (Department of Psychological Foundations,
Faculty of Education)

University of Victoria

Supervisor: Dr. David F. Hultsch

ABSTRACT

Recent empirical findings (Hultsch et al., 1998) demonstrated the central importance of comprehension speed as a mediator of episodic memory performance. However, as comprehension speed represents a complex amalgam of cognitive abilities, the Hultsch et al. (1998) findings contradict a general resource account of cognitive performance mediation. The primary purpose of this thesis was to more closely examine characteristics of the Search-for-Answer comprehension speed measure used in the Hultsch et al. comprehension model. Specifically, this investigation examined performance on the Search-for-Answer comprehension speed task in an attempt to better understand age differences, predictors of age differences, and predictors of overall task performance. A cross-sectional sample of 501 community-dwelling mature adults (337 women and 164 men) between the ages of 54 and 84 years (M = 68.06, SD = 7.18) provided complete data on all cognitive measures. These participants were members of the Victoria Longitudinal Study, an ongoing longitudinal study utilizing 3 year retest intervals to investigate cognitive aging. In addition, a young comparison cross-sectional sample of 97 university students (52 women and 45 men) between the ages of 17 and 36 years (M = 23.35, SD = 4.91) completed all relevant cognitive measures. All participants completed an extensive battery of cognitive tests including measures of perceptual speed, semantic speed, working memory, and episodic memory. Both the Search-for-Answer comprehension speed task and the Reading Comprehension Speed task represented dependent measures of interest.

Results indicated that marked age differences in Search-for-Answer comprehension speed latency and accuracy performance exist in favour of younger age groups. Further, these age differences are accentuated as a function of Search-for-Answer passage characteristics. More cognitively taxing passage characteristics are associated with diminished Search-for-Answer performance. Interestingly, these results indicated that age differences and cognitively taxing passage characteristics may themselves be a function of available processing resources. Hierarchical prediction models revealed that semantic speed represented the most influential predictor of total Search-for-Answer latency variance with working memory accounting for the most accuracy variance. Conversely, perceptual speed proved to be the best indicator of age-related latency and accuracy variance. Based on these findings, both task specific and general speed influenced Search-for-Answer performance. The more cognitively specific semantic speed and working memory measures represented important components of overall comprehension speed performance, whereas the general perceptual speed measure was closely related to age differences in comprehension speed performance. These findings support both the Hultsch et al. (1998) comprehension model findings as well as Salthouse's (1996b) processing speed theory of cognitive aging.

Examiners:

[redacted]

Dr. David F. Hultsch, Supervisor (Department of Psychology)

[redacted]

Dr. Esther Strauss, Departmental Member (Department of Psychology)

[redacted]

Dr. Roger A. Dixon, Departmental Member (Department of Psychology)

[redacted]

Dr. Geraldine H. Van Gyn, Outside Member (School of Physical Education)

[redacted]

Dr. Brian Harvey, External Examiner (Department of Psychological Foundations,
Faculty of Education)

Table of Contents

Page

Title Page i

Abstract ii

Table of Contents iv

List of Tables ix

List of Figures xi

Acknowledgements xii

Dedication xiii

CHAPTER I: INTRODUCTION 1

Specific Construct Accounts 2

General Resource Accounts 4

Processing Resources as Mediators of Cognitive Aging 5
Perceptual Speed as Processing Resource. 6
Working Memory as Processing Resource. 7

Alternatives to Processing Resource Accounts of Cognitive Aging 8
Does General or Task-Specific Speed Influence Cognitive Aging? 9
Is Processing Speed more Fundamental than Working Memory? 11
Other Abilities as Mediators of Age Differences in Performance. 13

Contrasting General and Specific Accounts of Cognitive Aging: Recent Evidence from a Study of Episodic Memory 16

Purpose of the Present Inquiry 20

CHAPTER II: RESEARCH RATIONALE 24

Research Rationale 24

Rationale #1: Merits of the Measure. 24

Table of Contents (cont.)

Page

Rationale #2: A Potential Relation Between Comprehension Speed Performance and Cognitive Aging? 24

Rationale #3: Is the Search-for-Answer Comprehension Speed Measure Simply an Instantiation of Basic Resources? 26

Rationale #4: Is Comprehension Speed an Index of the Long-Term Working Memory Construct? 27

CHAPTER III: METHOD 31

Participants 31

Materials 33

Dependent Measures 34
    Search-for-Answer Task 34
    Reading Comprehension Speed. 34

Predictor Tasks 35
    Perceptual Processing Speed Measures. 35
    Verbal Processing Speed Measures. 36
    Working Memory Measures. 37
    Episodic Memory Measures. 38

Experimental Procedures 39

Statistical Procedures 40
    Mean Level Analyses. 40
    Hierarchical Prediction Analyses. 43

CHAPTER IV: OBJECTIVES AND HYPOTHESES 45

Identifying Age Differences in Search-for-Answer Performance 45

    Latency and Error. 45
    Latency Differences as a Function of Error. 46
    Increased Latency as a Function of Passage Length. 46
    Increased Response Errors as a Function of Passage Length. 47
    Increased Response Errors as a Function of Fry Reading Grade Level. . 47

Table of Contents (cont.)

Page

Increased Response Errors as a Function of Flesch-Kinkaid Reading Grade Level. 47
Increased Response Errors as a Function of Target Sentence Length. . . . 48
Increased Response Errors as a Function of Distance to Target Sentence Response. 48
Increased Response Errors as a Function of Target Sentence Complexity. 48

Predicting Performance and Performance Differences on the Search-for-Answer Task 49
Prediction Models for Total Variance Associated with Response Latency. 51
Prediction Models for Total Variance Associated with Response Accuracy 52
Prediction Models for Age-Related Variance Associated with Response Latency. 52
Prediction Models for Age-Related Variance Associated with Response Accuracy. 53
Additional Analyses Predicting Total Variance Associated with Response Errors as a Function of Reading Grade Levels. 53

Predicting Response Latency as a Function of All Passages Correct Versus One or More Errors 54

CHAPTER V: RESULTS 57

Age Differences 57
Latency. 57
Errors. 59
Latency Differences as a Function of Error. 60

Potential Factors Underlying Increased Response Latency 61
Length. 61

Potential Factors Underlying Increased Number of Errors 64
Length. 64
Reading Grade Level. 66
Target Sentence Length. 70
Distance to Target Sentence Response. 71
Target Sentence Complexity. 76

Table of Contents (cont.)

Page

Predicting Search-for-Answer Performance Using Hierarchical Regression . . . 77

Correlates of Search-for-Answer Performance. 77

Predictors of Search-for-Answer Performance. 81

Total Variance Prediction Equations for Latency Performance. 81
Perceptual Speed Model. 81
Semantic Speed Model. 83
Working Memory Model. 84
Long-Term Working Memory Model. 85

Total Variance Prediction Equations for Error Performance. 86
Perceptual Speed Model. 87
Semantic Speed Model. 89
Working Memory Model. 90

Age-Related Variance Prediction Equations for Latency Performance. . 92
Perceptual Speed Model. 92
Semantic Speed Model. 94
Working Memory Model. 95

Age-Related Variance Prediction Equations for Error Performance. . . . 98
Perceptual Speed Model. 98
Semantic Speed Model. 99
Working Memory Model. 100

Additional Analyses Predicting Error Variance for Passage Characteristics . . . 101

Prediction as a Function of Passage Reading Grade Level 102
Perceptual Speed Model for Low Reading Grade Level. 102
Semantic Speed Model for Low Reading Grade Level. 103
Working Memory Model for Low Reading Grade Level. 104

Perceptual Speed Model for High Reading Grade Level. 105
Semantic Speed Model for High Reading Grade Level. 105
Working Memory Model for High Reading Grade Level. 107

All Passages Correct Versus One or More Errors Performance Prediction 108

Table of Contents (cont.)

Page

Predicting Response Latency for Correct on All Passages Performance. 110
Predicting Response Latency for 1 or More Errors on All Passages Performance. 111
Adding Semantic Speed to the Prediction of Performance for Perfect and Error Passage Groups. 113
Comparing the Prediction of Perfect Passage Performance and Reading Speed. 116

CHAPTER VI: DISCUSSION 118

Identifying Mean Age Differences 118

Predicting Search-for-Answer Response Latency and Accuracy 127
Total Latency Variance Prediction. 127
Total Error Variance Prediction. 130
Age-Related Latency Variance Prediction. 131
Age-Related Error Score (Accuracy) Variance Prediction. 134

Predicting Performance Error Variance as a Function of Passage Characteristics 137
Prediction of Passage Reading Grade Level. 137

Predicting All Passages Correct Versus One or More Errors Response Latency Performance 141

Summary 149

References 152

List of Tables

Page

Table 1 - Classification Criteria and Category for Passage Characteristics 41

Table 2 - Search-for-Answer Latency and Error Mean Scores as a Function of Age and Gender 59

Table 3 - Age-related Variance in Response Latency Prior To and Following the Statistical Covariation of Performance Errors 61

Table 4 - Intercorrelations Among Length, Readability, and Complexity Indicators 66

Table 5 - Correlations Among Latency, Error, and Cognitive Measures for Young Age Group 79

Table 6 - Correlations Among Latency, Error, and Cognitive Measures for Young-Old Age Group 79

Table 7 - Correlations Among Latency, Error, and Cognitive Measures for Mid-Old Age Group 80

Table 8 - Correlations Among Latency, Error, and Cognitive Measures for Old-Old Age Group 80

Table 9 - Hierarchical Regression Models Predicting Total Latency Variance ... 82

Table 10 - Hierarchical Regression Models Predicting Total Error Variance 88

Table 11 - Hierarchical Regression Model Predicting Age-Related Latency Variance 93

Table 12 - Hierarchical Regression Model Predicting Age-Related Latency Variance 95

Table 13 - Hierarchical Regression Model Predicting Age-Related Latency Variance 96

Table 14 - Hierarchical Regression Models Predicting Age-Related Variance Associated with Task Errors 99

Table 15 - Hierarchical Regression Models Predicting Variance Associated with Task Errors for Lower Flesch-Kinkaid Reading Grade Level 103

List of Tables (cont.)

Page

Table 16 - Hierarchical Regression Models Predicting Variance Associated with Task Errors for Higher Flesch-Kinkaid Reading Grade Level . . . 106

Table 17 - Number of Participants by Age Group for Perfect and Error Performance 110

Table 18 - Hierarchical Regression Models Predicting Correct on All Passages Search-for-Answer Latency Performance 111

Table 19 - Hierarchical Regression Models Predicting 1 or More Errors on All Passages Search-for-Answer Latency Performance 112

Table 20 - Revised Hierarchical Regression Models Predicting Correct on All Passages Search-for-Answer Latency Performance 114

Table 21 - Revised Hierarchical Regression Models Predicting 1 or More Errors on All Passages Search-for-Answer Latency Performance 115

Table 22 - Perceptual Speed Model Predicting Correct on All Passages Search-for-Answer Latency and Reading Time Latency 117

List of Figures

Page

Figure 1 - Basic Resource Model. 18

Figure 2 - Comprehension Model 19

Figure 3 - Hypothetical Relations Between Age, Comprehension Speed, and Cognitive Resources 25

Figure 4 - Search-for-Answer Latencies as a Function of Age 58

Figure 5 - Mean Search-for-Answer Response Latency as a Function of Age and Length 63

Figure 6 - Mean Search-for-Answer Response Errors as a Function of Age and Length 65

Figure 7 - Mean Search-for-Answer Response Errors as a Function of Age and Fry Readability Grade 68

Figure 8 - Mean Search-for-Answer Response Errors as a Function of Age and Flesch-Kinkaid Reading Grade Level 69

Figure 9 - Mean Search-for-Answer Response Errors as a Function of Age and Target Sentence Length 71

Figure 10 - Mean Search-for-Answer Response Errors as a Function of Age and Distance to Target Sentence Response 73

Figure 11 - Mean Search-for-Answer Response Errors as a Function of Age and Distance to Target Sentence Response 74

Figure 12 - Mean Search-for-Answer Response Errors as a Function of Age and Target Sentence Complexity 77

Acknowledgements

To begin, I would like to thank Dr. David F. Hultsch for his unwavering support through the many peaks and valleys of this project. Without question, his professional guidance, enthusiasm, patience, and friendship have provided the foundation for both my present and future successes. For this, I will forever be indebted. Every graduate student should be so fortunate to have a mentor like Dr. Hultsch.

In addition, I would like to express my gratitude to a number of other professionals instrumental in my development. I would first like to thank my committee members for their diligent perusal of drafts, excellent suggestions for improvement, and, above all, their understanding nature. Each of these special individuals deserves a separate acknowledgement page unto themselves. A very special thanks to Dr. Christopher Hertzog, a luminary both professionally and personally, who takes the time to care. Perhaps more than anyone, Dr. Hertzog has shown me the way. In addition, a special thanks to Dr. Scott Maitland who has taught me more in 12 months than I gleaned from my entire undergraduate degree. Finally, I would like to thank all my Victoria Longitudinal Study peers, in particular Deb Ball, Janine Hazlitt, Ron Martin, and Terry Perkins. These individuals have contributed to my development on a daily basis.

On a more personal front, I would like to thank my uncle, William C. McKay and my grandmother, Gertrude E. Swain. Without question, they are the most unique and caring individuals I have ever met. Their love and support directly underlie my ability to freely pursue my dreams. I sincerely consider Gertrude Swain and William McKay to be expert instructors of a course not offered in higher learning institutions, the essential course of life. Their influence will forever shape my direction in life and challenge me to be a better person. Also, I would like to thank my parents, George and Jane MacDonald, and my sister Kathleen MacDonald for tolerating, for understanding, and for loving - unconditionally. They are the most incredibly gifted individuals I know - I can only aspire to reach the heights of their talents. And finally, I would like to thank my beautiful and incredibly talented wife Jennifer Barber. My feelings for Jennifer transcend the limitations of written prose.

Dedication

To my grandmother, whose love and spirit inspires me everyday.

Chapter I

INTRODUCTION

Investigations of memory and cognition across adulthood reveal the vicissitudes associated with cognitive development with increasing age, particularly late in life (for an overview, see Blanchard-Fields & Hess, 1996; Craik & Salthouse, in press). Substantial empirical research suggests that younger adults outperform older adults on many cognitive tasks including memory (Hultsch & Dixon, 1990; Kausler, 1994; Salthouse, 1991a). Among older adults, there is evidence of normative decline in cognitive performance, particularly after age 75 (e.g., Giambra, Arenberg, Zonderman, Kawas, & Costa, 1995). These general characterizations of aging and cognition are, of course, subject to many caveats (Hultsch, Hertzog, Dixon, & Small, 1998). These include (a) the fact that many findings in support of decline are based on cross-sectional comparisons of age groups rather than longitudinal observations of individual change over time, (b) evidence suggesting the existence of large individual differences in change among individuals, and (c) data supporting the conclusion that cognition in later life may be characterized by considerable plasticity or potential for growth. Nevertheless, despite these and other caveats to the general conclusion, a complete picture of cognitive functioning in adulthood requires attention to the concept of decline.

Beyond empirical observations of age-related differences or decline, it is less clear why aging is associated with cognitive loss. Light (1991) and Salthouse (1991a) review and categorize several explanatory frameworks. For example, it has been suggested that older adults perform complex cognitive tasks less well than younger adults because they (a) process information differently than younger adults, (b) are deficient in metacognitive knowledge necessary for strategy selection and monitoring, (c) experience losses in a small number of basic processing mechanisms that serve as resources for a wide range of tasks, (d) have suffered an atrophy of cognitive skills due to disuse, and (e) are affected by various performance factors such as anxiety, fatigue, or cautiousness that mask their competence. Light (1991) and Salthouse (1991a) judge all of these and other frameworks to be inadequate explanations of cognitive change in adulthood. Despite the ongoing search for a completely adequate theoretical explanation of aging and cognition, two of the more informative attempts to date have taken the form of specific construct accounts and general resource accounts (Smith & Earles, 1996).

Specific Construct Accounts

Specific construct accounts attempt to describe and explain cognitive processes such as memory by reference to specific systems. Systems are often seen as consisting of a neural substrate and associated cognitive processes. For example, Tulving (1985) proposed that memory consists of three systems. Procedural memory involves the ability to retain learned connections between stimuli and responses. Semantic memory is characterized by the ability to represent material that is not perceptually present. Episodic memory permits the acquisition of information about personally experienced events located in time and space. These systems are seen as hierarchically ordered from procedural memory at the more primitive level to episodic memory at the more advanced level. Memory systems are also characterized by various processes. For example, episodic recall is often seen as involving encoding and retrieval processes. The former involve operations on the to-be-learned information that relate it to what is already known, whereas the latter involve accessing cues that will reinstate the conditions of encoding and lead to recovery of the information (Tulving & Thomson, 1973).

Memory component approaches provide a framework for localizing and describing age effects. Considerable focus has been devoted to the question of which memory systems are impaired and which are spared (Burke & Light, 1981; Hultsch et al., 1998). Typically, observing age dissociations in performance between young and old adults has provided the means of identifying which specific systems or processes are influenced by biological aging (Smith & Earles, 1996). For example, younger adults tend to outperform older adults on most variants of episodic memory tasks, whereas age differences are typically minimal on indicators of semantic or procedural memory (see Howard, 1988; Hultsch & Dixon, 1990; Mitchell, Brown, & Murphy, 1990; Park & Shaw, 1992). Further, studies specifically examining age effects in episodic memory have attempted to localize the processes associated with performance declines. Assumptions underlying encoding accounts of decline suggest that age differences in episodic memory may be a consequence of less elaborate initial processing with increasing age. Alternatively, assumptions underlying retrieval accounts suggest that episodic memory deficits are localized at the retrieval stage – perhaps due to a greater difficulty accessing retrieval stores for older adults. However, despite these efforts, localizing age effects in any one particular stage has proven problematic (for a summary, see Smith, 1996). Indeed, age-related differences in performance may best be characterized as a consequence of various mechanisms.

General Resource Accounts

The multiplicity of mechanisms responsible for age-related differences and changes hypothesized within specific construct accounts is minimized in general resource approaches. These accounts postulate the existence of a finite pool of resources available for cognitive expenditure on virtually all cognitive tasks. Several different cognitive mechanisms have been offered as representations of these limited resources (Hasher & Zacks, 1979; Salthouse, 1991a). Salthouse (1991a) has categorized these into three metaphorical domains: limitations of time (e.g., speed of processing), limitations of space (e.g., working memory) and limitations of energy (e.g., attention). According to resource accounts, age differences in cognitive performance occur when task demands exceed available cognitive resources. Presumably aging results in reductions in resources, and the restriction of available resources, in turn, negatively affects performance on many tasks. It is important to note that age differences in performance are not observed in all instances since tasks vary in their resource demands.

Research associated with the resource perspective attempts to link decline on many measures with concomitant decline on comparatively few resource measures. Thus, in contrast to specific construct accounts which attempt to demonstrate age dissociations on different tasks or processes, processing resource accounts focus on documenting commonalities in age-related decline across many measures. From this perspective, age differences on a broad spectrum of tasks may be symptomatic of a general underlying factor. If this is the case, then age-related variance for a variety of cognitive measures should substantially overlap with variance associated with the proposed general resource factor in question (e.g., speed of processing).

Without question, significant research contributions to investigations of memory and aging have emerged from both specific construct and processing resource accounts. However, the latter perspective has recently garnered considerable research attention as a potential explanation for age-related effects. We now turn to address the assumptions underlying processing resource accounts of cognitive aging.

Processing Resources as Mediators of Cognitive Aging

The origins of the processing resource perspective stem from investigations of the age-complexity effect (for a summary, see Salthouse, 1991a). The age-complexity effect refers to the observation that age differences in performance between younger and older adults are magnified as the complexity of a cognitive task increases. This phenomenon has been documented across many measures of cognitive performance. Moreover, this widespread relationship between age and task complexity is consistent with a processing resource account of cognitive decline (Salthouse, 1988; Salthouse, 1991a). That is, if more difficult tasks require more resources, and if older adults indeed have fewer resources than younger adults, then age differences in performance will increase as task difficulty increases.

But what is meant by processing limitations and what specific mechanisms comprise this relatively small stable of influential factors? As noted, Salthouse (1991a) has suggested three potential candidates that may operate as processing resource mechanisms: limitations in processing speed, working memory, and inhibitory capacity or attention. Of these three, however, limitations related to processing speed and working memory have received the greatest attention in the aging literature. For the purposes of this thesis, only restrictions in perceptual speed and working memory will be considered.

Perceptual speed as processing resource. The slowing of behaviour is among the most well established findings in the aging literature (for a summary, see Birren, 1965; Salthouse, 1985; 1991a). Further, this age-related slowing appears to be pervasive – few if any behaviours from simple to complex are spared. Dating as far back as Welford (1958) and Birren (1965), this general slowing of behaviour has been considered a potential explanation for age-related declines in cognitive performance. More recently, Salthouse (1996b) has articulated a theoretical account, the processing-speed theory of cognitive aging, arguing that the bulk of age differences in cognition are mediated by age-related reductions in the speed of executing cognitive operations.

In support of this position, numerous investigations have demonstrated a relation between declines in cognitive performance to concomitant declines in speed of processing (e.g., Hertzog, 1989; Salthouse, 1993, 1994a, 1994b). These and other investigations have shown that statistically covarying measures of perceptual processing speed attenuates the majority of age-related variance on a wide range of cognitive tasks. Effectively, little age-related variance remains to be accounted for. Salthouse (1996b) offers two mechanisms to account for these speed induced impairments. The limited time mechanism stipulates that slowness of processing with age prevents task relevant operations from being successfully completed thereby resulting in cognitive performance declines. The simultaneity mechanism suggests that products from earlier processing operations are no longer available upon completion of later processing thereby preventing integration and successful performance. Both the simultaneity mechanism and the limited time mechanism represent plausible accounts of the effect limited speed of processing exerts on cognitive performance (Salthouse, 1996b).

Working memory as processing resource. Processing speed is not the only construct to show promise as a universal resource account of age-related decline. Working memory represents another suitable construct as it is hypothesized to be an important factor involved in successful performance on many cognitive tasks (Salthouse, 1991a). Working memory enables temporary storage of information in memory while concurrently acting on this information or maintaining products from earlier processing operations to be used in later operations (Baddeley, 1986).

Research indicates there are substantial age differences in favour of the young on working memory tasks (Park et al., 1996; Salthouse & Babcock, 1991; Stine & Wingfield, 1990). In addition, recent longitudinal evidence demonstrates sharp declines in working memory from late middle age through old age (Hultsch et al., 1998). Restrictions in working memory capacity are suggested to take the form of one of the following: declining performance due to reduced storage capacity, declining performance due to impaired processing efficiency, or declining performance due to a diminished ability to simultaneously coordinate storage and processing operations (Salthouse, 1991a). Based on their decomposition of working memory, Salthouse and Babcock (1991) suggest that age-related declines in working memory are the result of reduced processing efficiency.

Following from findings of the importance of working memory for many complex cognitive tasks and the observation of age differences and changes on this construct, several strands of work suggest that individual differences in working memory may account for a substantial proportion of age-related effects in memory performance. As was the case with processing speed, investigations using variance partialing techniques indicate that covarying individual differences for certain working memory tasks attenuates age differences on many measures of cognition (for a summary, see Salthouse, 1991a; Hultsch et al., 1998). Other statistical approaches such as structural equation modeling have also been used to examine relations between working memory and cognition. For example, Park et al. (1996) contrasted two structural model accounts of cognitive function: one incorporating only speed as the primary mediator with the second including both speed and working memory. Their findings indicated both speed and working memory contributed significantly to explanations of cognitive aging.

Alternatives to Processing Resource Accounts of Cognitive Aging

The structural parsimony associated with processing resource accounts has obvious merit for explaining cognitive aging. However, a number of recent empirical studies have indicated that the processes associated with cognitive aging may be more complex than can be explained by restrictions in one or two resource factors which precipitate decline across many tasks. In particular, three areas of inquiry are of interest to the present discussion: whether declines are better characterized as the result of general or task-specific influences on processing speed, whether perceptual processing speed should command primary consideration over working memory as an explanatory construct, and whether abilities other than resource constructs are required to fully account for age-related effects.

Does general or task-specific speed influence cognitive aging? Any attempt to investigate the viability of processing speed as a mediator of age-related cognitive decline necessarily requires valid estimation of a general speed construct. Unfortunately, attempts to meaningfully measure processing speed for the purposes of age-comparative research have uncovered a paradox (Salthouse, 1991a). Presumably, if all speed measures are in fact multiple indicators of a general processing speed construct, high intercorrelations between speeded measures should be apparent. Contrary to this intuitive prediction, however, measures of processing speed hypothesized to represent a common speed factor have revealed only small proportions of shared variance across measures (for a summary, see Salthouse, 1991a).

The failure to find a high degree of intercorrelation between speeded measures has several interpretations. This could simply mean that every individual measure of speed has multiple determinants: both idiosyncratic influences that are specific to each task as well as common influences shared between a number of speeded tasks. As is the case with many other complex cognitive processes, a single factor alone rarely explains all of the variance of interest. Indeed, the absence of high intercorrelations between multiple indicators of speed implies the existence of several independent speed factors. For example, Babcock, Laguna, and Roesch (1997) used a structural equation modeling approach to factor reduce nine multiple indicators of speed into a motor speed factor, an alphanumeric speed factor, and a geometric speed factor. Similarly, a study by Tomer and Cunningham (1993) used confirmatory factor analysis to identify five first order factors of speed derived from sixteen speeded measures. Moreover, a number of other studies have reported the existence of more than one speed factor using a structural equation modeling approach (Hertzog, 1989; Hertzog, Raskind, & Cannon, 1986; Hultsch, Hertzog, & Dixon, 1990). Although arguably these independent speed factors may eventually be encompassed by a higher-order perceptual speed factor, significant differences do exist between speed measures both within and across tasks. The lack of intercorrelations coupled with the multiple factor structure of speed suggest that specific influences are important explanatory factors for cognitive aging.

In contrast, in a recent comprehensive review of the literature, Salthouse (1996b) argued in favour of a common influence explanation of cognitive aging. Despite the fact that large relationships are not evident among all measures of speed (see Salthouse, 1991a), Salthouse (1996b) contends that the common influences of speed still outweigh idiosyncratic contributions from specific measures. For example, Brinley plot analyses of reaction time data indicate moderate predictability of age differences in certain speed measures by using predictors of age differences in other speed measures (Salthouse & Coon, 1993). Further, in contrast to earlier findings, a number of empirical results have indicated that many speed measures share considerable amounts of their respective age-related variances (for a review, see Salthouse, 1996b). Indeed, at least four studies demonstrate that a significant proportion of age-related variance for a wide array of perceptual speed measures is shared as opposed to unique (Salthouse, 1996a). However, these facts aside, investigations of the proportion of age-related variance shared between varying measures of speed does not provide information about the number of age-related influences; only the extent to which these measures have common or specific age-related influences (Salthouse, 1996b). Further, even though various speed measures seem to share common variance, third-variable criticisms still qualify these general accounts (e.g., speed of processing may be a once-removed factor from a higher-order factor such as brain/CNS integrity).

Is processing speed more fundamental then working memory? Although Salthouse (1991a) initially considered several possible resource mechanisms, he has recently indicated that adult age differences in cognition are best viewed as the result of restrictions in a single resource: the speed of executing cognitive operations (Salthouse, 1996b). However, other accounts have suggested that both perceptual processing speed and working memory resource mechanisms may not represent independent constructs (see Salthouse, 1991b; Hultsch et al., 1998). Why then, postulate perceptual processing speed as being of primary importance over and above working memory? What is the nature of the relationship between these resources?

One distinct possibility is that aging processes exert their influence on cognitive performance directly through speed of processing but only indirectly through working memory. More precisely, all age influences including those on working memory exert their influence on cognition directly through processing speed. The hypothesis that age differences in cognition are indirectly mediated by working memory through processing speed has been previously considered (see Salthouse, 1991b). Results from several studies support the contention that speed is the more fundamental of these two resource mechanisms. For example, Salthouse (1991b) found that although decreases in working memory are associated with age-related declines in cognitive performance, the bulk of the age differences in working memory are mediated by simple measures of psychomotor speed. Other studies have also reported similar results (Salthouse & Babcock, 1991; Salthouse & Meinz, 1995). The common theme of these findings suggests that, in accord with Occam's Razor, explaining age-related variance in working memory as well as many other facets of cognition is most efficiently and parsimoniously done in terms of the construct of perceptual speed of processing.

However, in contrast, a second strand of research suggests that working memory may account for significant amounts of age-related variance independent of processing speed. For example, Hultsch, Hertzog, and Dixon (1990) used a hierarchical regression approach to assess the extent to which verbal processing speed and working memory attenuated age-related variance associated with episodic memory performance. Although processing speed significantly attenuated variance associated with episodic memory, working memory accounted for significant amounts of age-related variance over and above speed. More recently, Hultsch et al. (1998) applied structural equation modeling techniques to longitudinal data to examine the relationship among changes in cognitive processes over six years. These analyses showed that changes in episodic memory and other cognitive factors were driven largely by changes in working memory rather than changes in verbal processing speed. However, these findings have been criticized. Salthouse, among others, suggests the importance of working memory in the Hultsch et al. (1998) findings is suspect on account of the speed measures used. Although verbal processing speed most certainly reflects speed of executing cognitive operations, it is a more complex measure of speed compared with basic psychomotor measures (see Salthouse, 1992a).

In summary, is processing speed more influential than working memory? At least from a general resource perspective, evidence would tend to weigh in favour of processing speed for several reasons: (a) speed mediates a greater variety of tasks (Park et al., 1996); and (b) when reversing order of entry of speed and working memory in hierarchical regression equations, speed generally accounts for all variance that working memory does and more. Given this rationale, it appears that there is something more fundamental about the relation of elementary speed of executing operations to cognitive aging. In fact, Salthouse (1996b) argues that the explanatory capacity of working memory is based on its elementary speeded component. However, despite these insights, any definitive statements favouring processing speed over working memory are still premature based on extant empirical data. Although there is little doubt that a relationship exists between speed and working memory resources, a clear understanding of this interrelation has not yet materialized. Moreover, whether directly or indirectly, working memory demonstrably represents an important factor influencing the relation between age and cognition. Thus, in some respects, it does not make sense to consider working memory and perceptual speed as separate general resource hypotheses: they appear to be inextricably linked.

Other abilities as mediators of age differences in performance. Thorough investigations of cognitive aging should incorporate both basic resources as well as more specific abilities in the same explanatory framework. Addressing this issue, the third and final instalment of potential alternatives to processing resource accounts suggests that a number of other abilities, both cognitive and social, may contribute to explanations of cognitive decline. Clearly, such an hypothesis implies that cognitive aging processes are more involved and require more complex models (i.e., models including specific abilities) to explain decline than afforded by restrictive general resource models. Although plausible, does evidence exist in support of the hypothesis that specific abilities are important factors in mediating age differences in performance? We now consider evidence in favour of this contention.

Generally speaking, inferential evidence exists in support of the influence of specific abilities. General resource factors such as speed and working memory rarely account for all of the age-related variance associated with a particular task. One might argue that even though the age variance is not fully accounted for, the proportion of variance left to explain is trivial. However, several empirical investigations would argue that this is not the case (Hartley, 1986; Hultsch et al., 1990; Hultsch, Hammer, and Small, 1993; Zelinski, Gilewski, & Schaie, 1993). Each of these investigations have documented the significant contributions that certain specific abilities make in predicting age differences in cognition over and above variance predicted by general resources.

Consider Hultsch et al.'s (1990) paper on ability correlates of memory performance with age which incorporated a continuum of cognitive influences ranging from basic processes of cognition (e.g., verbal speed) to more complex products of cognition (e.g., crystallized intelligence, long-term memory). Even after partialing variance associated with basic resources (i.e., verbal speed and working memory) from an episodic memory task, Hultsch et al. (1990) found that crystallized intelligence accounted for a significant proportion of the remaining variance. Similarly, Zelinski et al. (1993) contrasted the amount of variance that specific intellectual abilities (e.g., reasoning) and age accounted for in a test of list recall over a period of 3 years. Interestingly, the findings indicated that performance change over this time period could be predicted by either the reasoning or age variable, but neither variable was sufficient to account for all of the change variance independently. Zelinski et al. concluded that neither age nor reasoning was solely predictive of cognitive declines with age. In fact, in line with our consideration of the influence of specific abilities, this research suggests that seeking out universal accounts of change may be inappropriate given the diversity of predictors (both general and specific) found to reliably predict memory performance across studies. Finally, some evidence exists outlining the influence of specific ability text variables (e.g., lexical access speed, vocabulary, abstract reasoning) on mediating cognitive performance (Hartley, 1986).

In addition to the influence of other cognitive abilities, research considering social and health predictors has also supported specific ability accounts of mediating cognitive performance differences with age. For example, Hultsch et al. (1993) found that age-related performance differences on multiple measures of cognition were attenuated to varying degrees by partialing individual differences in activity and self-reported health. However, save for verbal fluency, age effects for the measures of cognitive performance were not fully accounted for by partialing health and life style variables. More recently, Hultsch, Hertzog, Small, and Dixon (in press) found that although several indices of social activity and health failed to predict age-related changes in cognitive functioning, intellectually engaging activities did.

Based on findings such as those just outlined, it is scientifically prudent to include an array of specific and general ability predictors. At minimum, the inclusion of a broad spectrum of predictors is important to methodologically allow for the possibility that more specific abilities can contribute to the explanation of cognitive decline over and above the influences of general resources. If, as implied by the aforementioned research findings, specific abilities play an important role for mediating age-related cognitive performance, then explanatory models of cognitive decline should be more structurally complex than general resource models. Evidence in support of a more complex model of cognitive change has recently emerged from an ongoing longitudinal investigation (Hultsch et al., 1998). We turn now to address some important findings from this investigation of cognitive aging.

Contrasting General and Specific Accounts of Cognitive Aging: Recent Evidence from a Study of Episodic Memory

The Victoria Longitudinal Study (VLS) has programmatically investigated cognitive aging for the past 12 years. Recently, a monograph chronicling findings of the VLS has been published (Hultsch et al., 1998). Of particular interest to the current investigation, the authors assessed the contributions of both a basic resource perspective and a specific abilities perspective for explaining episodic memory performance.

Measures of Word and Text Recall were used as multiple indicators of episodic memory. In order to predict episodic memory performance, the authors established several structural models contrasting basic versus specific (i.e., more complex) resource accounts: one model included only basic resources (e.g., working memory, semantic processing speed) whereas the second model incorporated both basic resources and more specific complex indicators of episodic memory performance (e.g., working memory, semantic speed, reading comprehension, reading speed, and comprehension speed). For convenience, the former will be referred to as the basic model (see Figure 1) while the latter will be referred to as the comprehension model (see Figure 2). As expected, the confirmatory structural findings for the basic model indicated that both working memory and semantic speed were the primary mediators of all other influences on the two episodic memory measures. However, the more structurally complex comprehension model yielded some partially unexpected results. Hultsch et al. (1998) discovered that the addition of two specific-ability latent constructs vitally altered the mediation of episodic memory performance. Although this pattern of results was partially anticipated, the comprehension speed and reading comprehension constructs (i.e., the two latent variables related to comprehension) mediated almost all episodic memory influences, including entirely all influences exerted by both semantic speed and working memory! Gender had the only direct effect on both episodic memory measures. This pattern of relationships among these variables is very interesting in light of expected outcomes based on processing resource accounts. Processing resources are said to reflect basic components of cognition: components necessary for more complex cognitive operations. However, the fact that several hypothesized processing resources appear to operate through these latent constructs can be interpreted in one of several ways.

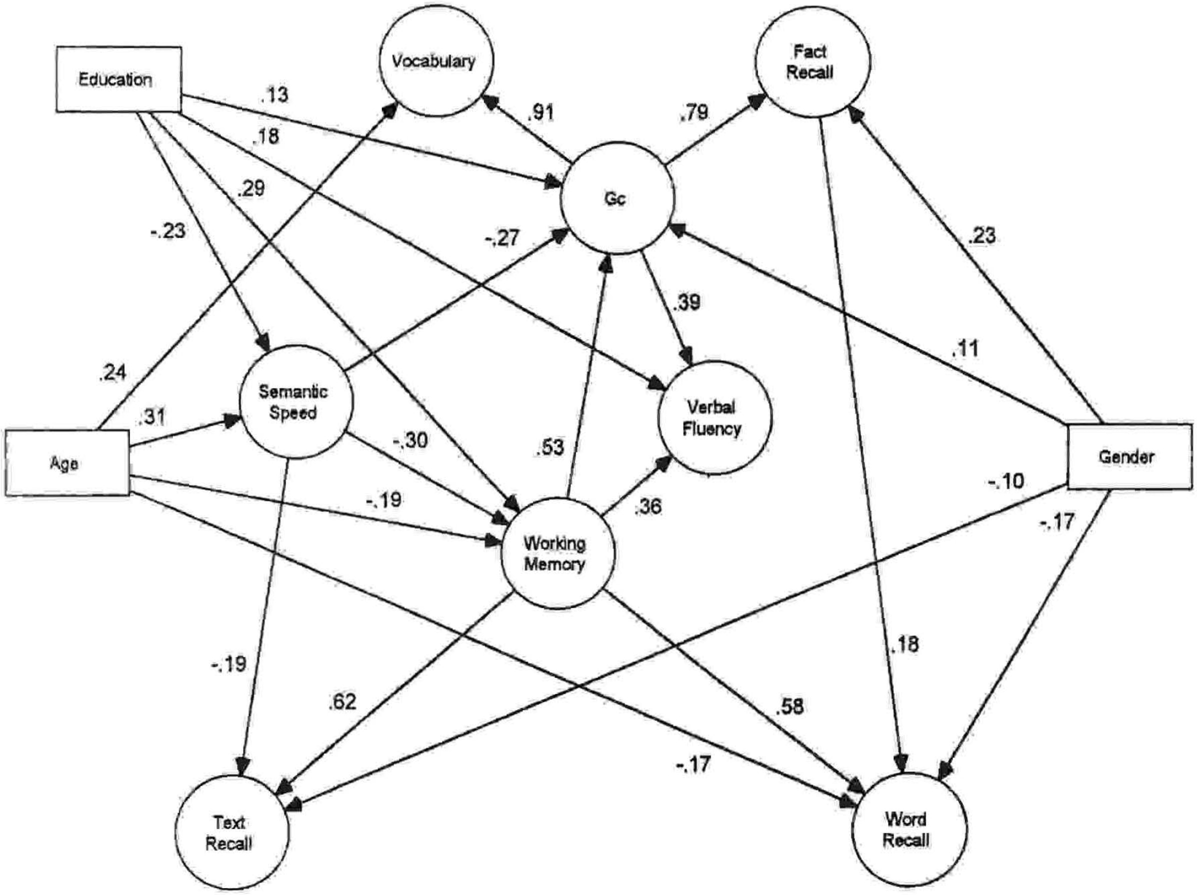

Figure 1. Basic Resource Model. From Hultsch et al., 1998, p.178.

From one standpoint, these findings can be criticized. The inclusion of a complex comprehension speed construct, for example, in addition to working memory and semantic speed factors necessitates a certain amount of overlapping variance among measures. Complex factors like comprehension speed do not represent individual component processes (e.g., working memory) specific to episodic memory tasks. Rather, the complex makeup of the comprehension speed construct may reflect components of variance redundant with more basic processing resources. Arguably then, complex

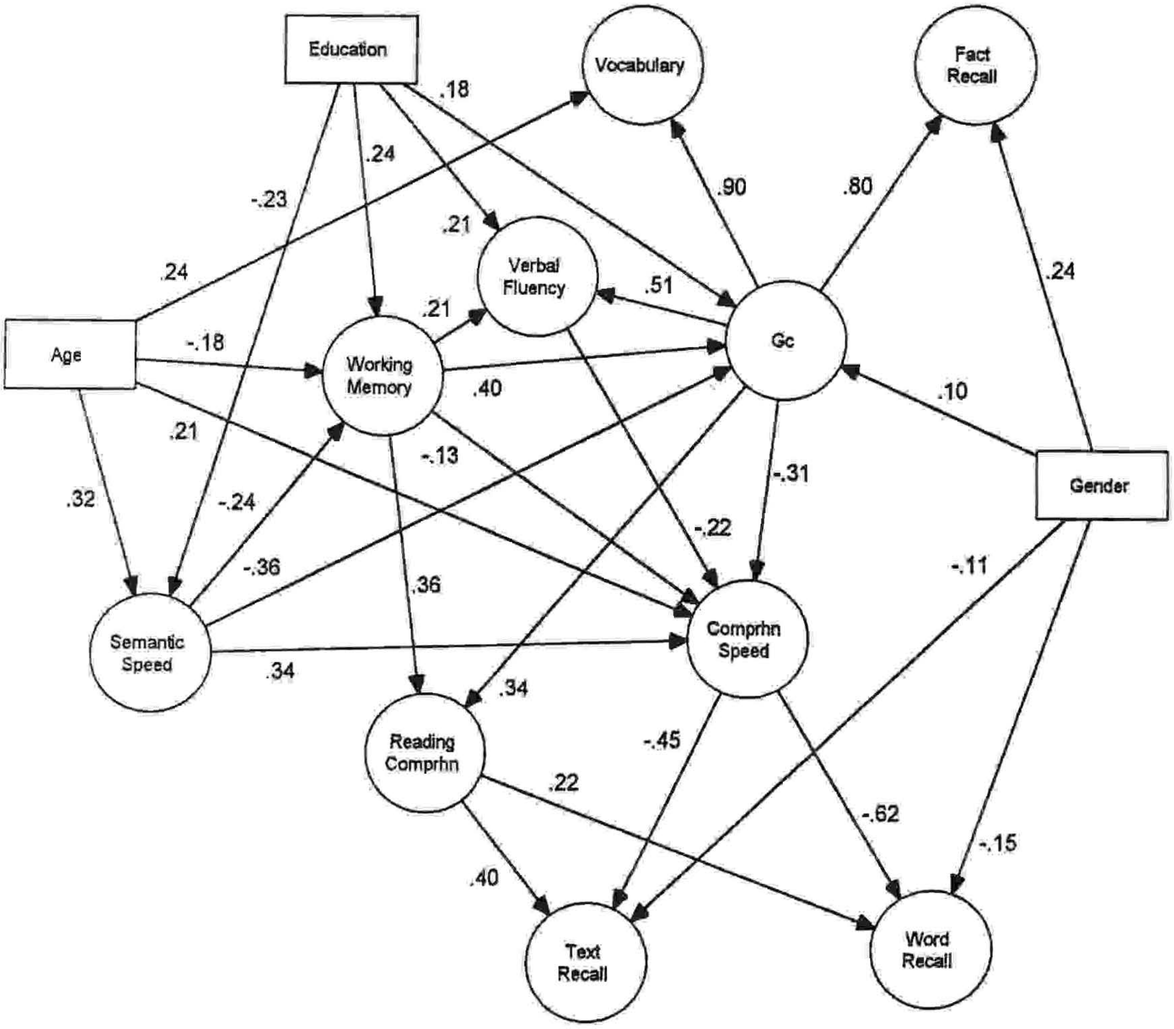

Figure 2. Comprehension Model. From Hultsch et al., 1998, p.183.

measures such as comprehension speed are predetermined to act as pivotal mediators of elementary resource variables. Conversely, although there is most certainly redundant variance shared between comprehension speed, basic speed, and working memory resources, an alternative perspective suggests that the relational structure of the comprehension model may indicate much more than just superfluous mediation. Based on the previously documented relations of processing resources to cognitive aging and in light of the fact that comprehension speed constructs mediate these basic resources, it seems plausible that comprehension speed may reflect processes important to memory and aging as well.

How then, can we reconcile the explanatory importance of processing resources with the fact that these resources exert only an indirect effect on episodic memory through comprehension speed? Is this simply a case of overlapping variance or the discovery of a variable potentially important to studies of cognitive aging? The potential relation between comprehension speed and cognitive aging provides the context and establishes the focus of the present investigation.

Purpose of the Present Inquiry

The comprehension model (Hultsch et al., 1998) portrays a structurally sound explanation of aging and episodic memory performance in contrast to a more basic resource account. However, is the comprehension model simply an instantiation of the basic processing measures included in the model, or does it explain variance associated with episodic memory performance over and above these basic resources? Before further defining the parameters of this investigation, it is important to make several clarifications. First, it is essential to differentiate between the latent construct of comprehension speed (as seen in Figure 2) and the manifest indicators that comprise it. The comprehension speed construct is a multi-determined latent factor. Confirmatory factor analyses (Hultsch et al., 1990; Hultsch et al, 1992; Hultsch et al, 1998) indicate that both a Reading Speed and Search-for-Answer indicator converge to form the complex comprehension speed factor. The reading speed indicator was one of several outcome measures derived from the Reading Comprehension Task. This task required participants to read six passages at their normal reading pace. After reading each passage, participants answered five specific questions derived from passage content. The reading time indicator was computed as time taken per proposition. The second indicator, the Search-for-Answer comprehension speed task (Masson, 1983), again required participants to read text passages. However, in this instance, the purpose was for participants to read each passage as quickly as possible in search of the correct response to a question posed prior to beginning to read the passage. The amount of time required to find the correct response per passage, for a total of 15 passages, served as the indicator of comprehension speed.

A second point requiring clarification, both at the latent level and the manifest level, concerns the choice of target measure for the present investigation. Although the reading comprehension construct represents a latent comprehension factor, this proposal considers only the comprehension speed construct for several reasons. At the latent level, age had a direct effect of .22 on the comprehension speed construct over and above the indirect influence of the basic resource measures; age had no direct effect on the reading comprehension construct (Hultsch et al., 1998). Further, as outlined in Figure 2, comprehension speed exerted larger direct effects on Word Recall and Text Recall (-.62 and -.45 respectively) than those exerted by reading comprehension (.22 and .40 respectively). As we are interested in the relationship between age and comprehension speed and given the larger direct influences the construct exerts, it seems justified to focus on the latent comprehension speed construct.

Refining the focus even further, this proposal targets only the manifest Search-for-Answer comprehension speed task as the primary measure of comprehension speed potentially related to aging. Several rationale underlie this decision. As a representative indicator of the latent comprehension speed construct, Hultsch et al. (1998) report that the Search-for-Answer task is a better statistical indicator of latent comprehension speed than the reading time indicator (a standardized factor loading of .84 versus .68 respectively). Moreover, this measure yields several different scores, both response latency and number of errors committed, affording greater flexibility for assessing age effects in the present investigation. Response time latency was recorded as a function of time to read each sentence, mean time to find the correct response per passage, and mean time to find the correct response averaged across all 15 passages (response latencies include additional attempts due to errors). The number of errors committed were also tallied for each passage. An error is defined as the number of additional attempts (to a maximum of three) required to read through a passage in order to find the correct response. Considering these factors, the Search-for-Answer task provides methodological advantages not afforded by the reading time measure. Based on its more complex structure (including both latency and error measures), the Search-for-Answer task lends itself better to investigating how age influences comprehension speed performance. With these justifications in mind, we now consider the research purpose and rationale.

The primary purpose of the present investigation is to more closely examine the characteristics of the Search-for-Answer task used in the Hultsch et al. (1998) comprehension model. Comprehension speed acts as a pivotal variable mediating the bulk of the influence of the basic processing resource measures. Confirmatory models indicate that age, working memory, crystallized intelligence, and semantic speed all exert their influence on episodic memory directly through the latent comprehension speed construct (Hultsch et al., 1998). But why does comprehension speed play such a central role in terms of mediating age-related decline on episodic memory tasks?

As comprehension processes are quite complex, undoubtedly a full understanding to the above question requires experimental examination. However, it is still desirable to examine this question and the complexity of the Search-for-Answer task using extant VLS data. The general rationale for this approach rests on 4 main points: (a) the merits of the Search-for-Answer comprehension speed measure; (b) the potential relation between comprehension speed and cognitive aging; (c) whether the Search-for-Answer comprehension speed measure is simply an instantiation of more basic processing resources; and (d) the possibility that the Search-for-Answer task is an index of a Long-Term Working Memory construct. Each of these points are respectively addressed in turn.

Chapter II

RESEARCH RATIONALE

Research Rationale

Rationale #1: Merits of the measure. The complex nature of comprehension speed is apparent given its wealth of predictors. Numerous underlying processes contribute to the comprehension speed construct including lexical access, working memory, inference building, and long-term retention, integration, and retrieval of information (Masson, 1983; Salthouse, 1991a; Sticht, 1977).

However, lacunae exist in the extant literature concerning the relative contributions of substrate component processes to comprehension speed performance. Ironically, it is precisely the complex composition of the Search-for-Answer task that makes it an ideal medium in which to better understand processes (e.g., aging) associated with its component derivatives. Investigating the construct of comprehension speed may renew interests in the component processes (e.g., working memory, psychomotor speed) that contribute to comprehension speed. Moreover, a better understanding of the relationships among these component measures may provide insight into age-related differences in complex cognitive performance.

Rationale #2: A potential relation between comprehension speed performance and cognitive aging? A thorough investigation of the Search-for-Answer task is warranted to clarify the relations between age, cognition, basic resources, and comprehension speed. Given documented relations between aging and comprehension speed as well as aging and cognitive resources (see Salthouse, 1991a), it seems plausible to hypothesize

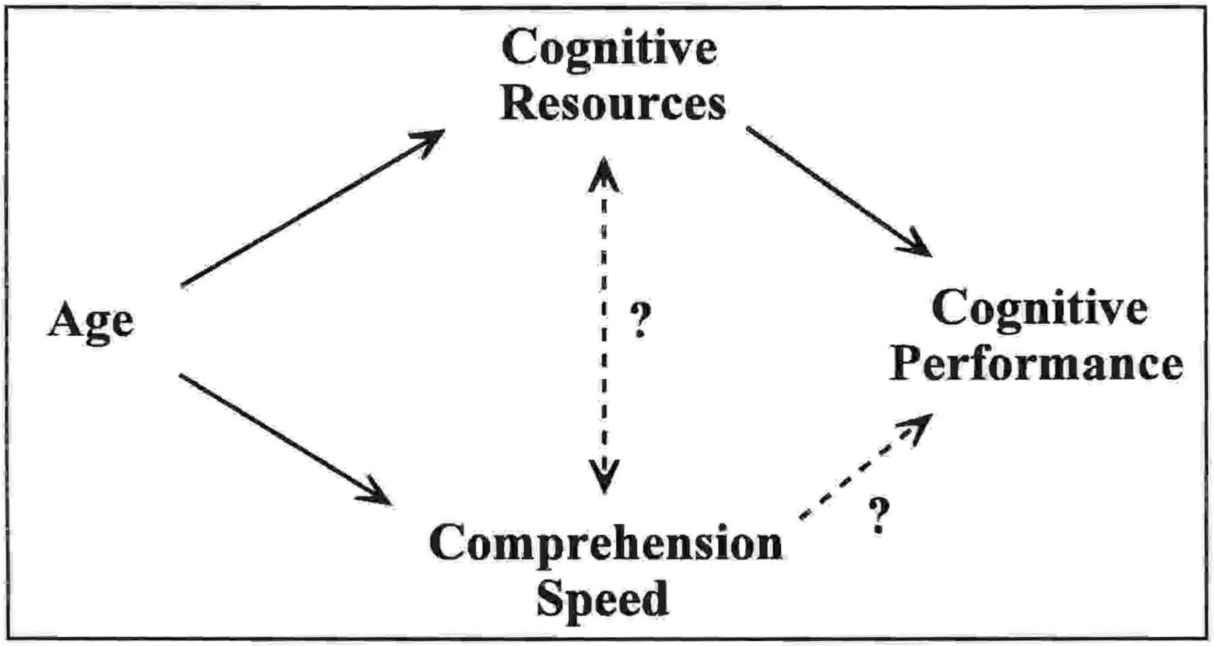

Figure 3. Hypothetical relations between age, comprehension speed, and cognitive resources

associations between comprehension speed (and its determinants) and cognition including age-related decline in cognition (see Figure 3). Although the Hultsch et al. (1998) comprehension model indicates that comprehension speed is an important mediator of age differences for cognitive tasks, it is not clear whether basic resource components of comprehension speed account for this finding. Contrary to previous findings demonstrating direct relations between cognitive resources and cognitive performance, basic cognitive resources exert their influence on cognition through comprehension speed in the Hultsch et al. findings. In accord with previous demonstrations of relations between age and complex cognitive measures (for a review, see Hultsch & Dixon, 1990; Kausler, 1994 ; Salthouse, 1991), comprehension speed may similarly prove important to cognitive aging research based on its association with underlying components or mechanisms of age-related decline. Although the Search-for-Answer task represents but a single indicator of the overall construct of comprehension speed, the substrates and related variance associated with this task are of primary importance. Indeed, interest in the Search-for-Answer comprehension speed task transcends any relation this measure might share with comprehension speed proper. The present investigation is primarily concerned with the association this task and its component processes share with processes involved in cognitive aging.

Rationale #3: Is the Search-for-Answer comprehension speed measure simply an instantiation of basic resources? Although the comprehension model provides a good structural fit to the data (slightly better that the basic resource account), the model may be criticized as representing a redundant instantiation of the basic processing measures included in the model. If this is truly the case, then an investigation of the Search-for-Answer task contributes little of consequence to investigations of cognitive aging. However, it is not clear whether the Search-for-Answer task explains variance associated with age-related decline over and above these basic resources.

In an attempt to respond to this potential criticism, Hultsch et al. (1998) tested an alternative to the comprehension model that considered direct effects of intelligence on word recall, text recall, reading comprehension, and comprehension speed. The resource measures of working memory and semantic speed were used as the principal (i.e., direct) predictors of episodic memory. Essentially, the hypothesis associated with this model evaluated whether the basic resource measures are the true source of effects on episodic recall (Hultsch et al., 1998). Hultsch et al. (1998) found that although this model fit well, there was a slight loss of fit relative to the original comprehension model. The structural evaluation of this model indicates that comprehension speed is probably not simply an instantiation of basic resources. Based on this hypothesis test, Hultsch et al. (1998) report that any explanation incorporating basic resources as the sole source of prediction for episodic recall can be rejected due to the relative fit of the model.

However, although we know that inclusion of the latent comprehension speed construct produces complex interrelationships in structural models, what exactly are these relations and what do they indicate about the Search-for-Answer comprehension speed measure? One possibility proposed by Hultsch et al. (1998) is that the Search-for-Answer task represents an approximation of Ericsson and Kintsch's (1995) Long-Term Working Memory (LT-WM) construct.

Rationale #4: Is comprehension speed an index of the long-term working memory construct? The construct of LT-WM was first conceived in an attempt to account for seemingly expert performance in spite of large cognitive demands. The standard definition of working memory refers to the temporary storage of information that is readily accessible for only a short period without resorting to rehearsal (e.g., Baddeley, 1986). However, many expert tasks such as text comprehension require the maintenance of large amounts of information in a readily accessible form (e.g., the individual needs contextual information to coherently integrate information presented in the current sentence with the text previously read). How then, given the restrictions apparent in standard definitions of working memory, can we account for expert performance for example? Can the same account that explains limited working memory capacity in simple lab tasks also account for the greatly expanded working memory capacity of experts and skilled performers? This seems unlikely. In fact, Ericsson and Kintsch (1995) argue that a LT-WM mechanism is necessary to reconcile extant research findings.

To clarify terminology, Eriscsson and Kintsch (1995) refer to traditional working memory as Short-Term Working Memory (ST-WM) and label the skilled use of storage in Long-Term Memory (LTM) as Long-Term Working Memory (LT-WM). Unlike the unstable nature of information stored in traditional working memory, information available to LT-WM is stored in a stable form. However, in some respects similar to the temporary storage of information in traditional working memory, reliable access to information stored in LT-WM is maintained only temporarily by means of retrieval cues in Short-Term Working Memory (ST-WM). Thus, LT-WM is distinguished from ST-WM based on both durability of storage it provides as well as the need for sufficient retrieval cues in attention in order to access the information in long-term memory (Ericsson & Kintsch, 1995). Of note, failures of LT-WM would not be a consequence of forgetting but rather a consequence of inaccessible retrieval cues: presumably the skilled information stored in LTM remains intact. Although investigations of the LT-WM mechanism are only in preliminary stages, support for this mechanism is derived from findings indicating that skilled activities (e.g., mental chess) can be interrupted and resumed after delay without adversely affecting performance (Ericcson & Kintsch, 1995).

Interestingly, the description of this LT-WM mechanism parallels the Hultsch et al. (1998) comprehension model findings in several key ways. In many respects, conceptual explanations of the theoretical construct of LT-WM reflect the same patterns observed in the structural findings. For example, LT-WM postulates a relation between working memory performance and episodic memory performance. Specifically, retrieval cues present in working memory permit access to information stored in long-term memory, such as episodic memory. How then, does this pattern of associations relate to the comprehension model? The Hultsch et al.(1998) findings posit comprehension speed as a mediator of episodic memory performance. More specifically, the Search-for-Answer task was shown to mediate the influence of basic resource factors including working memory on long-term episodic memory performance. Based on these findings, an argument could be made suggesting the Search-for-Answer task demonstrates empirically the construct Ericsson and Kintsch (1995) specified theoretically.

According to Ericsson and Kintsch (1995), superior text comprehension for example, reflects superior skill in encoding information in long-term memory thus allowing a larger amount of information to remain accessible by means of cues in ST-WM. Such a prediction makes sense in light of the structural outcomes documented: Text and Word Recall are mediated by comprehension speed, perhaps due to the variance comprehension shares with processes involved in LT-WM. Also of interest, the comprehension model shows independent paths not only from working memory but from semantic speed and crystallized intelligence as well. The pattern of results depicted in the comprehension structural model are consistent with what would be expected based on Ericsson and Kintsch's (1995) description of LT-WM.

Given the obvious similarities between the LT-WM construct and their findings, Hultsch et al. (1998) have suggested that the comprehension speed measure "may be a relatively good index of the kind of dynamic, on-line process of exchange between working memory and long-term memory that Ericsson and Kintsch (1995) first characterized as long-term working memory" (p.278). Not only is the comprehension speed measure an excellent predictor of episodic recall, age itself has an independent structural path to comprehension speed performance separate from the mediational influence of any basic resource factors. This too is curious as the dynamic, complex Search-for-Answer task is far more age-sensitive than would have been hypothesized by any processing resource accounts or than would be expected with the inclusion of basic resource variables (Hultsch et al., 1998).

Through examining the underlying determinants, association with age, and relationships to other cognitive resources, the purpose of this investigation is to provide a better understanding of what the Search-for-Answer task is a proxy for and how it can best be utilized in future investigations of cognitive aging.

Chapter III

METHOD

The present analysis is based on cross-sectional data from Sample 2 of the Victoria Longitudinal Study (VLS). The design of the VLS consists of longitudinal sequences in which multiple cross-sectional samples of middle-aged and older adults are retested at intervals of three years with new samples added at intervals of six years. The general design, participants, measures, and procedures of the VLS have been described extensively elsewhere (see Dixon, Wahlin, Maitland, Hertzog, & Bäckman, manuscript submitted for publication), and therefore, these components of the method will only be summarized here as they pertain to this report.

Participants

Participants in the VLS were community dwelling adults living in a medium-size metropolitan area (Victoria, British Columbia) recruited through advertisements in the public media and appeals to community groups. The initial cross-section of Sample 2 consisted of 530 adults (355 women and 175 men) ranging in age from 54 to 94 years ($\underline{M} = 68.53$, $\underline{SD} = 7.61$) and tested in 1992-93. An additional sample of 100 university students (52 women and 42 men) ranging in age from 17 to 36 years ($\underline{M} = 23.35$, $\underline{SD} = 4.91$) comprised the Young age group. A total of 602 participants (392 women and 210 men) provided complete data on the measures relevant to the present analyses. Of the 602 participants who completed the VLS battery, 4 participants were omitted from the present analyses. Two participants had difficulty performing the computer reaction time tasks due to serious vision conditions (glaucoma and legal blindness). The other 2 participants were omitted subsequent to a screening analysis indicating their scores showed substantial departure from the normal distribution for most of the target measures. In particular, the scores for these individuals were 5.65 and 8.69 standard deviation units above the mean score on the criterion Search-for-Answer task (the next nearest outlier was 3.79 standard deviations above the mean for a distribution of 602 participants). Omission of these participants had no impact on the main findings; in fact, a gender difference surfaced in favour of males upon omitting the single male outlier (SD = 8.69). Thus, with respect to complete data, the mean age of the 501 community dwelling participants was 68.1 years (SD = 7.18) whereas the mean age of the 97 university participants was 23.4 years (SD = 4.91).

Examination of the characteristics of the 501 older adults indicated that the participants constituted a relatively select group compared to the general population. Within this sample, 88.7% had completed at least 11 years of education and 51.1% had completed at least 14 years of education. Comparable figures for the Province of British Columbia are 51% and 18%, respectively (Statistics Canada, 1989b). The average level of education of the sample was 14.81 years (SD = 3.15). Although most of the participants were retired, they also showed substantially higher levels of occupational attainment than the general population. Within the sample, 59.6% held, or previously held, professional or semiprofessional jobs, whereas only 2.0% were classified as unskilled. This compares to 27% professional and semiprofessional and 9% unskilled for the population of the province (Statistics Canada, 1989a). In addition, over 85% of the participants rated their health as very good or good. On a 5-point scale ranging from (0) very good to (4) very poor, a mean self-perceived health rating of 1.3 was observed (SD = 1.34). Neither the correlation between years of education and age (-.08) nor self-perceived health and age (-.005) was statistically significant.

In order to further facilitate age comparisons and accentuate age-related trends in comprehension speed performance, the full sample of 598 adults was divided into four age groups representing different birth cohorts. The following values summarize the age characteristics for each of these 4 categories: (a) the Young age group (n=97) ranged in age from 17 to 36 years with a mean of 23.4 years (SD = 4.91); (b) the Young-Old age group (n=174) ranged in age from 54 to 64 years with a mean of 60.4 years (SD = 2.95); (C) the Mid-Old age group (n=225) ranged in age from 65 to 74 years with a mean of 69.3 years (SD = 2.83); and (d) the Old-Old age group (n=102) ranged in age from 75 to 84 years with a mean of 78.5 years (SD = 2.66). These age classifications facilitate cross-sectional analyses focused on documenting age-related differences in comprehension speed performance.

Materials

The test battery for the VLS consists of over 20 measures ranging from indicators of fluid and crystallized intelligence to tests of sensory acuity. However, only a small subset of these measures are germane to this thesis. Tasks relevant to the current research investigation include measures of perceptual speed (e.g., Identical Pictures and Number Comparison), verbal speed (e.g., Lexical Decision Task and Semantic Verification Task), working memory (Sentence Construction, Number Span, and Word Span), episodic memory measures (Word and Text Recall) and measures of comprehension speed

(Search-for-Answer task and Reading Comprehension Speed). As the battery and its component measures have been thoroughly presented elsewhere (for a comprehensive review, Hultsch et al., 1998), the measures pertinent to the current analysis will be only briefly described here.

Dependent Measures

Search-for-answer task. The Search-for-Answer task, a complex cognitive task, incorporates several component processes, including information processing, working memory, and knowledge. Participants were required to read a question and then to skim over passages of varying length in search for an answer to this question. Fifteen passages were presented, one sentence at a time, with passages varying from 1 to 9 sentences in length. All answers to the questions posed were contained in each passage; the correct answer was always found in the last sentence of each passage. Participants who failed to find the correct response on their first attempt were required to read through the passage a second time. If necessary, participants were given three chances to find the correct response for each of the 15 passages. Dependent variables of interest include response latency and response accuracy (number of errors committed). Total response latency averaged across all 15 passages as well as total response latency per passage (including additional attempts) were recorded as response latency outcome measures. Total mean errors averaged across all 15 passages and total errors per passage represent the error outcome measures.

Reading comprehension speed. Performance on the reading comprehension measure was assessed on the basis of recording the amount of time taken by each participant to read a series of 6 passages, one sentence at a time. Participants were instructed to read at their normal speed and to press a button in order to display the subsequent sentence for each passage. Approximately 8 sentences were included in each of the 6 passages. The reading time measure was computed as the amount of time taken to read each proposition averaged across all passages. This reading time measure is one of the indicator measures of comprehension speed in the comprehension model (Figure 2). Immediately after reading each of the 6 passages, participants were required to answer 5 factual questions about the passage in order to ensure their comprehension of the material (i.e., to ensure they were not simply skimming the material at a rate precluding comprehension). Performance on this portion of the task underlies the reading comprehension construct in the comprehension model (Figure 2). The number of errors made in response to these questions for each passage were also recorded.

Predictor Tasks

Perceptual processing speed measures. Previously, Salthouse (1992c) has identified 2 general measures used to approximate perceptual processing speed: the Identical Pictures and Number Comparison measures. Both of these measures are included in the VLS battery. The Number Comparison and Identical Pictures tests each consist of pages containing pairs of numbers and pattern arrays on which to base ones response. For the Number Comparison Task, the goal is to identify whether or not the number on each side of a target pairing is identical or not. If the numbers comprising the pair are not identical, an ‘X’ is to be placed on the line between them. Otherwise, participants are instructed to continue with the next pairing. Similarly, the goal of the

Identical Pictures Task is to match patterns from a specified target with its counterpart in a comparison array by marking a line below the correct match. A time limit of 90 seconds is imposed for each test with the total number of correct responses indicating approximate speed of performance. As previous research (Salthouse, 1992c) has indicated these tasks both approximate perceptual processing speed, composite scores based on the average of standardized z scores for each of these measures were computed for the purposes of entry into the hierarchical regression analysis. This composite score comprised of number comparison and identical picture performance is arguably the best predictor of the processing-speed theory of cognitive aging.

Verbal processing speed measures. The two measures chosen to represent the amount of time required for verbal processing include the Lexical Decision Task and the Semantic Verification Task. Performance on the Lexical Decision Task represents the amount of time required to recognize words. As formatted for the VLS, the Lexical Decision Task consists of a computer presentation of strings of letters forming either English words or nonsense words. Participants are asked to discriminate between words and non-words and to indicate their response by pressing ‘y’ or ‘n’ keys on a response keyboard. Mean response latencies in milliseconds are recorded over 60 trials. The Semantic Verification or decision time task is a variant of the Lexical Decision Task which requires participants to assess whether a presented target sentence is meaningful. Participants are asked to judge the plausibility of 50 sentences; performance latency response time is recorded by keystroke response in milliseconds. Confirmatory factor analyses (for a review, see Hultsch et al., 1990; Hultsch et al., 1992) reveal that both the

Lexical and Semantic Decision Tasks converge to form a simple verbal processing time factor. For the purposes of entry into the current hierarchical regression analyses, mean correct response latencies for both measures are converted into standardized z scores and subsequently averaged to form a composite verbal processing speed measure. Although this composite measure is not reflective of solely psychomotor or perceptual speed, verbal processing speed is considered to be a basic speeded resource contributing to success on more complicated cognitive tasks. Given this rationale, verbal processing speed is suggested to represent a variant of Salthouse's (1996b) perceptual speed of cognitive decline hypothesis.

Working memory measures. Three measures were administered in order to approximate participant's working memory. The Sentence Construction Task as well as measures of Reading Span and Computation Span were demonstrated to converge to form a working memory factor on the basis of a confirmatory factor analysis (Hultsch et al., 1992). The Sentence Construction measure required participants to read a series of sentences. While reading the series, target words in each sentence were highlighted and participants were instructed to remember the highlighted word for each sentence. Upon completion of reading the series of sentences, participants were asked to recall the highlighted target words in order: when combined across the series, these highlighted words formed a sentence. Task difficulty was varied by increasing the number of sentences and consequently the number of words to be recalled in each series (ranging from 3 to 6 words to be recalled). The number of correctly reproduced new sentences was the measure of interest.

The Reading Span and Computation Span tasks are fully outlined elsewhere (Salthouse, 1992b). Trials in the Reading Span task involved the presentation of a sentence followed by a short question and the choice of three responses. Participants chose the best response and then proceeded to the next sentence. A specified number of sentences followed by questions and responses were presented until such time that participants were asked to recall the last word presented in each sentence. The Computation Span Task was analogous save for the fact that mathematical problems were presented that required the recall of the last digit in each problem rather than the last word. The response measure used was the largest number of items recalled correctly for at least two of three trials for a given sequence length.

As the Sentence Construction, Reading Span, and Computation Span measures have previously shown to converge on a common latent working memory factor (Hultsch et al., 1990), standardized scores were used to create an unweighted working memory composite measure for the purposes of the present investigation. This working memory composite measure serves as the representation of working memory entered into the hierarchical prediction models of comprehension speed performance.

Episodic memory measures. The measures of Word and Text Recall were included in order to represent episodic memory performance. Although on a continuum of basic cognitive processes these factors represent products rather than processes, they are nonetheless important to this investigation. In particular, given the hypothesized importance of comprehension speed to Long Term-Working Memory, we would expect to find a relationship between episodic memory performance and comprehension speed

The Reading Span and Computation Span tasks are fully outlined elsewhere (Salthouse, 1992b). Trials in the Reading Span task involved the presentation of a sentence followed by a short question and the choice of three responses. Participants chose the best response and then proceeded to the next sentence. A specified number of sentences followed by questions and responses were presented until such time that participants were asked to recall the last word presented in each sentence. The Computation Span Task was analogous save for the fact that mathematical problems were presented that required the recall of the last digit in each problem rather than the last word. The response measure used was the largest number of items recalled correctly for at least two of three trials for a given sequence length.

As the Sentence Construction, Reading Span, and Computation Span measures have previously shown to converge on a common latent working memory factor (Hultsch et al., 1990), standardized scores were used to create an unweighted working memory composite measure for the purposes of the present investigation. This working memory composite measure serves as the representation of working memory entered into the hierarchical prediction models of comprehension speed performance.

Episodic memory measures. The measures of Word and Text Recall were included in order to represent episodic memory performance. Although on a continuum of basic cognitive processes these factors represent products rather than processes, they are nonetheless important to this investigation. In particular, given the hypothesized importance of comprehension speed to Long Term-Working Memory, we would expect to find a relationship between episodic memory performance and comprehension speed performance in the hierarchical prediction equations.

The Word Recall test required participants to study two word lists, from a total set of six, consisting of 30 common English nouns for 2 minutes each. Each list was comprised of 6 words from 5 taxonomic categories (e.g., fruits, tools) appearing randomly on a single page. After each 2 minute study period, participants were provided 5 minutes for free recall. The total number of words recalled from each of the two lists yielded the target measure of total word recall.

Text Recall was measured by gist recall of two narrative stories concerning life events of older adults. A total of 6 stories were selected from a larger set of 25 structurally equivalent texts developed by Dixon, Hultsch, and Hertzog (1989). Each story was structured to contain approximately 300 words and 160 propositions. Participants were provided 4 minutes to study each story followed by10 minutes to write down what they recalled. The proportion of propositions recalled (gist recall) from each story were evaluated by raters according to scoring criteria specified in Dixon et al. (1989). Inter-rater reliability exceeded 90%. Gist propositions recalled from both stories were summed to yield the total measure of text recall.

Experimental Procedures

All of the measures included in the VLS were administered during the course of 4 separate testing sessions, each approximately 2 hours in length scheduled over a period of approximately 30 days. Planned rest periods were taken part way through each session. Groups of 10 or fewer participants were administered all of the paper-and-pencil component measures of the VLS battery during the course of the first two sessions. The remaining computer-based tasks included in the battery were conducted on an individual basis during the third and fourth testing sessions. For all participants included in the analysis, the order of tasks within the 4 testing sessions was invariant.

Statistical Procedures

Two separate data analytic approaches were associated with this investigation. The analysis of mean age differences in Search-for-Answer response latency and accuracy used an Analysis of Variance (ANOVA) approach. The second analytic approach used hierarchical linear regression to further examine cognitive predictors of Search-for-Answer task performance. Particulars associated with each of these statistical approaches are discussed below.

Mean level analyses. A general factorial ANOVA approach was used to examine age group differences for both response latency and response accuracy scores. Several additional analyses were conducted subsequent to the introductory ANOVA investigations. First, a linear regression approach was used to covary the influence of response errors in order to determine the influence of accuracy on latency. The linear regression approach was adopted as opposed to an Analysis of Covariance (ANCOVA) in order to derive increment in R^2 estimates. Second, a repeated measures ANOVA approach was used to examine age differences as a function of a variety of Search-for-Answer passage characteristics (see Table 1). For response latency performance, a repeated measures ANOVA tested age differences as a function of passage length only. For response accuracy, separate repeated measures ANOVAS were conducted to examine age differences as a function of each type of passage characteristic. The

Table 1. Classification criteria and category for passage characteristics

Passage Number	Number of Words Per Passage and Category	Fry Graph Reading Grade Level and Category	Flesch-Kinkaid Reading Grade Level and Category	Target Sentence Length (words) and Category
1	49 (Short)	10 (Lower)	11.54 (Higher)	13 (Short)
2	118 (Long)	7 (Lower)	7.94 (Lower)	17 (Short)
3	101 (Long)	13 (Higher)	10.95 (Higher)	16 (Short)
4	57 (Short)	12/13 (Higher)	10.05 (Lower)	16 (Short)
5	83 (Short)	7 (Lower)	6.72 (Lower)	8 (Short)
6	126 (Long)	9 (Lower)	10.63 (Lower)	18 (Long)
7	46 (Short)	11/12 (Higher)	10.10 (Lower)	23 (Long)
8	34 (Short)	11/12 (Higher)	10.48 (Lower)	20 (Long)
9	143 (Long)	9 (Lower)	11.98 (Higher)	32 (Long)
10	105 (Long)	12 (Higher)	13.53 (Higher)	20 (Long)
11	41 (Short)	12/13 (Higher)	18.82 (Higher)	41 (Long)
12	43 (Short)	15/16 (Higher)	13.65 (Higher)	28 (Long)
13	55 (Short)	13 (Higher)	12.07 (Higher)	15 (Short)
14	88 (Short)	9 (Lower)	9.57 (Lower)	17 (Short)
15	111 (Long)	8 (Lower)	7.19 (Lower)	17 (Short)

continued

repeated measure variables included length of passage, Fry reading grade level, Flesch-Kinkaid reading grade level, target sentence length, distance to target sentence response, and target sentence complexity. Classification criteria and categories for each of these passage characteristics are presented in Table 1. The length of passage classification was based on the total number of words per Search-for-Answer passage. The Fry reading grade level index was computed by plotting syllables per 100 words as a function of

Table 1 (cont'd). Classification criteria and category for passage characteristics

Passage Number	Two Group Distance to Target Sentence Response (words) and Category	Four Group Distance to Target Sentence Response (words) and Category	Target Sentence Complexity (embedded clauses) and Category
1	13 (Long)	13 (Med-Long)	1 (Complex)
2	10 (Short)	10 (Med-Short)	0 (Simple)
3	8 (Short)	8 (Short)	0 (Simple)
4	9 (Short)	9 (Short)	0 (Simple)
5	8 (Short)	8 (Short)	0 (Simple)
6	18 (Long)	18 (Long)	1 (Complex)
7	11 (Short)	11 (Med-Short)	1 (Complex)
8	9 (Short)	9 (Short)	0 (Simple)
9	22 (Long)	22 (Long)	1 (Complex)
10	12 (Long)	12 (Med-Long)	0 (Simple)
11	17 (Long)	17 (Long)	1 (Complex)
12	15 (Long)	15 (Med-Long)	0 (Simple)
13	10 (Short)	10 (Med-Short)	0 (Simple)
14	17 (Long)	17 (Long)	0 (Simple)
15	11 (Short)	11 (Med-Short)	0 (Simple)

sentences per 100 words on Fry's graph for estimating readability (Fry, 1977). Plotting these two variables yielded a whole number Fry reading grade for each of the 15 passages. Flesch-Kinkaid reading grade level was computed using a mathematical formula (see Schuyler, 1982) that considers number of sentences, words, and syllables per passage. As opposed to the Fry reading grade level, the Flesch-Kinkaid index was computed directly. Target sentence length classification represented the number of words in the final sentence (i.e., the target sentence) for each passage. A variant of target sentence length, the distance to target sentence length classification was based on the number of words appearing in each target sentence prior to the correct response. If the target response does not appear until the end of the target sentence, this index is the same as the target sentence length index. Note that two classifications for distance to target sentence response were specified. Finally, the target sentence complexity classification was a function of sentence syntax (Norman et al., 1991). Complex target sentence constructions contain left-branching sentences (e.g., relative clause between subject and predicate) whereas simple target sentence constructions are comprised of right-branching or single clause sentences.

For all univariate and repeated measures statistical tests, a criterion alpha of .05 was used. Further, all post hoc pairwise multiple comparisons made among individual group means employed Tukey's Honestly Significant Difference (HSD) adjusted alpha levels; all multiple comparisons of group means were significantly different at an adjusted alpha level of .05.

Hierarchical prediction analyses. A linear hierarchical regression approach was used to examine predictors of Search-for-Answer performance. Several composite measures were computed for entry into the hierarchical models. Creation of composite measures required the derivation of standardized scores. These standardized scores were summed and averaged for all indicators relevant to a particular composite measure. Cognitive composite measures included Perceptual Speed (average standardized scores of

Number Comparison and Identical Pictures), Semantic Speed (average standardized scores of Lexical Decision Task and Semantic Verification Task), Working Memory (average standardized scores of Reading Span, Computation Span, and Sentence Construction Task), as well as Episodic Memory (average standardized scores of Word Recall and Text Recall). These composite cognitive measures represent both processes and products of cognition. Three a priori hierarchical regression models representing the resources of perceptual speed, semantic speed, and working memory were specified. The logic underlying the use of this approach to determine predictors of Search-for-Answer performance rests on varying the order of variable entry. On theoretical grounds (see Hultsch et al., 1990; Salthouse, 1991a), processes or resources of cognition (e.g., perceptual speed, working memory) are alway entered first in each model followed by products of cognition (e.g., episodic memory). Contrasting the variance accounted for by varying the order of predictor entry will determine whether individual differences in any of these cognitive composites accounts for variance associated with Search-for-Answer task performance. These hierarchical models were applied to the prediction of variance associated with total response latency, total response accuracy, age-related response latency, age-related response accuracy, and total response accuracy as a function of reading grade level.

At this juncture, it is appropriate to specifically state the hypotheses and expectations associated with this inquiry.

Chapter IV

OBJECTIVES AND HYPOTHESES

The focus of this investigation concerns understanding performance on the Search-for-Answer task, both in the sense of examining the nature of the task's relationship to age and in the sense of identifying indicators of task performance . In pursuing answers to these questions, this investigation has three primary objectives: (a) to examine age differences in Search-for-Answer comprehension speed performance, (b) to identify individual differences in cognitive abilities that predict Search-for-Answer comprehension speed performance, and (c) to contrast predictors of response latency for participants who performed perfectly across all Search-for-Answer passages compared with those who made 1 or more errors. These objectives and their associated hypotheses are discussed below.

Identifying Age Differences in Search-for-Answer Performance

Latency and error. In order to examine specific factors underlying differences on Search-for-Answer comprehension speed performance, it is first necessary to document the existence of reliable age differences on the task. Thus, the first objective of this investigation is to examine age differences in Search-for-Answer task performance. Further, age differences for both latency in arriving at the correct answer as well as number of errors made prior to reporting the correct answer will be examined. It is hypothesized that significant differences in performance will emerge between the Young, Young-Old, Mid-Old, and Old-Old age groups. Longer response latencies and an increased number of performance errors are expected for older age groups.

Latency differences as a function of error. The possibility exists that age differences in response latencies are simply a function of an increased number of performance errors. For every instance a response error is made, the participant must reread the entire passage prior to having an additional opportunity to respond. Obviously, response latencies will be slower for participants who make more response errors. Thus, a question that requires clarification concerns whether slower Search-for-Answer response latency is merely a function of response errors. It is hypothesized that significant age differences in response latency will remain even after partialing the influence of response errors.

Beyond these global indicators of performance, we are also interested in age differences in response latency and accuracy as a function of more specific influences. A number of Search-for-Answer passage characteristics (see Table 1) were identified as plausible influences of age differences. Each of these passage characteristics is hypothesized to place differential demands on cognitive resources. Salthouse (1985) has suggested that individual differences in processing ability (i.e., available resources) potentially explain decrements in cognitive performance with age. For example, based on both general and specific resource accounts, we might expect older age groups (Mid-Old and Old-Old) to exhibit slower response latencies and increased performance errors for more taxing passage characteristics compared with relatively easy ones. Hypotheses associated with each of these passage characteristics are considered in turn.

Increased latency as a function of passage length. As each of the 15 Search-for-Answer passages varies between 1 to 9 sentences in length (and thus in terms of the number of words per passage), the length of the passage may disproportionately affect response latencies, in particular for Mid-Old and Old-Old age groups. It is hypothesized that older age groups will exhibit increased response latencies relative to younger age groups for longer Search-for-Answer passages. Thus, of primary interest is the Age x Passage Length interaction.

Increased response errors as a function of passage length. Length of passage may also disproportionately influence the number of Search-for-Answer response errors. Conceivably, longer passages are more demanding, particularly for older age groups (e.g., Mid-Old and Old-Old). It is hypothesized that increased response errors will be observed for longer passages with increasing age: a significant Age by Passage Length interaction.

Increased response errors as a function of Fry reading grade level. Several passage characteristic categories were derived from information more specific than number of words. Fry reading grade level is an index of passage readability derived from the number of syllables and sentences in a passage. Based on the principle of limited resources, it is hypothesized that passages associated with a higher Fry reading grade level will produce a greater number of response errors. Further, it is hypothesized that this relation will be accentuated for older age groups (Mid-Old and Old-Old). The Age x Reading Grade Level interaction is of primary interest.

Increased response errors as a function of Flesch-Kinkaid reading grade level. The Flesch-Kinkaid index represents an additional measure of reading grade level. It is computed using the number of syllables, words, and sentences per passage. Higher scores on the Flesch-Kinkaid index indicate that the passage is more difficult to read. According to a theory of limited resources with age, it is hypothesized that passages associated with a higher Flesch-Kinkaid reading grade level will also be associated with a greater number of response errors, particularly for older age groups. The Age x Reading Grade Level interaction is of primary interest.

Increased response errors as a function of target sentence length. Although based on number of words, the target sentence length characteristic is not identical to the passage length characteristic. Target sentence length refers to the number of words in the target sentence (i.e., the final sentence of each passage). Just as a longer passage length might overtax available resources, it is hypothesized that longer target sentences will also be associated with an increase in response errors for older age groups (e.g., Mid-Old, Old-Old). The Age x Target Sentence Length interaction is of primary interest.

Increased response errors as a function of distance to target sentence response. A variant of the target sentence length characteristic, the distance to target sentence response category refers to the number of words that appear in the target sentence prior to the emergence of the correct response. It is hypothesized that longer distances to target sentence responses will be associated with increased response errors for older adults. The focus is the Age x Distance to Target Sentence Response interaction.

Increased response errors as a function of target sentence complexity. A final passage characteristic to be assessed reflects the syntactic structure of target sentences. Complex sentences include embedded clauses which are more difficult to process compared with single clause simple structure target sentences. It is hypothesized that older age groups will produce more response errors for complex target sentence structures compared with younger age groups. Again, of specific interest to this hypothesis is the Age x Target Sentence Complexity interaction.

Moving beyond the investigation of age differences, the following section considers individual differences in cognitive abilities that predict Search-for-Answer task variance.

Predicting Performance and Performance Differences on the Search-for-Answer Task

It is expected that significant age differences will be found for Search-for-Answer response latency and response error performance. However, determining that older age groups exhibit poorer average performance than younger age groups on the Search-for-Answer task does not indicate why this decline occurs. Building on the initial assessment of mean level patterns of age difference, a second objective of this investigation is to determine what factors predict Search-for-Answer performance for the target dependent measures (latency and errors) as well as what factors predict variance associated solely with age-related differences in performance. As outlined in the statistical methods section, a hierarchical regression approach will be used to identify the most influential predictors of Search-for-Answer performance.

Based on a theoretical conception of limitations in resources (Salthouse, 1985; 1991a), several hierarchical resource models are proposed. As mentioned in the introduction, both general resource and specific construct accounts of age-related decline have been proposed. To complement these accounts, measures of cognition included in the hierarchical analysis span a continuum from cognitive processes (e.g., perceptual speed) to cognitive products (e.g., episodic memory). Thus, both general resources and task specific influences will be evaluated as predictors of Search-for-Answer performance. Three basic models of interest apply to all of the proposed prediction analyses. These include a perceptual speed model, a semantic speed model, and a working memory model. In order to judge the relative importance of cognitive variables within hierarchical regression models, the order of variable entry needs to be varied. Specified according to this rule, each of the three basic hierarchical models enters basic processes of cognition first followed by products of cognition. Thus, the perceptual speed, semantic speed, and working memory predictors are entered first in their respective models followed by the entry of the other two resource measures. In the last block of each model, episodic memory is entered to represent the influence of products of cognition.

Although general resource compared with more specific resource accounts might both predict similar patterns of Search-for-Answer task performance, the relative type and importance of predictors would potentially differ. General accounts would postulate that individual differences in performance should be predicted by one or two factors that approximate general cognitive resources (e.g., perceptual speed) implicated in decline across many cognitive measures. Conversely, a task-specific account of performance differences might postulate a more complex or diverse pattern of predictors (i.e., a number of significant predictors) compared with a general resource account. Although one or several factors might be of particular importance for task-specific resource models, other indicators would significantly contribute to the prediction of Search-for-Answer performance over and above the influences of general resource measures.

Can both total and age-related variance be accounted for by one or several important predictor variables or does a more complex array of predictors (both general and specific) account for the majority of this variance? Based on the findings of Salthouse (1996b), it is hypothesized that perceptual speed, regardless of entry order into the hierarchical regression models, will attenuate a significant proportion of both total and age-related variance associated with comprehension speed performance. Quite simply, as it is suggested to represent a general resource, the results should indicate that perceptual speed is an important predictor of a broad cross-section of measures including Search-for-Answer performance. However, the general question remains as to whether other potential predictors of performance, such as working memory or episodic memory, will account for significant proportions of variance over and above the hypothesized importance of perceptual speed. Based on the Hultsch et al. (1998) findings, significant contributions from both semantic speed and working memory are anticipated. Results from the hierarchical models will hypothetically indicate whether Search-for-Answer performance differences are associated with concomitant individual differences in cognitive resources. Further, the pattern of predictor contributions will assist interpretation of why comprehension speed is such an important mediator of basic resources in the comprehension model findings (Hultsch et al., 1998). Prediction of performance for each variance type is discussed below.

Prediction models for total variance associated with response latency. Four hierarchical models are specified to examine total response latency variance: a perceptual speed model, a semantic speed model, a working memory model, and a Long Term-

Working Memory (LT-WM) model. As mentioned, regardless of order of entry, perceptual speed is hypothesized to be an important predictor of variance. However, the comprehension model findings (Hultsch et al., 1998) also indicate that semantic speed and working memory will be important influences. Further, if Search-for-Answer performance represents an approximation of the LT-WM construct (a facilitator between working memory and long term memory) as suggested by Hultsch et al. (1998), then it is hypothesized that both working memory and episodic memory will be significant predictors of Search-for-Answer performance.

Prediction models for total variance associated with response accuracy. Three hierarchical models are specified to examine variance associated with total response accuracy: a perceptual speed model, a semantic speed model, and a working memory model. These models will be useful for examining whether Search-for-Answer performance errors can be considered a manifestation of restricted processing resources. It is hypothesized that perceptual speed will be an important predictor of performance error variance but that semantic speed and working memory will also exert considerable predictive capacity.

Prediction models for age-related variance associated with response latency. Three hierarchical models are specified: a perceptual speed model, a semantic speed model, and a working memory model. As before, the order of variable entry is based on restricted resource accounts of age-related decline. It is hypothesized that perceptual speed will represent the most important predictor of age differences in Search-for-Answer response latency.

Prediction models for age-related variance associated with response accuracy. The approach for predicting age-related response error variance is identical to that of the response latency approach. The three basic hierarchical models are examined: the perceptual speed model, the semantic speed model, and the working memory model. As before, perceptual speed is hypothesized to be the most important predictor of age-related variance associated with response errors.

Additional analyses predicting total variance associated with response errors as a function of reading grade levels. In addition to total and age-related variance prediction analyses, the importance of predictors as a function of Flesch-Kinkaid passage reading grade level will be examined. As mean level analyses may indicate that age differences in response errors change as a function of passage characteristics, investigating differential patterns of prediction for specific passage characteristics is considered potentially important. A good index of passage characteristic difficulty is the Flesch-Kinkaid reading grade level index. It is hypothesized that prediction of response errors may change as a function of passage reading grade level. For example, it may be possible that general resources are less important for predicting lower reading grade level passages whereas these same general resources might exert considerable predictive influence for higher reading grade level passages. Indeed, such a pattern of results may be a function of differential demands placed on available resources for lower and higher reading grade level passages. In order to test this differential prediction hypothesis, three hierarchical models are examined for each reading grade level: a perceptual speed model, a semantic speed model, and a working memory model.

Predicting Response Latency as a Function of All Passages Correct Versus One or More Errors

Finally, the third objective of this thesis is to compare and contrast Search-for-Answer latency performance for participants who performed perfectly across all passages (perfect passage performance) compared with those who made 1 or more errors across passages (error passage performance). Thus, the purpose is to determine whether cognitive measures differentially predict perfect compared with error passage performance. It is important to examine similarities and differences between perfect and error passage performance in order to better understand how age and comprehension speed interact. For example, perhaps response latency performance for participants who answered correctly on the first attempt is better predicted by perceptual processing speed while response latency performance for participants requiring more than one attempt to correctly respond on at least 1 passage is better predicted by working memory. Intuitively, passage errors may be a function of restrictions in working memory. Thus, it is conceivable that Search-for-Answer performance for participants who make 1 or more errors across passages is predicted by individual differences in working memory. In comparison, performance for participants who respond perfectly across all 15 passages may be better predicted by perceptual speed.

This investigation is important for several reasons. To this point, hypotheses concerning Search-for-Answer comprehension speed performance have focused on measures comprised of a combination of perfect and error passage performance. Even though performance errors have been closely scrutinized in previous analyses, there is still good reason to separate and contrast perfect versus error passage performance. Essentially, analyzing total variance including correct and error performance may produce a biased estimate of the influence of certain predictors. On this basis, it is hypothesized that the importance of cognitive measures predicting performance including 1 or more errors will differ in magnitude (and potentially number) compared with cognitive measures predicting perfect performance across all passages. More specifically, it is hypothesized that working memory will be more highly associated with error passage performance compared with perfect passage performance. Contrasting the differences between perfect versus error passage performance may help explain Search-for-Answer age performance patterns with respect to restrictions in certain cognitive resources. Three hierarchical models (perceptual speed, semantic speed, and working memory) will be used to examine this hypothesis.

To further extrapolate on the above investigation, a final analysis is proposed. The distinction between prediction patterns for perfect versus error passage performance is potentially an important one. To the extent that perfect passage performance analyses show the importance of perceptual speed (and not working memory), the Search-for-Answer task may not be substantially different from other speeded tasks, at least with respect to common predictors. For example, previous structural equation models have indicated that the Search-for-Answer task and the Reading Comprehension Speed task load well on a single latent comprehension speed factor (Hultsch et al., 1990; Hultsch et al., 1992; Hultsch et al., 1998). Based on these documented empirical similarities, what factors really differentiate performance on the Search-for-Answer task from the Reading

Comprehension Speed task? Put another way, if only perfect passage performance is analyzed for the Search-for-Answer task, will the predictors of Search-for-Answer speed and reading comprehension speed differ at all? From this perspective, analyzing overall performance on the Search-for-Answer task and concluding that it has a complex structure may be misleading. Although working memory seemingly shares an important relation to overall Search-for-Answer performance (Hultsch et al., 1998), this relationship may be contingent on the inclusion of participant performance errors in the analysis. Ultimately, the goal is to determine whether patterns of age differences (and thus importance of cognitive resources) are differentially associated with perfect versus error passage performance. If differences do exist, it is imperative to depict in what way errors are influencing performance outcomes.

Chapter V

RESULTS

To coincide with the three research objectives, the following results are presented in three primary sections. The first section focuses on age differences in Search-for-Answer latency and accuracy. The second section considers the differential importance of cognitive measures as predictors of Search-for-Answer performance. The final section contrasts predictors of performance for participants who performed perfectly on all passages versus participants who made 1 or more performance errors.

Age Differences

The first research objective was to determine whether age differences were observed for Search-for-Answer comprehension speed performance; both response latency and errors were used as criterion variables.

Latency. Figure 4 shows the distribution of Search-for-Answer latency performance as a function of the Young, Young-Old, Mid-Old, and Old-Old age groups. The observed shift in distributions towards increased latencies across age group is consistent with our hypothesis of performance differences with age. The actual significance of these age differences are statistically evaluated in the following analysis of variance (ANOVA).

Table 2 shows the means and standard deviations associated with latency and error performance by age group and gender. To test for significant age differences in performance latencies, an Age x Gender (4 x 2) ANOVA was computed on mean latency performance averaged across the 15 Search-for-Answer passages. The main effect of age

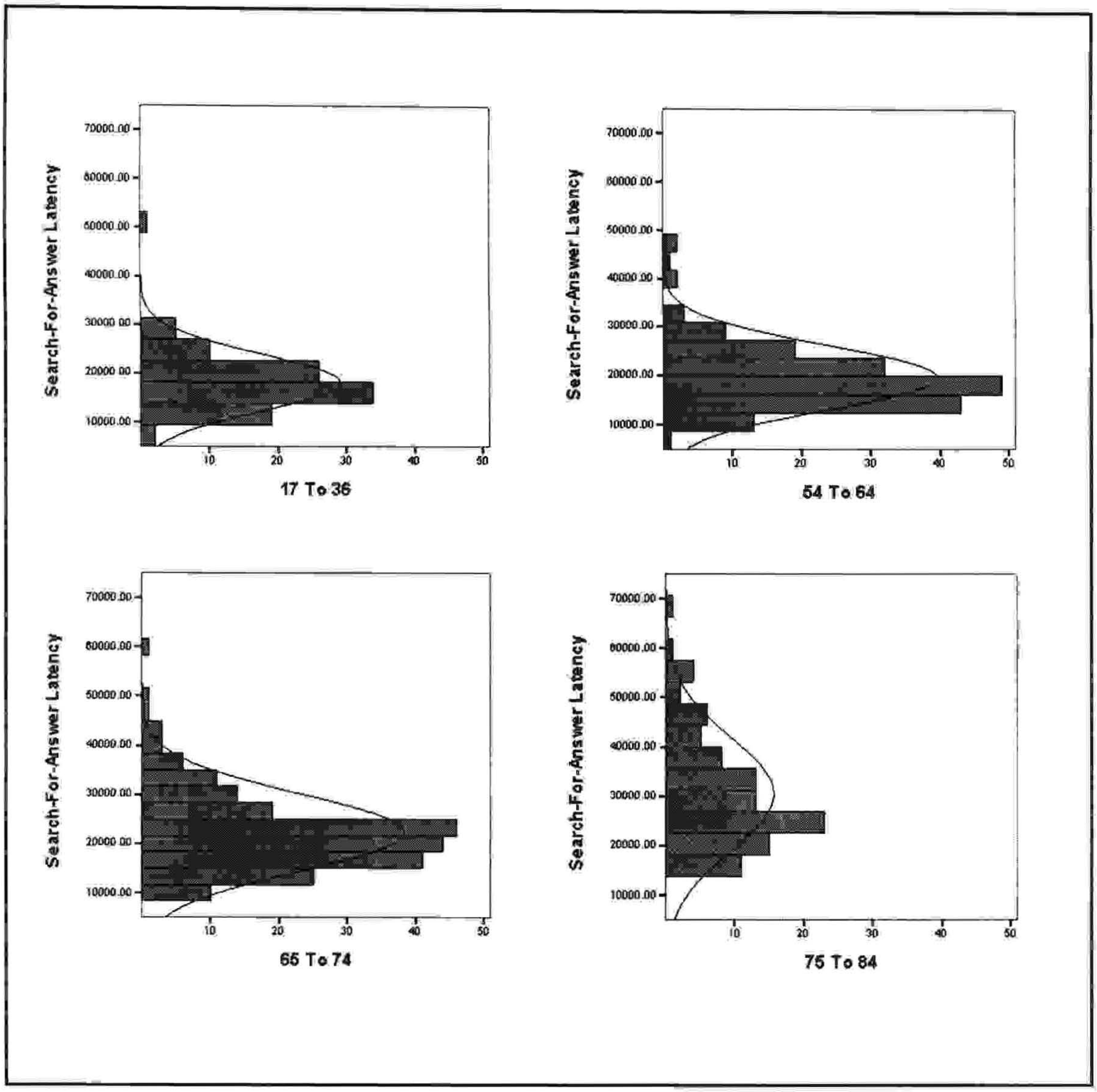

Figure 4. Search-for-Answer Latencies as a Function of Age

was statistically significant, F(3, 590) = 38.40, p < .001, $\eta^2 = .163$. Older adults had significantly longer response latencies than younger adults. In order to further evaluate which means differed significantly, a post-hoc Tukey's HSD multiple pairwise comparison was conducted. Save for the comparison between the Young and Young-Old

Table 2. Search-for-Answer latency and error mean scores as a function of age and gender

	Young (17-36 Years)		Young-Old (54-64 Years)		Mid-Old (65-74 Years)		Old-Old (75-84 Years)	
	Women (n = 52)	Men (n = 45)	Women (n = 117)	Men (n = 57)	Women (n = 143)	Men (n = 82)	Women (n = 77)	Men (n = 25)
Latency								
M	18307	17775	20180	18272	22966	21069	31109	28464
SD	6449	5066	7056	4873	8134	7081	11766	10088
Errors								
M	1.16	1.16	1.17	1.13	1.20	1.17	1.30	1.25
SD	.106	.116	.121	.097	.143	.114	.232	.205

Note. Total n = 598.

age groups, the results indicated significant differences in mean latencies for all remaining age group comparisons. In addition, the main effect of gender was also significant, F(1, 590) = 5.60, $p < .05$, $\eta^2 = .009$, indicating that males outperformed females on the Search-for-Answer task. However, the Age x Gender interaction was not significant.

Errors. An Age x Gender (4 x 2) ANOVA was conducted on the mean number of errors averaged across the 15 Search-for-Answer passages. The main effect of age was statistically significant, F(3, 590) = 13.60, $p < .001$, $\eta^2 = .065$. Older adults made significantly more errors on the task than younger adults. In order to further determine whether these mean error responses (see Table 2) significantly differed between each of the 4 age groups, post-hoc Tukey's HSD comparisons were conducted. The results indicated that the Old-Old age group differed significantly from each of three other age groups in terms of number of errors produced. No other adjacent group comparisons were statistically significant. The main effect of gender was also statistically significant, $\underline{F}(1, 590) = 4.41$, $\underline{p} < .05$, $\eta^2 = .007$, indicating that women made significantly more errors that men. As before, the Age x Gender interaction failed to reach significance.

For both of these preliminary analyses assessing differences in latency and error performance, the main effect of gender was statistically significant. However, as we made no a priori hypotheses regarding gender differences and, more importantly, because gender did not significantly interact with age, we will not explore gender differences any further in the remaining analyses.

Latency differences as a function of error. Based on the significance of the main effect for error in the above ANOVA, it is plausible that response latencies increase with age simply as a function of decreased response accuracy. In order to test whether the age effect for response latency was solely a function of increased errors, a hierarchical regression approach was used. Two models were computed. The first model considered only age whereas the second model entered errors in the first block followed by age in block 2. Comparison of the amount of variance accounted for by age with and without error in the equation provides an estimate of the variance associated with age independent of errors. Table 3 shows the statistical control of error resulted in over 50%[1] attenuation of age-related variance in Search-for-Answer latency performance. Despite the

---

[1] Computation of this proportion of variance is derived from the following equation: the R^2 for age alone (.113) subtract the increment in R^2 for age (.053) divided by the R^2 for age alone (.113) = .5309 multiplied by 100 produces the observed proportion.

Table 3. Age-related variance in response latency prior to and following the statistical covariation of performance errors

Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	% Attenuation Age Variance
Age	.113	.113	76.03*	
Number of Errors	.323	.323	284.42*	
Age	.376	.053	50.61*	53.1%

*$p < .01$.

substantial attenuation of age-related variance by the error variable, the addition of age into the hierarchical analysis after covarying error was still highly significant $F(1, 595) = 78.89$, $p < .001$. The increment in R^2 for age indicates that the age variable still uniquely explains 5.3% of the variance in latency performance over and above what error predicts. Further, relative to the initial total age-related variance in latency performance (11.3%), 46.9% of this initial age-related variance remains to be accounted for after partialing error variance. Thus, significant differences with age in Search-for-Answer performance latencies are not merely reflective of an increased number of performance errors; the main effect of age remains even subsequent to covarying variance associated with errors. Nonetheless, it is apparent that performance errors exert a considerable influence on performance latency.

Potential Factors Underlying Increased Response Latency

Length. The preliminary analyses indicated that Search-for-Answer response times increased with age irrespective of response errors. Thus, it remains unclear what additional factors contribute to this increase and how such factors are related to age. One plausible account considers the influence length of passage exerts on increased response latencies. In particular, the interaction between length of passage and age is of interest. It was hypothesized that age differences in favour of the young would be greater on longer passages than on shorter passages. In order to test this hypothesis, a 4 x 2 (Age x Length) repeated measures ANOVA was conducted. Length of passage represents the repeated measures variable with length categories constructed by ranking the 15 passages according to total number of words. Two composite categories, short and long, were created based on this ranking (see Table 1). The main effects in this analysis associated with age and passage length are not of practical and theoretical interest. The main effect of age essentially duplicates the previous analysis and the main effect of passage length is theoretically trivial since longer passages take more time to read irrespective of ability. The interaction between age and length, however, is potentially meaningful. Indeed, as hypothesized, the 4 x 2 (Age x Length) mixed-design interaction, $\underline{F}(3, 594) = 31.74$, $\underline{p} < .001$, $\eta^2 = .138$ was significant. This interaction indicates that the age-related differences in response latencies are greater for longer passages compared with shorter passages (see Figure 5).

In order to identify what was driving this interaction, a simple effects analysis was used to statistically decompose the differences between short and long passage lengths within each age group level. Within each level of age, the simple effects analysis indicated that response latencies were significantly larger for long versus short passages (Young, $\underline{F}(1, 594) = 277.77$, $\underline{p} < .001$, $M_{\underline{short}} = 11756.15$, $SD = 4655.82$, $M_{\underline{long}} = 23932.29$, $SD = 7567.38$; Young-Old, $\underline{F}(1, 594) = 751.54$, $\underline{p} < .001$, $M_{\underline{short}} = 11704.90$, SD =

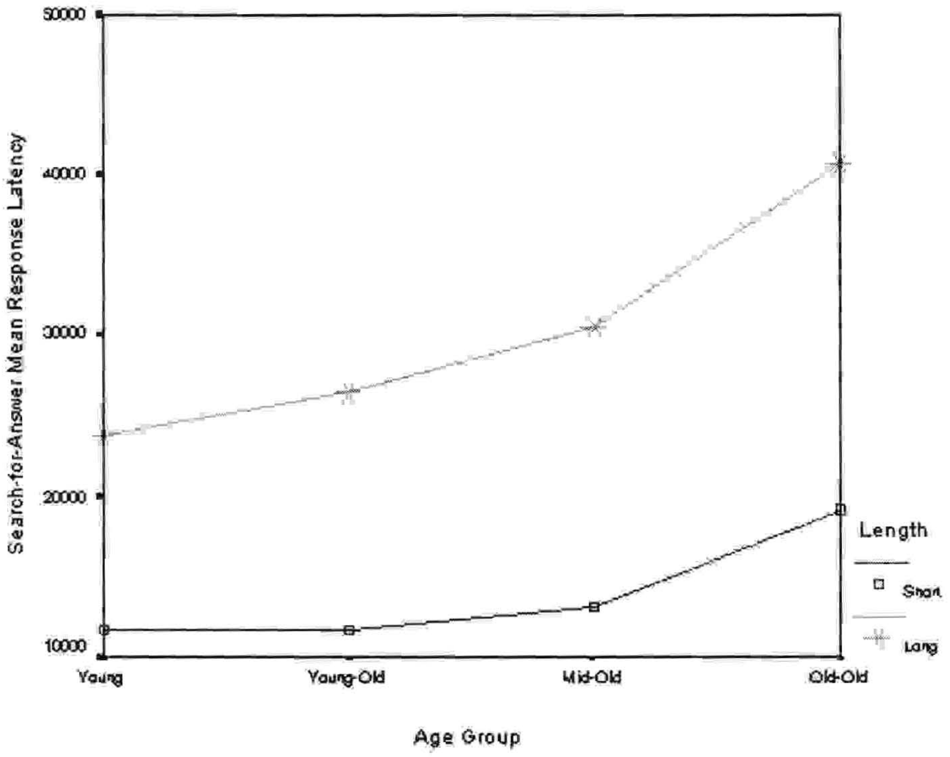

Figure 5. Mean Search-for-Answer response latency as a function of age and length

4349.80, M_{long} = 26658.77, SD = 9063.25; Mid-Old, F(1, 594) = 1320.29, p < .001, M_{short} = 13160.33, SD = 5574.59, M_{long} = 30590.18, SD = 10699.69; and Old-Old, F(1, 594) = 907.09, p < .001, M_{short} = 19313.70, SD = 8101.88, M_{long} = 40771.03, SD = 15389.70). Figure 5 shows a summary function of these simple effects comparisons.

Finally, post hoc pairwise multiple comparisons were computed separately for short and long passages. For short passages, the results indicated that the Old-Old age group significantly differed from all other age groups. However, for long passages, Tukey HSD comparisons indicated that all but the Young and Young-Old age groups showed significant differences in response latencies. These pairwise comparisons further corroborate the Age x Length interaction; both sets of findings suggest the relation between age and response latency differ as a function of passage length.

Potential Factors Underlying Increased Number of Errors

Length. In addition to response latency, the preliminary ANOVA's also indicated errors in Search-for-Answer performance increased with age. The next step was to consider possible factors related to increased errors and age. Consistent with the previous analysis on factors underlying increased latency, it was hypothesized that length of passage would also exert an influence on increased response errors. More specifically, it was hypothesized that age differences in accuracy in favour of the young would be greater for long passages than for short passages. In order to test this hypothesis, a 4 x 2 (Age x Length) repeated measures ANOVA was computed using response errors as the criterion measure. The results indicated that the repeated measures main effect of length, $F(1, 594) = 13.68$, $p < .001$, $\eta^2 = .023$ was statistically significant. Paradoxically, the main effect of length indicated that the mean number of errors for short passages ($M_{short} = 1.20$, SD = .187) was significantly greater than the mean number of errors for long passages ($M_{long} = 1.18$, SD = .183). The between-subjects main effect of age was reported previously and requires no explanation here. Finally, the 4 x 2 (Age x Length) mixed-design interaction, $F(3, 594) = 9.25$, $p < .001$, $\eta^2 = .045$ was significant. However, contrary to the hypothesized effect, the interaction revealed that short passages were associated with a greater number of errors than long passages for both the Young and Old-Old age groups (see Figure 6).

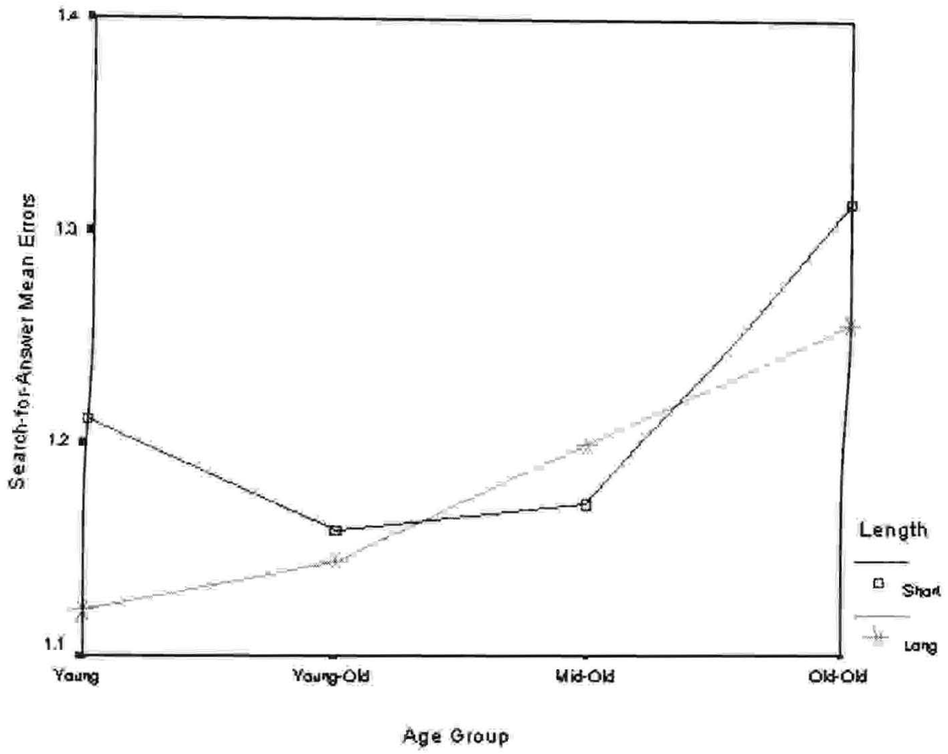

Figure 6. Mean Search-for-Answer response errors as a function of age and length

In order to better understand this interaction, a simple effects analysis was used to statistically decompose the differences between short and long passage lengths within each age group level. These results indicated that Young adults made significantly more errors, F(1, 594) = 19.01, p < .001 on short versus long passages (M_{short} = 1.21, SD = .162, M_{long} = 1.12, SD = .140) and that Old-Old adults made significantly more errors, F(1, 594) = 7.73, p < .01 on short versus long passages (M_{short} = 1.32, SD = .247, M_{long} = 1.26, SD = .258). Differences between errors produced on short and long passages for Young-Old and Mid-Old groups respectively failed to reach significance. These simple effects comparisons are readily apparent in Figure 6.

In addition, post hoc Tukey HSD pairwise multiple comparisons were computed separately for short and long passages. Results for short passages indicated that only the Old-Old age group significantly differed from all other age groups. For long passages, all but the Young and Young-Old age group comparison showed significant differences in errors. Based on the non-intuitive relationship of the error criterion variable to length of passage and age, it is important to consider other potential explanations underlying decreased accuracy with age. Several of these potential factors are considered below including reading grade level of passage, target sentence length, and target sentence complexity. Intercorrelations among these indicators are presented in Table 4.

Reading grade level. It was hypothesized that several reading grade level indices would be related to error performance and age. Specifically, it was predicted that

Table 4. Intercorrelations among length, readability, and complexity indicators

Indicator	1	2	3	4	5	6
1. Passage Length	—					
2. Fry Grade	-.55**	—				
3. Flesch-Kinkaid Grade	-.35	.65*	—			
4. Target Sentence Length	-.12	.35	.78*	—		
5. Target Sentence Length to Response	.33	-.07	.45	.63**	—	
6. Target Sentence Complexity	.02	-.10	.39	.48	.61**	—

Note. *p < .01. **p < .05.

passages representing a higher reading grade level would produce more errors for older adults. Fry reading grade levels and Flesch-Kinkaid reading grade levels were calculated for each individual passage. For both of these indices, passages were then separated into 2 categories representing lower (easier to read) and higher (more difficult to read) reading grade level classifications (see Table 1).

In order to test the hypothesis that higher Fry reading grade level passages are associated with increased Search-for-Answer performance errors for older adults, a 4 x 2 (Age x Grade) repeated measures ANOVA was computed. Given our hypothesis, the main effects of grade and age are not of consequence. Of interest, the 4 x 2 (Age x Grade) interaction for error performance was statistically significant, $\underline{F}(3, 594) = 8.93$, $\underline{p} < .001$, $\eta^2 = .043$. This interaction indicates a complex relationship between errors and reading grade levels across age groups (see Figure 7). In order to test these observed differences across reading grade levels for each age group separately, a simple effects analysis was performed. These results indicate that Young adults made significantly more errors, $\underline{F}(1, 594) = 4.61$, $\underline{p} < .05$ on higher versus lower reading grade level passages ($M_{\underline{lower}} = 1.14$, SD = .158, $M_{\underline{higher}} = 1.18$, SD = .131) and that Mid-Old adults made significantly more errors, $\underline{F}(1, 594) = 21.80$, $\underline{p} < .001$ on lower versus higher reading grade level passages ($M_{\underline{lower}} = 1.22$, SD = .195, $M_{\underline{higher}} = 1.16$, SD = .143). Differences between lower and higher reading grade level passages for Young-Old and Old-Old age groups failed to reach significance.

The previous analysis was replicated using the Flesch-Kinkaid reading grade level as an alternative index of passage reading grade level. A 4 x 2 (Age x Grade) repeated

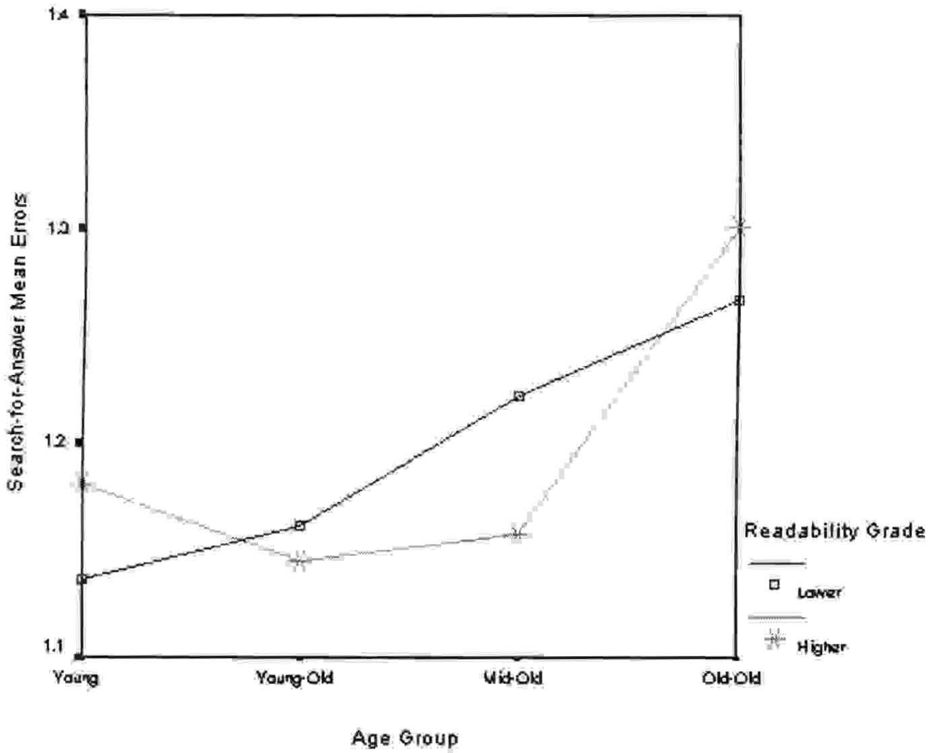

Figure 7. Mean Search-for-Answer response errors as a function of age and Fry readability grade

measures ANOVA was conducted to determine whether higher Flesch-Kinkaid reading grade levels are associated with increased Search-for-Answer performance errors for older adults. As before, our hypothesis specifically relates to the two-way interaction of Age x Grade; the independent main effects are not pertinent to this investigation. The results indicate that the 4 x 2 (Age x Grade) interaction for error performance was statistically significant, $\underline{F}(3, 594) = 4.87$, $\underline{p} < .005$, $\eta^2 = .024$. This interaction more clearly demonstrates the hypothesized relation between age and readability for error performance; older age groups produced significantly more performance errors for higher readability passages than for lower ones compared with younger age groups (see Figure 8). In order to test these observed differences across Flesch-Kinkaid reading grade level for each age group separately, a simple effects analysis was performed. The simple effects findings indicated that Young-Old adults made significantly more errors, F(1, 594) = 15.82, $p < .001$ on higher versus lower reading grade level passages (M_{lower} = 1.12, SD = .143, M_{higher} = 1.19, SD = .157), that Mid-Old adults made significantly more errors, F(1, 594) = 35.56, $p < .001$ on higher versus lower reading grade level passages (M_{lower} = 1.15, SD = .151, M_{higher} = 1.23, SD = .190), and that Old-Old adults made significantly more errors, F(1, 594) = 12.73, $p < .001$ on higher versus lower reading grade level

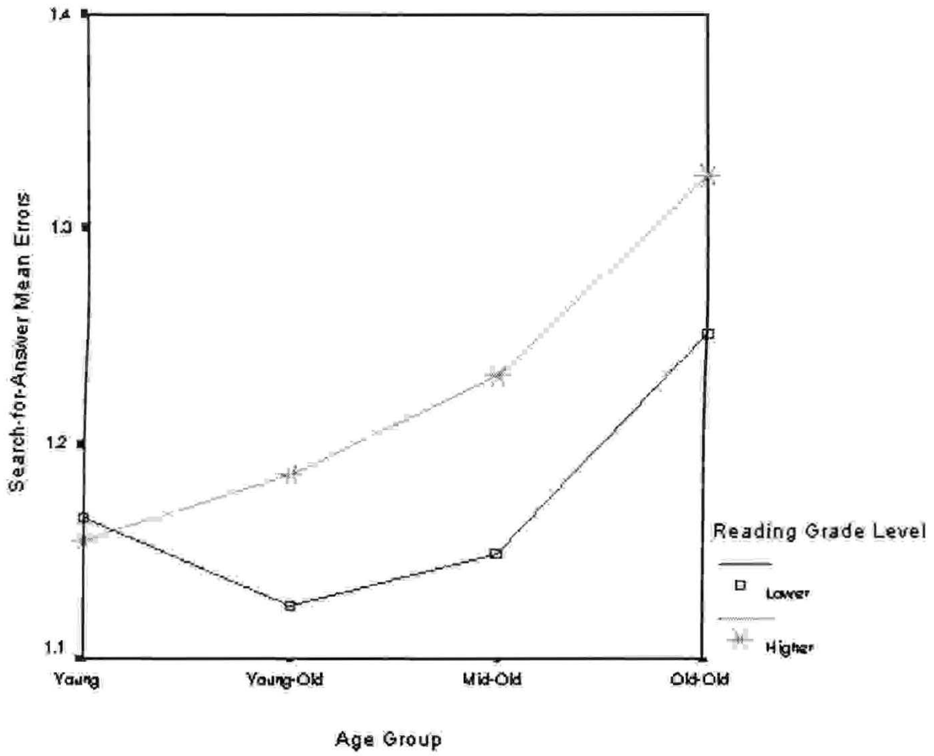

Figure 8. Mean Search-for-Answer response errors as a function of age and Flesch-Kinkaid reading grade level

passages ($M_{\underline{lower}}$ = 1.25, SD = .232, $M_{\underline{higher}}$ = 1.32, SD = .282). The difference between Flesch-Kinkaid reading grade levels for young adults failed to reach significance.

Target sentence length. Another factor potentially related to increased errors in performance is the length of the target sentence. It was hypothesized that longer target sentences would be related to increased error performance, particularly for older adults. For each passage, the number of words in the sentence containing the answer were determined. Two length categories were created representing short and long target sentences (see Table 1). In order to test the hypothesis, a 4 x 2 (Age x Target Sentence Length) repeated measures ANOVA was computed. As hypothesized, the Age x Target Sentence Length interaction was statistically significant, $\underline{F}(3, 594) = 3.21$, $\underline{p} < .05$, $\eta^2 = .016$. Interestingly, the trends in this interaction are similar to those observed for the Flesch-Kinkaid readability interaction. Older age groups produced significantly more performance errors for longer as opposed to shorter target sentences compared with younger age groups (see Figure 9). The observed differences across target sentence lengths depicted in Figure 9 were subjected to a simple effects analysis. The results of this simple effects analysis indicated that Young-Old adults made significantly more errors, $\underline{F}(1, 594) = 14.40$, $\underline{p} < .001$ for longer versus shorter target sentences ($M_{\underline{short}}$ = 1.13, SD = .130, $M_{\underline{long}}$ = 1.19, SD = .165), that Mid-Old adults made significantly more errors, $\underline{F}(1, 594) = 26.65$, $\underline{p} < .001$ for longer versus shorter target sentences ($M_{\underline{short}}$ = 1.15, SD = .165, $M_{\underline{long}}$ = 1.23, SD = .189), and that Old-Old adults made significantly more errors, $\underline{F}(1, 594) = 16.90$, $\underline{p} < .001$ on longer versus shorter target sentences ($M_{\underline{short}}$ = 1.25, SD = .232, $M_{\underline{long}}$ = 1.33, SD = .282). Mean errors for longer and shorter target sentences for

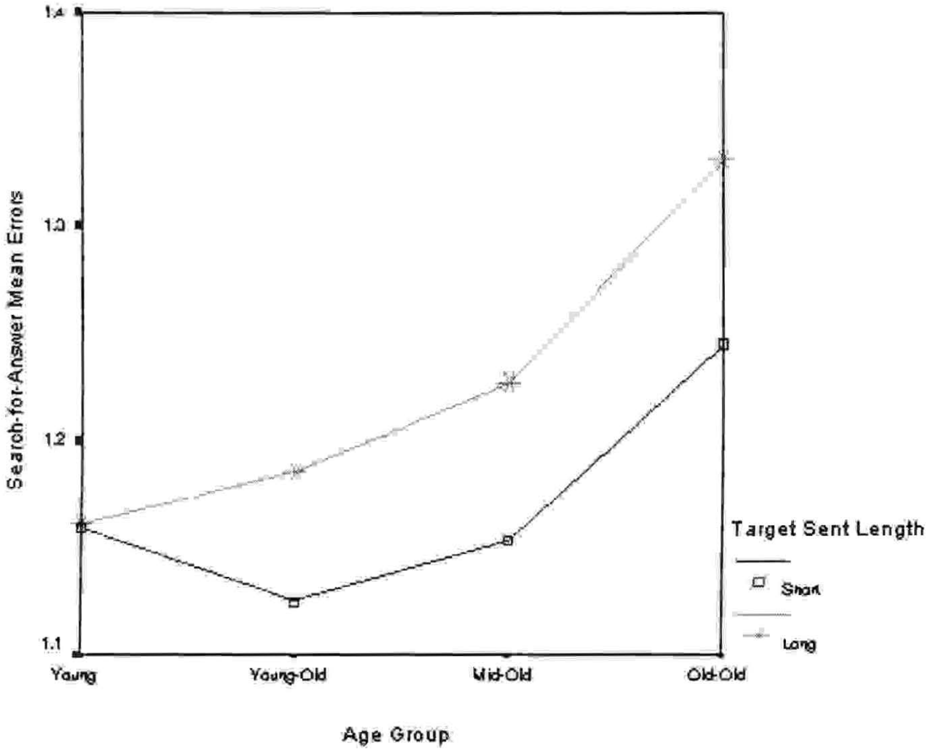

Figure 9. Mean Search-for-Answer response errors as a function of age and target sentence length

Young adults did not significantly differ.

Distance to target sentence response. A variant of the previous analysis, length to correct answer within target sentences may prove more sensitive for understanding error performance. It was hypothesized that correct responses occurring later in target sentences would be associated with increased performance errors compared with responses found earlier in target sentences, particularly in older age groups. For each of the 15 passages, the number of words prior to the correct response in the target sentence were determined. Once again, 2 length categories were created; one representing shorter distances to the correct response and the other representing longer distances to the correct response within target sentences (see Table 1). A 4 x 2 (Age x Distance to Target Sentence Response) repeated measures ANOVA was computed to test the hypothesis that longer intervals prior to the correct response for older adults would result in increased errors compared with younger age groups. A significant 4 x 2 (Age x Distance to Target Sentence Response) interaction, $\underline{F}(3, 594) = 8.19$, $\underline{p} < .001$, $\eta^2 = .040$, supported the hypothesis. This interaction indicates that significantly more errors are associated with longer distances to target sentence response and in particular for older age groups. Compared with the previous factors assessed, the marginal means plot of this interaction provides perhaps the best differentiation between levels of the within-subject factor (see Figure 10). As before, the observed differences across length to target sentence response levels depicted in Figure 10 were statistically assessed using a simple effects analysis. These results indicated that significantly more errors were made for the longer distance to target response category compared with the shorter distance category for all age groups; Young adults, $\underline{F}(1, 594) = 22.2$, $\underline{p} < .001$, $M_{\underline{short}} = 1.10$, $SD = .111$, $M_{\underline{long}} = 1.21$, $SD = .162$; Young-Old adults, $\underline{F}(1, 594) = 103.84$, $\underline{p} < .001$, $M_{\underline{short}} = 1.07$, $SD = .099$, $M_{\underline{long}} = 1.23$, $SD = .186$; Mid-Old adults, $\underline{F}(1, 594) = 253.29$, $\underline{p} < .001$, $M_{\underline{short}} = 1.07$, $SD = .116$, $M_{\underline{long}} = 1.30$, $SD = .220$; and Old-Old adults, $\underline{F}(1, 594) = 80.33$, $\underline{p} < .001$, $M_{\underline{short}} = 1.19$, $SD = .204$, $M_{\underline{long}} = 1.38$, $SD = .308$).

Given the marked differences in the trends observed in Figure 10, an additional analysis was performed creating 4 length categories (as opposed to 2) derived from the number of words prior to the correct response within each target sentence. It was

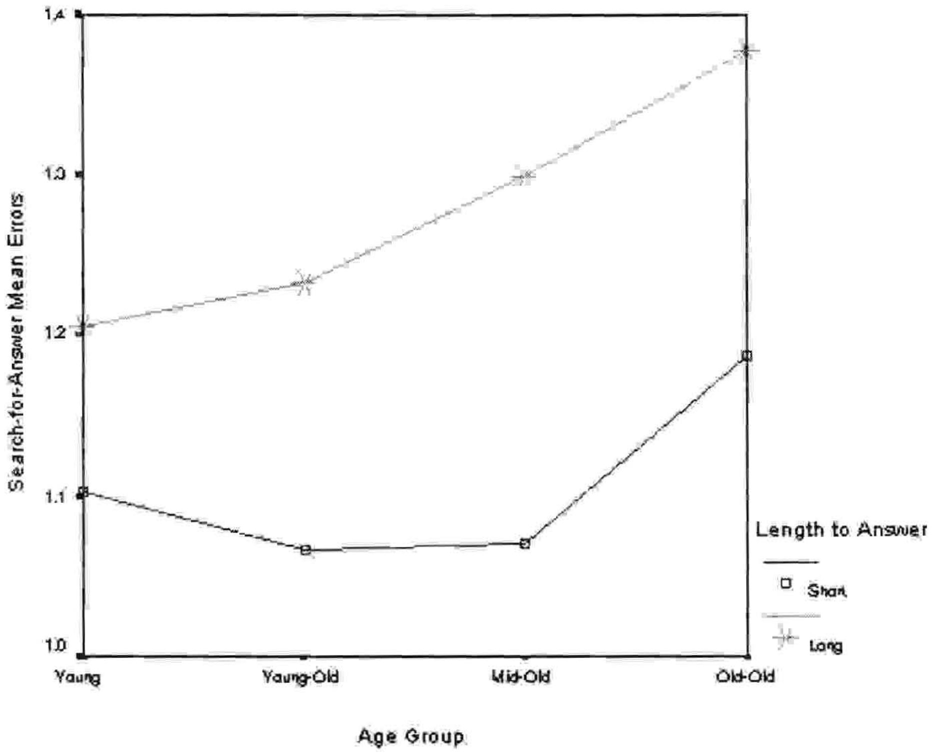

Figure 10. Mean Search-for-Answer response errors as a function of age and distance to target sentence response

hypothesized that the creation of 4 response categories would better assist attempts to isolate the contributing source(s) of the interaction. Respectively, the 4 length categories represented short, medium-short, medium-long, and long distances to the correct response for each target sentence. Consistent with the 2 group length to correct response analysis, it was hypothesized that correct responses occurring later in target sentences would be associated with increased performance errors compared with responses found earlier and that this difference would be accentuated with increasing age. In order to test this hypothesis, a 4 x 4 (Age x Distance to Target Sentence Response) repeated measures

ANOVA was conducted. The results yielded a significant 4 x 4 (Age x Distance to Target Sentence Length) interaction, F(9, 1794) = 4.80, p < .001, $\eta^2 = .024$. As can be seen in Figure 11, this interaction indicates that significantly more errors are associated with older age groups as a function of increased distances to correct responses, particularly for the long length to response category. Contrasted with Figure 10, Figure 11 more precisely demonstrates the nature of the interaction by further partitioning levels of the within-subject factor. A simple effects analysis evaluated the observed differences across the 4 length levels separately for each level of age group. To control for familywise error, a Scheffé adjustment to critical F was performed, $F_s = (4 - 1)\ F_{(3,\ 1782)} =$

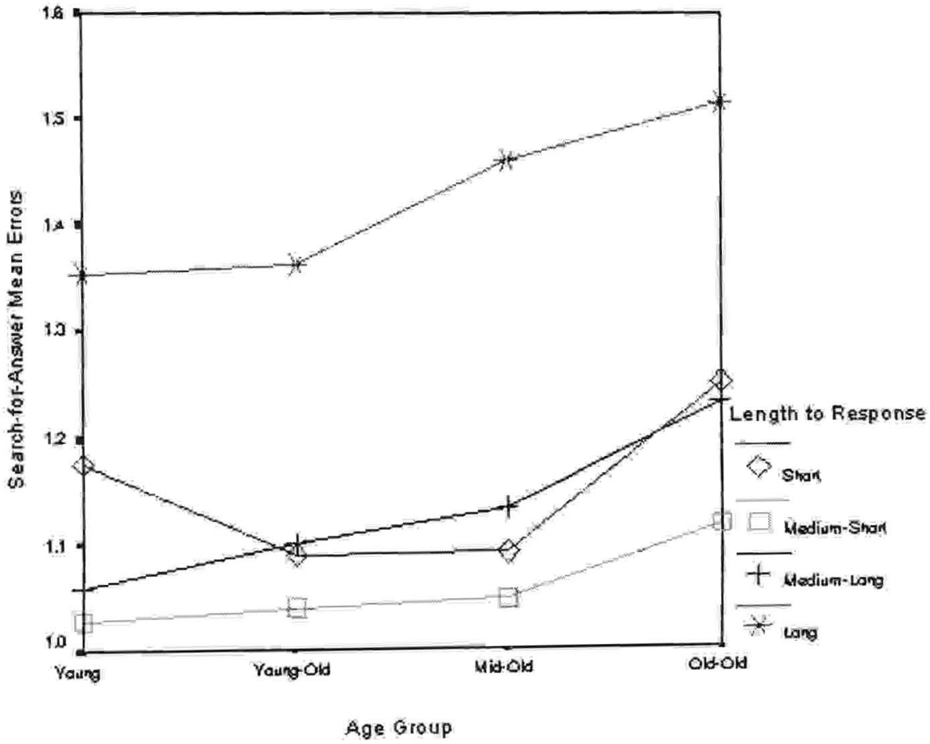

Figure 11. Mean Search-for-Answer response errors as a function of age and distance to target sentence response

7.80 preserving an alpha criterion of .05. The results indicated that there are reliable mean differences in error performance across levels of length for each age group. All F values for the simple effects exceeded the adjusted critical F: Young age group, F(3, 1782) = 46.41, Young-Old age group, F(3, 1782) = 80.58, Mid-Old age group, F(3, 1782) = 174.45, and the Old-Old age group, F(3, 1782) = 63.04.

Although these findings indicate that there are reliable differences in mean error performance across levels of length for all age groups, they are still ambiguous because there are more than two lengths. Thus, it was necessary to apply specific contrast coefficients to the levels of the length repeated measure in order to further decompose error performance differences. For each individual age group, a specific contrast analyzed whether the pooled mean for the short, medium-short, and medium-long length to response levels significantly differed from the mean for the long length to response level. Once again observing $F_s = 7.80$, this contrast yielded significant results for each age group: Young age group, F(1, 594) = 11.68, Young-Old age group, F(1, 594) = 44.55, Mid-Old age group, F(1, 594) = 101.06, and the Old-Old age group, F(1, 594) = 12.05. For each of the 4 age groups, this significant contrast indicates that significant mean differences in error performance exist between the long length to correct response in target sentence category and a mean composite of short, medium-short, and medium-long lengths to correct response in target sentences (see Figure 11). Although the 2 level length to response analysis yielded significant differences in error performance for length as a function of age, the 4 level analysis examined this effect in greater detail. The specific contrast results indicated that the long length to response level represented a particularly important contributor to the significant Age x Distance to Target Sentence Response interaction.

Target sentence complexity. Target sentence complexity represents a final indicator hypothesized to be differentially related to number of errors produced. Consistent with previous findings, it was hypothesized that more complex target sentences would be associated with increased performance errors and that this relationship would be accentuated for older age groups. Complexity of target sentence was based on syntactic structure. Specifically, the target sentence for each passage was syntactically decomposed and subsequently categorized as either simple sentence structure (single clause, multiple clause, right-branching clause) or complex sentence structure (embedded clauses, left-branching clauses). Thus, two complexity categories were created representing simple and complex sentence syntax.

In order to assess the target sentence complexity hypothesis, a 4 x 2 (Age x Length) repeated measures ANOVA was computed. Results indicated that the main effect of complexity was significant, $F(1, 594) = 161.48$, $p < .05$, $\eta^2 = .214$. As expected, syntactically complex sentences were associated with a greater number of Search-for-Answer response errors. However, as before, our main focus concerns how performance varies as a function of age.

Contrary to the complexity interaction hypothesis, the Age x Complexity interaction failed to reach statistical significance, $F(3, 594) = 2.55$, $p = .055$, $\eta^2 = .013$. Although this interaction approached significance, the trends for simple and complex sentence structure in Figure 12 indicate that an increasing number of errors for both

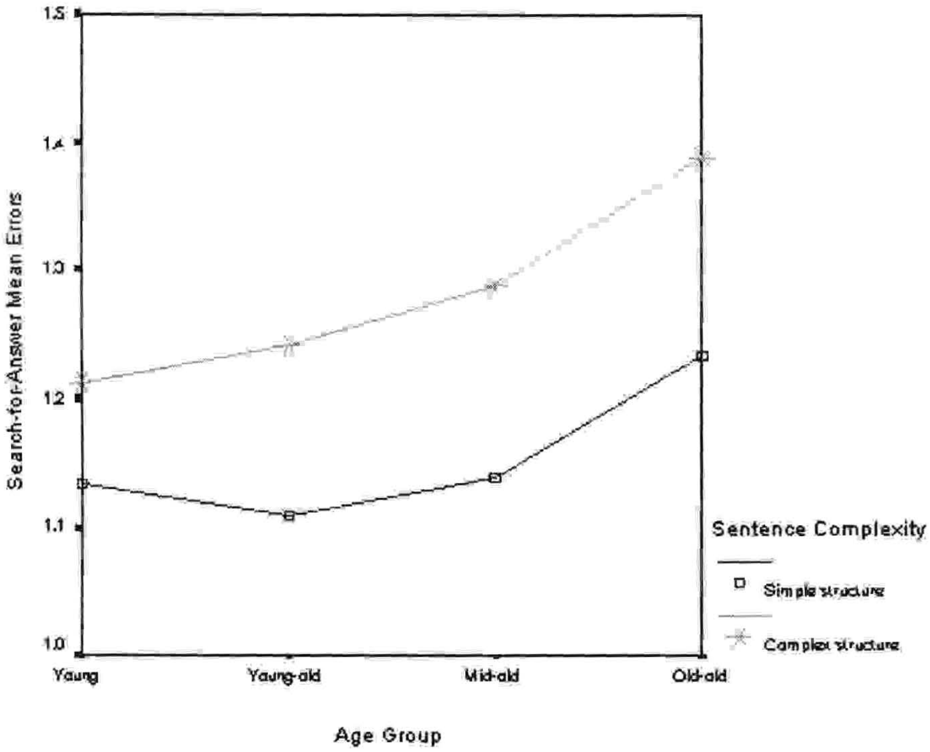

Figure 12. Mean Search-for-Answer response errors as a function of age and target sentence complexity

simple and complex syntax occur with age. Notably, the trends for this interaction are similar to those seen in Figure 9 (errors as a function of age and target sentence length) and Figure 10 (errors as a function of age and distance to target sentence response). However, as the Age x Complexity interaction was not significant, further simple effects analyses for each level of age were not statistically warranted.

Predicting Search-for-Answer Performance Using Hierarchical Regression

Correlates of Search-for-Answer performance. As expected, significant age differences were found for Search-for-Answer latency and error performance.

Preliminary attempts to understand why these age differences exist benefit from investigating what cognitive factors these dependent measures are related to. Tables 5, 6, 7, and 8 show intercorrelations among Search-for-Answer latency and error performance and various cognitive predictor measures for Young, Young-Old, Mid-Old, and Old-Old age groups respectively. In general, correlations among these performance measures tended to increase across age groups, in particular for comprehension speed latency. Of note, latency performance was significantly related to semantic speed for all age groups. For each age group, the correlation between semantic speed and latency exceeded $r = .50$, a large effect size based on Cohen's convention (Cohen, 1969). Perceptual speed also proved significantly related to latency for all age groups. However, the magnitude of the relation was only comparable to that of semantic speed for the Old-Old group. In fact, all cognitive measures were significantly related to latency for the Old-Old group with each of these relations representing a large effect size. It is important to note that even though the relation of processing speed composites to latency are of primary importance, the fact that working memory, episodic memory, and errors also share significant relations with latency across age groups should not be overlooked.

Some notable relations also emerged for error performance. Only the working memory composite was significantly related to error performance for all age groups. The magnitude of this relationship represented a respectable medium effect size. Interestingly, both working memory and episodic memory were significantly related to error performance for the Young-Old, Mid-Old, and Old-Old age group. Each of these relations also reflect a medium effect size. Although error performance was not

Table 5. Correlations among latency, error, and cognitive measures for Young age group

Indicator	1	2	3	4	5	6
1. Latency	—					
2. Errors	.34*	—				
3. Perceptual Speed	-.24**	-.08	—			
4. Semantic Speed	.56*	.05	-.38*	—		
5. Working Memory	-.21**	-.29*	.18	-.14	—	
6. Episodic	-.27*	-.12	.31*	-.36*	.25**	—

Note. *p < .01. **p < .05. N = 97.

Table 6. Correlations among latency, error, and cognitive measures for Young-Old age group

Indicator	1	2	3	4	5	6
1. Latency	—					
2. Errors	.43*	—				
3. Perceptual Speed	-.32*	-.05	—			
4. Semantic Speed	.50*	.11	-.40*	—		
5. Working Memory	-.45*	-.32*	.38*	-.36*	—	
6. Episodic	-.46*	-.31*	.28*	-.37*	.46*	—

Note. *p < .01. **p < .05. N = 174.

significantly related to many of the cognitive indicators in the younger age groups, all of the cognitive indicators were significantly related to error performance in the Old-Old age group.

Overall, these correlation tables indicate that Search-for-Answer latency and error

Table 7. Correlations among latency, error, and cognitive measures for Mid-Old age group

Indicator	1	2	3	4	5	6
1. Latency	—					
2. Errors	.46*	—				
3. Perceptual Speed	-.31*	-.25*	—			
4. Semantic Speed	.54*	.08	-.41*	—		
5. Working Memory	-.39*	-.30*	.23*	-.15**	—	
6. Episodic	-.42*	-.32*	.36*	-.21*	.38*	—

Note. *p < .01. **p < .05. N = 225.

Table 8. Correlations among latency, error, and cognitive measures for Old-Old age group

Indicator	1	2	3	4	5	6
1. Latency	—					
2. Errors	.64*	—				
3. Perceptual Speed	-.56*	-.47*	—			
4. Semantic Speed	.58*	.29*	-.58*	—		
5. Working Memory	-.56*	-.44*	.57*	-.47*	—	
6. Episodic	-.54*	-.44*	.39*	-.33*	.41*	—

Note. *p < .01. **p < .05. N = 102.

performance are related to a number of composite cognitive indicators. Moreover, correlation trends for both latency and error performance reflect increasing relationships with cognitive predictors across age. However, not only are these composites highly related to Search-for-Answer latency and error performance, but they are highly related to one another as well. Thus, in order to discriminate between the importance of cognitive composites as they relate to Search-for-Answer comprehension task performance, further analyses are required. For the purposes of this investigation, a hierarchical regression approach will assist teasing apart which of the composite cognitive measures contributes the most to explaining total and age-related Search-for-Answer performance variance.

Predictors of Search-for-Answer Performance. A series of a priori hierarchical regression models were developed. Models were specified to predict total variance and age-related variance associated with latency and errors. In addition, as a complement to the additional mean level analyses for task errors, hierarchical models predicting variance associated with passage readability were specified.

Total variance prediction equations for latency performance. Four hierarchical prediction models were assessed for predicting total variance associated with Search-for-Answer task latency: a perceptual speed model, a semantic speed model, a working memory model, and a long-term working memory model (see Table 9). By varying order of variable entry, the patterns of variance accounted for by these basic resources within each of the specified hierarchical models will indicate the importance of the resource to the prediction of latency on the Search-for-Answer task. If a particular measure accounts for the majority of variance irrespective of its position in the model, this represents strong evidence for the fundamental contribution of this factor.

Perceptual speed model. Results for the perceptual speed model indicate that while perceptual speed alone accounts for 22.9% of the total Search-for-Answer latency

Table 9. Hierarchical regression models predicting total latency variance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Perceptual Speed Model				
Perceptual Speed	.229	.229	177.11*	
Semantic Speed	.401	.172	171.16*	22.3%
Working Memory	.470	.068	76.58*	11.4%
Semantic Speed Model				
Semantic Speed	.360	.360	334.76*	
Perceptual Speed	.401	.042	41.39*	6.6%
Working Memory	.470	.068	76.58*	11.4%
Working Memory Model				
Working Memory	.264	.264	213.83*	
Semantic Speed	.461	.197	217.35*	26.8%
Perceptual Speed	.470	.009	9.78*	1.7%
Long-Term Working Memory Model				
Perceptual Speed	.229	.229	177.11*	
Semantic Speed	.401	.172	171.16*	22.3%
Working Memory	.470	.068	76.58*	11.4%
Episodic Memory	.504	.034	40.99*	6.4%

__Note.__ Statistically, any variance not accounted for is technically considered error variance. The proportional reduction of error (PRE) is essentially a proportion statistic that considers the amount of unique variance accounted for by a variable relative to the amount of variance remaining to be accounted for (i.e., the proportion of error variance reduced due to the addition of a single variable relative to the proportion of error variance remaining to be accounted for prior to its contribution). An example calculation of PRE for the perceptual speed model (table 10) is as follows: as semantic speed uniquely accounts for 17.2% of total variance over and above perceptual speed, its proportional reduction of error relative to the error variance remaining to be explained with only perceptual speed in the equation is .172/(1 - .229) = 22.3% (i.e., over and above perceptual speed, semantic speed further reduces error variance remaining to be accounted for by 22.3%).

*$\underline{p} < .01$.

variance, the addition of semantic speed further accounts for an additional 17.2% of the variance over and above perceptual speed. This unique contribution was statistically significant, $p < .01$. In addition, the final composite measure entered, working memory, uniquely accounted for 6.8% of the total variance over and above both perceptual and semantic speed. Although this unique contribution was smaller than that of semantic speed, it too was significant, $p < .01$. Considering only these 3 resources as primary predictors, a reasonable 47% of the total latency variance in Search-for-Answer task performance was accounted for. In order to better interpret these findings, it was necessary to reverse the order of entry for perceptual and semantic speed. This shift in order of entry allowed direct comparisons of the amount of variance remaining to be accounted after initially covarying each of the theoretically important speed measures.

Semantic speed model. Upon reversing the order of entry, results from the semantic speed model noticeably diverged from perceptual model findings in several key ways. The first striking difference concerned the amount of variance accounted for by semantic and perceptual speed when entered first in their respective hierarchical models. Semantic speed, when entered first, accounted for 36% of total Search-for-Answer latency variance compared with the lesser 22.9% for perceptual speed (an increase of 13.3%). Even more telling was the discrepancy in variance accounted for that surfaced upon entry of the second variable. Semantic speed accounted for a respectable 17.2% of total latency variance over and above any contributions of perceptual speed. This unique contribution represents a 22.3% proportional reduction in error variance relative to variance unaccounted for by perceptual speed alone (i.e., perceptual speed in block 1).

However, when perceptual speed was entered after first covarying semantic speed, the more general speed measure accounted for a meagre 4.2% of overall variance (a 6.6% proportional reduction in error variance relative to what semantic speed left unaccounted for). Albeit perceptual speed's unique contribution of 4.2% was significant, it pales in comparison to the additional unique contribution of semantic speed. Finally, as only the order of variable entry was changed and not the number and type of predictors, the unique contribution of working memory in the semantic speed model was identical to the 6.8% of variance it accounted for in the perceptual speed model.

Working memory model. Given the statistical importance of semantic speed for predicting total Search-for-Answer task variance, a theoretically reasonable working memory model first specifies the entry of working memory followed by semantic speed and finally perceptual speed (see Table 9). The results of this model also support the general hypothesis that factors other than perceptual speed alone significantly predict Search-for-Answer task performance. Interestingly, when entered first, working memory accounts for 26.4% of total task variance. Comparatively, this coefficient of determination is smaller than the contribution of semantic speed (36%) but larger than that of perceptual speed (22.9%). As might be expected given the importance of semantic speed in the 2 previous models, entering semantic speed after covarying working memory accounts for an additional 19.7% of the total variance (a further 26.8% proportional reduction of error). The F value associated with this increment in R^2 is significant, $p < .01$. Similar to the perceptual speed model, semantic speed still exerts considerable influence over and above working memory. Perhaps most interesting is the pattern that emerges when all 3 indicators are entered in the model. The addition of perceptual speed over and above both working memory and semantic speed accounted for only an additional .9% of the total variance. Albeit significant ($\underline{p} < .01$), this unique variance associated with perceptual speed accounted for relatively little of the total Search-for-Answer task variance. In fact, using PRE as an estimate of effect size, the addition of perceptual speed accounted for a paltry 1.7% of unaccounted for variance.

Now, by contrasting the influence of perceptual speed when entered in block 3 with working memory entered in block 3, we can better interpret relative influences. As mentioned, when perceptual speed was entered after both semantic speed and working memory, it only accounted for less than 1% of the total variance. However, entering working memory after covaring both semantic and perceptual speed resulted in an additional 6.8% attenuation of total variance. Based on these divergent estimates of variance accounted for, it is apparent that perceptual speed shares considerable variance with both semantic speed and working memory. Although working memory also shares overlapping variance with the speed measures, even when entered in block 3 it accounted for a respectable 6.8% of total Search-for-Answer task variance. Thus, even after covarying hypothetical general resources, the importance of both semantic speed and working memory in these hierarchical models provides evidence supporting specific in addition to general predictors of total task variance.

Long-term working memory model. A final model specified to predict total Search-for-Answer task variance was the LT-WM model. The purpose of this model was to indirectly assess the LT-WM hypothesis. Specifically, if as hypothesized the LT-WM construct functions as a mediator between working memory and long-term memory, a relation between both these factors and Search-for-Answer comprehension speed performance should be observed (i.e., if indeed Search-for-Answer comprehension speed is representative of the LT-WM construct as suggested by Hultsch et al., 1998). Moreover, unlike the Hultsch et al. (1998) comprehension speed model, the inclusion of a general perceptual speed resource in the present analyses may provide a more stringent test of the viability of the LT-WM hypothesis. Conveniently, the structure of this model builds on the specified semantic and perceptual speed models; the only difference concerns the addition of episodic memory in block 4. Results derived from testing the LT-WM model indicate some support for the LT-WM hypothesis, albeit indirectly. As with the perceptual and semantic speed models, working memory significantly explained 6.8% of the total variance over and above the speed composites, $p < .01$. The addition of the episodic memory composite in block 4 significantly accounted for a further 3.4% of the total variance, $p < .01$. This unique contribution by episodic memory amounted to a 6.4% proportional reduction of error relative to what working memory, semantic speed, and perceptual speed failed to account for. These significant findings indicate that associations exist among working memory, episodic memory, and comprehension speed even after covarying more general resource factors. Such a pattern of results provides preliminary support for a LT-WM hypothesis. We now turn to consider total variance prediction for the error dependent variable.

Total variance prediction equations for error performance. In addition to recording Search-for-Answer response latency, the number of errors committed per passage represented an additional dependent measure of interest. Three a priori error prediction models were specified to account for total error variance: a perceptual speed model, a semantic speed model, and a working memory model (see Table 10). These resource dependent models were constructed based on the hypothesis that performance errors can be considered one possible manifestation of restricted resources. For each of the models specified in Table 10, notice that processes of cognition (e.g., perceptual speed) are entered into each model followed by products of cognition (e.g., episodic memory). As before, if a particular measure accounts for the majority of variance irrespective of its position in the model, this represents good evidence for the importance of this measure.

Perceptual speed model. Results for the perceptual speed model indicate that the perceptual speed composite measure accounted for 9.4% of the total Search-for-Answer error score variance. Although significant, $p < .05$, the addition of semantic speed over and above perceptual speed accounted for only a further 0.7% of the total error variance. Notably, the addition of working memory in block 3 uniquely accounted for an additional 7.1% of response error variance. Even after covarying both perceptual and semantic speed, the F for the working memory increment was significant, $p < .01$. Finally, the addition of episodic memory in block 4 accounted for an additional 2.9% of total error variance. Overall, the 4 composite measures in the perceptual speed model accounted for a mere 20.1% of the total Search-for-Answer error variance. As the predictors used in these equations largely reflected general resource constructs, the fact that only 20.1% of the total variance was explained indirectly supports a specific influences hypothesis.

Table 10. Hierarchical regression models predicting total error variance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Perceptual Speed Model				
Perceptual Speed	.094	.094	61.76*	
Semantic Speed	.101	.007	4.54**	.8%
Working Memory	.172	.071	50.84*	7.9%
Episodic Memory	.201	.029	21.22*	3.5%
Semantic Speed Model				
Semantic Speed	.051	.051	32.10*	
Perceptual Speed	.101	.050	32.85*	5.3%
Working Memory	.172	.071	50.84*	7.9%
Episodic Memory	.201	.029	21.22*	3.5%
Working Memory Model				
Working Memory	.151	.151	106.35*	
Perceptual Speed	.170	.019	13.40*	2.2%
Semantic Speed	.172	.002	1.12	.2%
Episodic Memory	.201	.029	21.22*	3.5%

Note. The proportional reduction of error (PRE) is essentially a proportion statistic that considers the amount of unique variance accounted for by a variable relative to the amount of variance remaining to be accounted for (i.e., the proportion of error variance reduced due to the addition of a single variable relative to the proportion of error variance remaining to be accounted for prior to its contribution).

*$p < .01$.

**$p < .05$.

The most striking result from the perceptual speed model concerned working memory. The PRE statistic for working memory indicated that it further reduced error remaining to be accounted for by 7.9% relative to what perceptual and semantic speed failed to account for. Moreover, even when entered in block 4 after other cognitive process measures, the episodic memory (cognitive product) measure proportionally reduced error variance by an additional 3.5% relative to what the previous block measures failed to account for. Again, both the working and episodic memory measures surfaced as important predictors of total task error variance, mirroring their importance in the LT-WM model predicting Search-for-Answer task latency. However, contrary to the latency prediction equations, semantic speed accounted for comparatively little total error score variance over and above perceptual speed. As before, in order to better interpret these findings, it was necessary to reverse the order of entry for perceptual and semantic speed.

Semantic speed model. Subsequent to varying entry order, a more definitive understanding of the contributions of perceptual and semantic speed to the prediction of Search-for-Answer error score variance was gained. When entered first, semantic speed accounted for only 5.1% of the total variance compared with 9.4% for perceptual speed (a decline of 4.3%). Entering perceptual speed on block 2 in the semantic speed model helped clarify the speed variables' contributions further. Perceptual speed accounted for an additional 5.0% of total error score variance over and above contributions from the semantic speed composite. Comparing these 2 blocks of the semantic speed model with the first 2 blocks of the perceptual speed model, it was evident that perceptual speed accounted for both more total (9.4% versus 5.1%) and more unique (5.0% versus .7%) total error variance than did semantic speed. Moreover, the unique contribution of perceptual speed was significant, $p < .01$, representing a proportional reduction in error variance of 5.3% relative to variance unaccounted for by semantic speed alone. Testing the converse of this, the unique contribution of semantic speed after first covarying perceptual speed represented a paltry 0.8% of variance reduced relative to what perceptual speed left unaccounted for. Even given its small size, however, this incremental F was also significant, $\underline{p} < .05$.

At least for the prediction of error score variance, the findings indicated that most of what semantic speed accounted for overlapped with contributions from perceptual speed. The larger unique contribution from perceptual speed further indicated that it was the more important speed predictor of total Search-for-Answer error variance. Finally, for block 4 of the semantic speed model, episodic memory explained 2.9% of the error task variance over and above the cognitive process measures. The fact that episodic memory remains significant after covarying general resource measures has implications for task specific performance influences.

Working memory model. An a priori working memory model was put forth to test the hypothesis that errors in Search-for-Answer performance might be related to restrictions in working memory. Working memory was entered on block 1 followed by perceptual speed, semantic speed, and episodic memory (see Table 10). For predicting error score variance, comparisons of the perceptual and semantic speed models indicated that perceptual speed was the more important of the 2 speed measures. Thus, reflecting its importance, the perceptual speed composite was entered in block 2 of the working memory model.

In line with the hypothesis, the working memory model findings support the postulated association between working memory and Search-for-Answer task errors. Working memory alone accounted for 15.1% of the total error score variance when entered on block 1. By way of comparison, this coefficient of determination was larger than both the initial contributions of perceptual speed (9.4%) or semantic speed (5.1%). In fact, working memory's predictive contribution was larger than both speed resources combined. Moreover, even though perceptual speed accounted for the most error variance of the speed composites, it uniquely accounted for a mere 1.9% of the total error variance over and above working memory. Although the F value associated with this increment was significant, $\underline{p} < .01$, the PRE statistic indicated only a 2.2% further reduction in error score variance relative to what working memory failed to account for. In order to better determine the importance of working memory, an alternate model was run entering perceptual speed followed by working memory (not listed in Table 10). These results indicated that working memory accounted for a significant 7.6% of the total error variance over and above perceptual speed, $\underline{F}_{\text{Increment}}(1, 595) = 54.64$, $\underline{p} < .01$. In fact, even when working memory was entered in block 3 after covarying both perceptual and semantic speed, it still accounted for 7.1% of total error variance. Although working memory shares overlapping variance with perceptual speed, it remains an important predictor of error score variance even after covarying general speed resources. Based on these findings, working memory can be considered a better predictor of total error task variance than either semantic or perceptual speed.

Considering the remainder of block entries in the working memory model, only the incremental F for episodic memory was significant, $\underline{p} < .01$. Episodic memory accounted for 2.9% of total error task variance over and above working memory, perceptual speed, and semantic speed. As was the case for latency prediction, both working memory and episodic memory were strong predictors of Search-for-Answer task errors.

Results from the three hierarchical models indicated that working memory was the best predictor of total error variance. However, to this point, we have only considered the prediction of total Search-for-Answer task variance. At this juncture, hierarchical models predicting age-related latency and error variance will be considered.

Age-related variance prediction equations for latency performance. Three hierarchical prediction models were assessed for predicting age-related variance associated with Search-for-Answer task latency: a perceptual speed model, a semantic speed model, and a working memory model (see Tables 11 to 13). The order of variable entry for these models was based on resource restriction accounts of age-related decline. Perceptual speed and working memory variables reflect general resource influences with semantic speed representing more specific influences. Varying the order of entry of these variables in the form of different models permits the determination of which of these predictors accounts for the most age-related variance.

Perceptual speed model. Results from the perceptual speed model underscore the importance of perceptual speed in predicting age-related variance associated with Search-for-Answer task performance. Table 11 shows each block of the hierarchical prediction equation for perceptual speed. In block 1, response latency was regressed on the chronological age variable. The age variable alone accounted for 11.3% of the total latency variance. This figure is identical to the one reported previously in the mean difference latency analysis section. Now, having determined the amount of age-related

Table 11. Hierarchical regression model predicting age-related latency variance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	% Attenuation Age Variance
Perceptual Speed Model				
Age	.113	.113	76.03*	
Perceptual Speed	.229	.229	177.11*	
Age	.234	.005	3.8	95.6%

Note. Predicting age-related variance requires that the age variable be the last variable entered for each block of the hierarchical regression equations. Computation of the proportion of age-related variance attenuated is derived form the generic form of the following example: R^2 for age alone (.113) subtract the increment in R^2 for age (.005) divided by R^2 for age alone (.113) = 0.9557 multiplied by 100 produces the observed proportion (see 95.6% in Table 11).
*$p < .01$.

variance, the assessment of each of the following hierarchical models will focus solely on determining which variables best predict this 11.3% of the total variance (i.e., the age-related variance). For our purposes, the 11.3% age-related variance figure is tantamount to 100% of the variance of interest. On the second block, response latency was regressed on perceptual speed followed by age. After covarying perceptual speed, only 0.5% of the original 11.3% age-related variance remain to be accounted for. Thus, the statistical control of perceptual speed resulted in a 95.6% attenuation of the age-related variance in Search-for-Answer response latency. In other words, only 4.4% of the total age-related variance remained unaccounted for. As might be expected given the large amount of variance attenuated, the 0.5% increment age accounted for over and above perceptual speed failed to reach significance. Thus, the addition of further variables into the equation to predict remaining variance is relatively meaningless as well as statistically unwarranted.

The results of this perceptual speed model underscore the importance of perceptual speed for predicting age-related variance. However, in order to make more definitive statements regarding the importance of predictors, the results from this model must be compared to additional models varying the order of predictor entry. The following hierarchical model assessed the importance of semantic speed as a predictor of age-related variance.

Semantic speed model. Hierarchical regression results for the semantic speed model facilitated the ability to discriminate between the predictive importance of perceptual and semantic speed. In contrast to the perceptual speed model findings, a markedly different pattern of results emerged for the semantic speed model (see Table 12). Even after partialling the influence of semantic speed, a sizeable 3.1% of the age-related variance remained to be accounted for. The statistical control of semantic speed resulted in a 72.6% attenuation of the age-related variance. In contrast, when perceptual speed was entered first, it attenuated 95.6% of the age-related variance in Search-for-Answer response latency. In addition, perceptual speed uniquely accounted for 2.5% (.031 - .006) of the age-related variance over and above semantic speed. Compared with the 0% of additional age-related variance accounted for by semantic speed over and above perceptual speed, these results indicate that perceptual speed is the more important predictor of age-related variance among the composite speed measures. As the increment for age was significant, $p < .05$, over and above the speed measures, working memory was added to the prediction equation. Working memory accounted for 0.5% of the age-

Table 12. Hierarchical regression model predicting age-related latency variance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	% Attenuation Age Variance
Semantic Speed Model				
Age	.113	.113	76.03*	
Semantic Speed	.360	.360	334.76*	
Age	.391	.031	30.11*	72.6%
Semantic Speed	.360	.360	334.76*	
Perceptual Speed	.401	.042	41.39*	
Age	.408	.006	6.23**	94.7%
Semantic Speed	.360	.360	334.76*	
Perceptual Speed	.401	.042	41.39*	
Working Memory	.470	.068	76.58*	
Age	.470	.001	.79	99.1%

*$p < .01$.
**$p < .05$.

related variance over and above the speed measures. The addition of working memory effectively attenuated all remaining age-related variance. Upon consideration of the effect size associated with covarying perceptual speed (95.6%, Table 11) and the small amount of age-related variance remaining to be accounted for (0.5%), any additional prediction of age-related variance is inconsequential. However, at this point, only the contributions of the speed composites have been contrasted. We turn now to consider the influence of working memory.

Working memory model. The results of the working memory model further clarified the contributions of the primary resource composites (see Table 13). After

Table 13. Hierarchical regression model predicting age-related latency variance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	% Attenuation Age Variance
Working Memory Model				
Age	.113	.113	76.03*	
Working Memory	.264	.264	213.83*	
Age	.282	.018	14.67*	84.1%
Working Memory	.264	.264	213.83*	
Perceptual Speed	.334	.070	62.67*	
Age	.334	.000	.04	100%

*$p < .01$.

covarying working memory, age accounted for a further 1.8% of the variance. This increment for age was significant, $p < .01$. Partialing the influence of working memory alone attenuated the age-related variance by 84.1%. By way of comparison, perceptual speed attenuated 95.6% of age-related variance with semantic speed attenuating 72.6%. Using the percent of variance attenuated as an effect size, the predictive contribution of working memory falls in between perceptual speed and semantic speed. Next, perceptual speed was added to the hierarchical model. Perceptual speed effectively accounted for the remaining 1.8% of age-related variance. In fact, after partialing both working memory and perceptual speed, literally no age-related variance remained to be accounted for. Together, these two composites attenuated fully 100% of the age-related variance. The increment for age over and above working memory and perceptual speed failed to reach significance. Thus, with no significant age-related variance remaining to be accounted for, the inclusion of semantic speed was not required nor warranted.

The working memory model indicated that working memory accounted for a substantial proportion of age-related variance. However, upon contrasting the relative contributions of both perceptual speed and working memory, it is evident that perceptual speed represents the dominant predictor of age-related response latency variance. Perceptual speed alone attenuated 95.6% of the age-related variance; in fact, no significant age-related variance remained to be accounted for after partialing perceptual speed. Although working memory also attenuated a large proportion of the age-related variance, the increment for age over and above working memory was significant indicating significant age-related variance remaining to be accounted for. Further, upon entering perceptual speed after working memory, the remaining age-related variance over and above working memory was fully attenuated by perceptual speed. Obviously, as literally no age-related variance in latency performance remained to be accounted for after partialing the influence of perceptual speed, testing more specific influences of age-related latency variance such as episodic memory would be meaningless.

As hypothesized, results from the age-related latency hierarchical models indicated that perceptual speed represents the single best resource predictor of age-related variance in Search-for-Answer task performance. However, as was the case for total variance prediction, the best predictor of age-related latency variance may not be the best predictor of age-related error score variance. Thus, it was necessary to test hierarchical models predicting age-related error performance variance as well. We now consider these hypothesized hierarchical models.

Age-related variance prediction equations for error performance. The approach for predicting age-related error performance mirrors the prediction of age-related latency performance. General and specific speed factors comprising the hierarchical models included perceptual speed, working memory, and semantic speed. As in the immediately preceding analysis, the order of variable entry for these models was based on theoretical restricted resource accounts of age-related decline. Perceptual speed and working memory reflect general resource influences with semantic speed representing more specific influences. Separate models for each of these cognitive resources were assessed in order to determine which predictor accounts for the most age-related variance. Three hierarchical prediction models were assessed for predicting age-related variance associated with Search-for-Answer errors: a perceptual speed model, a semantic speed model, and a working memory model (see Table14).

Perceptual speed model. Of all the hierarchical models specified, the perceptual speed model predicting age-related task error was the easiest to interpret. Surprisingly, age shared only a modest relation with Search-for-Answer task errors. In fact, age accounted for only 3.8% of total error variance. Upon covarying perceptual speed, fully 100% of the age-related error variance was attenuated. As no age-related variance remained to be accounted for, there were no statistical grounds to enter additional predictors of variance. Although in absolute terms the amount of age-related variance was modest, partialing perceptual speed fully attenuated the age effect. This finding supports the importance of perceptual speed as a fundamental predictor of age-related variance.

Table 14. Hierarchical regression models predicting age-related variance associated with task errors

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	% Attenuation Age Variance
Perceptual Speed Model				
Age	.038	.038	23.36*	
Perceptual Speed	.094	.094	61.76*	
Age	.094	.000	.23	100%
Semantic Speed Model				
Age	.038	.038	23.36*	
Semantic Speed	.051	.051	32.10*	
Age	.070	.019	11.91*	50.0%
Semantic Speed	.051	.051	32.10*	
Perceptual Speed	.101	.050	32.85*	
Age	.101	.000	.28	100%
Working Memory Model				
Age	.038	.038	23.36*	
Working Memory	.151	.151	106.35*	
Age	.153	.001	.82	97.4%
Working Memory	.151	.151	106.35*	
Perceptual Speed	.170	.019	13.40*	
Age	.171	.001	.93	97.4%

*$p < .01$.

Semantic speed model. Comparatively, results from the semantic speed model were not as impressive as the perceptual speed findings. Partialing the influence of semantic speed resulted in a 50.0% attenuation of age-related error variance. This value represents a reduction of 3.8% age-related variance to 1.9%. However, the increment for the remaining 1.9% of age-related variance was significant, p < .01. Thus, adding an additional predictor to the hierarchical model was warranted. Further partialing the effects of perceptual speed over and above semantic speed attenuated the remainder of the age-related variance. As would be expected based on the perceptual speed model findings, the 1.9% remaining age-related variance was fully accounted for. The addition of further predictors into the semantic speed model was not warranted as no age-related variance remained to be explained. Thus, comparing the semantic speed model with the perceptual speed model, it is clear that perceptual speed represents the more important predictor of age-related error score variance.

Working memory model. Although the perceptual speed model has already been shown to account for all 3.8% of the age-related variance, an investigation of the predictive influences of cognitive resources need also consider working memory. As it turned out, the results of the working memory model are similar to those of perceptual speed. Covarying the effect of working memory resulted in a 97.4% attenuation of age-related error variance. Although 0% of the age-related variance remained to be accounted for in the perceptual speed model, only 0.1% remained after partialing working memory. Moreover, this negligible increment for age over and above working memory did not reach significance. Despite the lack of significance for this age increment, perceptual speed was entered into the hierarchical model following working memory. Interestingly, the addition of perceptual speed did not account for the remaining .1% of age-related variance. The proportion of variance attenuated remained constant at 97.4%.

Additional Analyses Predicting Error Variance for Passage Characteristics

Results from mean level analyses of age differences in error performance indicated that patterns of age differences changed as a function of passage characteristics. For many of the passage characteristics assessed, older adults made more response errors than younger adults. Thus, in addition to predicting total and age-related error score variance, investigating differential patterns of prediction for specific passage characteristics was considered potentially important. A number of passage characteristic indices were used for the purposes of the mean level analyses. However, as the results indicated, many of the patterns of age differences were similar in spite of the various characteristics assessed. Thus, for the present purposes, hierarchical prediction equations were examined for only Flesch-Kinkaid reading grade level. The Flesch-Kinkaid reading grade level index was selected for several reasons. First, as the Age x Reading Grade Level interaction was significant, age differences obviously exist as a function of passage readability. Second, calculation of the Flesch-Kinkaid index is sensitive to a number of the passage characteristics assessed including length (takes into account number of sentences, words, and syllables per passage). Intended to complement the mean level analyses for task accuracy, three hierarchical prediction models for Flesch-Kinkaid low and high reading grade level were specified. It was suggested that predicting variance associated with low and high reading grade level may demonstrate differential importance of cognitive predictors.

Prediction as a Function of Passage Reading Grade Level

It was hypothesized that passages varying in Flesch-Kinkaid reading grade level would be differentially associated with cognitive resource predictors. If, for example, limited resources are taxed to a greater extent for passages associated with a higher reading grade level, we might expect resource measures to predict a greater proportion of error score variance for this passage characteristic. Further, certain cognitive predictors (e.g., perceptual speed) may better predict performance for lower reading grade levels with other predictors (e.g., working memory) increasing in predictive importance for higher reading grade levels. Three basic resource hierarchical regression models were specified for both lower and higher reading grade level. These models include a perceptual speed model, a semantic speed model, and a working memory model (see Tables 15 and 16).

Perceptual speed model for low reading grade level. Results for the perceptual speed model indicated that perceptual speed alone accounted for only 3.8% of variance associated with task errors for a low reading grade level. Although significant, $p < .01$, the increment for semantic speed further reduced error variance over and above perceptual speed by only 1.7%. This reduction represents a 1.8% proportional reduction of error relative to variance unaccounted for by perceptual speed. Of particular interest, the addition of working memory accounted for an additional 5.5% over and above both speed composites. The increment for working memory was significant, $p < .01$, with working memory proportionally reducing the error by a further 5.8%. The unique variance accounted for by working memory was impressive for several reasons: it was

Table 15. Hierarchical regression models predicting variance associated with task errors for lower Flesch-Kinkaid reading grade level

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Perceptual Speed Model				
Perceptual Speed	.038	.038	23.51*	
Semantic Speed	.055	.017	10.97*	1.8%
Working Memory	.110	.055	36.72*	5.8%
Episodic Memory	.129	.019	12.66*	2.1%
Semantic Speed Model				
Semantic Speed	.045	.045	28.10*	
Perceptual Speed	.055	.010	6.51**	1.0%
Working Memory	.110	.055	36.72*	5.8%
Episodic Memory	.129	.019	12.66*	2.1%
Working Memory Model				
Working Memory	.099	.099	65.64*	
Perceptual Speed	.102	.003	1.66	.3%
Semantic Speed	.110	.009	5.77**	1.0%
Episodic Memory	.129	.019	12.66*	2.1%

*$p < .01$.
**$p < .05$.

significant even after partialing general speed resources and uniquely accounted for more error variance than perceptual speed accounted for when entered in block 1. Not to be overlooked, the addition of episodic memory also predicted a significant 1.9% of error variance, $p < .01$. Even after partialing three major cognitive resource composites, episodic memory made a significant contribution to error prediction.

Semantic speed model for low reading grade level. Results for the semantic speed model assisted further understanding of the perceptual model results. Semantic speed accounted for 4.5% of Search-for-Answer task error variance when entered first in the model. This represents .7% more variance than perceptual speed accounted for when entered in the same model position. Interestingly, when perceptual speed is entered after first covarying semantic speed, it uniquely accounted for only 1.0% of error variance. Although this increment was significant, $p < .05$, the amount of unique variance predicted was less than the contribution of semantic speed over and above perceptual speed. Thus, by reversing the entry order for speed composites, it was determined that semantic speed accounts for more error variance associated with low Flesch-Kinkaid reading grade level. However, as in the perceptual speed model, working memory uniquely explained a further 5.5% of error variance over and above speed measures. To truly discriminate among the resource measures, a working memory model is required.

Working memory model for low reading grade level. Patterns of variance accounted for by predictors in the working memory model indicated that neither perceptual nor semantic speed represent the most influential predictor of low reading grade errors. In fact, working memory alone accounted for 9.9% of error variance, more than twice what either of the speed composites accounted for. Moreover, the addition of perceptual speed over and above working memory failed to reach significance. However, the unique contribution of semantic speed over and above both working memory and perceptual speed was significant, $p < .05$. Semantic speed accounted for an additional .9% of low reading grade performance errors.

Results from these three hierarchical models indicate that working memory represents the most influential predictor of errors for low reading level passages. Albeit marginally, semantic speed represents the second best predictor. Now, in order to test the hypothesis considering differential importance of predictors for different passage characteristics, the same three models will be applied to high Flesch-Kinkaid reading grade level passages.

Perceptual speed model for high reading grade level. Table 16 specifies three hierarchical regression models predicting accuracy variance for high Search-for-Answer reading grade level. Results for the perceptual speed model support the change of predictor importance hypothesis. When entered in block 1, perceptual speed accounted for 9.7% of high reading level errors. This variance accounted for represents a 5.9% increase over what perceptual speed accounted for in the low reading level investigation (9.7% versus 3.8%). Further, the increment for semantic speed was significant in the low reading level investigation but did not approach significance in the current model. Finally, the increment for working memory was significant, $p < .01$, over and above both speed composites. However, the unique contribution of working memory was reduced 1.3% relative to its contribution in the low reading level model (4.2% versus 5.5%). The unique contribution of episodic memory was relatively stable regardless of reading grade level.

Semantic speed model for high reading grade level. Contrary to the influence of perceptual speed, semantic speed declined in importance as a predictor of errors for high reading grade. Semantic speed accounted for only 2.6% of variance associated with number of errors made on high reading level passages. This represents a reduction of

Table 16. Hierarchical regression models predicting variance associated with task errors for higher Flesch-Kinkaid reading grade level

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Perceptual Speed Model				
Perceptual Speed	.097	.097	63.83*	
Semantic Speed	.097	.000	.02	0%
Working Memory	.138	.042	28.63*	4.7%
Episodic Memory	.159	.021	14.68*	2.4%
Semantic Speed Model				
Semantic Speed	.026	.026	15.91*	
Perceptual Speed	.097	.071	46.62*	7.3%
Working Memory	.138	.042	28.63*	4.7%
Episodic Memory	.159	.021	14.68*	2.4%
Working Memory Model				
Working Memory	.106	.106	71.03*	
Perceptual Speed	.138	.031	21.42*	3.5%
Semantic Speed	.138	.001	.52	.1%
Episodic Memory	.159	.021	14.68*	2.4%

*$p < .01$.
**$p < .05$.

1.9% (2.6% down from 4.5%). The contribution of semantic speed was not on par with perceptual speed as was the case in the low reading grade semantic model. Further underscoring a shift in predictor importance, perceptual speed accounted for 7.1% of high reading grade error variance over and above semantic speed (an increase of 6.1%). Just as perceptual speed's overall contribution increased for higher reading grade level, so too did its unique contribution. As semantic speed did not make a significant contribution over and above perceptual speed but the opposite was true, perceptual speed represents a more important predictor of high reading grade level errors. The unique contribution of working memory was reduced 1.3% relative to its contribution in the low reading grade semantic model. Nonetheless, this working memory increment was significant, $\underline{p} < .01$, reflecting a further 4.7% proportional reduction of error over and above what the speed composites failed to account for.

Working memory model for high reading grade level. Although the influence of perceptual speed increased for the high reading grade passages, results from the working memory model indicated that working memory remains the most important predictor of passage errors. Table 16 shows that when working memory was entered in block 1, it accounted for 10.6% of high reading grade error variance. This contribution reflects a .7% increase compared with the low reading level working memory model (9.9% compared with 10.6%). Further, this contribution was larger than the 9.7% perceptual speed accounted for when entered in block 1. Although the increment for perceptual speed over and above working memory was significant, $\underline{p} < .01$, the additional 3.1% perceptual speed accounted for did not surpass the unique 4.2% of variance working memory accounted for after partialing both perceptual and semantic speed. However, unlike the low reading level working memory model, perceptual speed represents a more important predictor of error variance than semantic speed. The increment for semantic speed failed to reach significance in the present model.

Results from these three hierarchical models indicated that working memory represents the most influential predictor of errors for high reading level errors as well.

Unlike the low reading level models, perceptual speed represents the second most influential predictor. Indeed, in support of the differential prediction hypothesis, importance of resource predictors can fluctuate when accounting for variance associated with different passage characteristics. Based on the findings, both working memory and perceptual speed increased in importance for predicting errors associated with higher reading grade level passages.

All Passages Correct Versus One or More Errors Performance Prediction

The final section examines predictors of performance for participants who performed perfectly on all passages versus participants who made 1 or more performance errors. Until this point, both the mean level and prediction analyses have focused on an aggregate response measure comprised of both correct and incorrect responses for Search-for-Answer passages. However, although both theoretically and statistically meaningful, the prediction equations previously specified may be misleading in some respects. Consider that analyses of Search-for-Answer latency include a penalty requiring each participant to read through an entire passage a second time if the correct response was missed on the first read through. Whatever influence this penalty exerted on the prediction of latency performance was included in the hierarchical equations analyzing total response latency variance. As a consequence, it is conceivable that analyzing total response latency variance may produce a biased estimate favouring certain predictors. For example, the influence of predictors associated with failure to find the correct response for the first attempt (e.g., working memory) might be overestimated as predictors of Search-for-Answer latency performance.

Given the importance attached to working memory and perceptual speed in this investigation, further analyses are appropriate to assess whether analyzing total variance for Search-for-Answer latency artificially inflated the contributions of certain predictors. It was hypothesized that factors predicting participant errors on 1 or more passages might very well differ in number and magnitude compared with factors predicting participants who performed perfectly for all passages. More specifically, it was hypothesized that working memory would be more highly associated with performance for participants who made errors versus those who performed correctly on all 15 passages. Conversely, it was further hypothesized that perceptual speed would be most highly related to performance for participants who made no errors across passages. In order to examine these predictions, hierarchical prediction equations were specified separately for each participant performance group.

Table 17 shows the breakdown for the number of participants in each age group who performed perfectly across all 15 Search-for-Answer passages. Also listed are the number of participants for each age group who made at least one error across the 15 passages. Only 61 of a possible 598 participants (10.2%) completed the Search-for-Answer passages without making an incorrect response. Interestingly, upon comparing the mean ages associated with correct and error performance groups, no discernable age distribution differences for a particular performance group were readily apparent. As might be expected, perfect performance was not solely associated with younger adults while errors on 1 or more passages were not noticeably larger for older adults. Age group representation for each performance type was somewhat evenly distributed.

Table 17. Number of participants by age group for perfect and error performance

	Young	Young-Old	Mid-Old	Old-Old
Correct On All Passages				
N (n = 61)	10	25	16	10
Mean Age (M = 59.7)	23	60.6	69.4	78.8
SD	4.22	2.71	2.39	1.99
Error On 1 Or More Passages				
N (n = 537)	87	149	209	92
Mean Age (M = 60.9)	23.4	60.3	69.3	78.5
SD	5	3	2.87	2.73

Predicting response latency for correct on all passages performance. As determined in the total latency prediction analyses, both working memory and perceptual speed were central predictors of Search-for-Answer task performance. Thus, for assessing differences between participants who performed perfectly on all passages compared with those who made 1 or more errors, both a perceptual speed and working memory hierarchical model were specified. As hypothesized, model results predicting correct on all passages latency performance identified perceptual speed as the most influential predictor. Table 18 shows the results of these models. Note that when entered first, perceptual speed accounted for a respectable 35.5% of correct on all passages latency variance. However, the increment for working memory after partialing the influence of perceptual speed was not statistically significant. Reversing the order of entry for the working memory model, working memory accounted for 13.3% of correct

Table 18. Hierarchical regression models predicting correct on all passages Search-for-Answer latency performance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Perceptual Speed Model				
Perceptual Speed	.355	.355	32.54*	
Working Memory	.360	.005	.44	.8%
Working Memory Model				
Working Memory	.133	.133	9.01*	
Perceptual Speed	.360	.228	20.65*	26.3%

*$p < .01$. N = 61.

on all passages variance when entered on block 1 (22.2% less than perceptual speed accounted for). However, even more telling was the unique 22.8% of correct on all passages variance that perceptual speed accounted for over and above working memory. The F for this increment was significant, $p < .01$. Relative to what working memory failed to account for, perceptual speed further proportionally reduced this latency variance by an additional 26.3%. As hypothesized, perceptual speed represents a better predictor than working memory for participants who perform correctly on all passages.

Predicting response latency for 1 or more errors on all passages performance. It was hypothesized that working memory would predict more variance than perceptual speed for participants who made 1 or more errors on the passages. Results from the hierarchical models in Table 19 support this hypothesis. When entered first, perceptual speed accounted for 22.1% of variance associated with making 1 or more errors across all passages. Although a respectable contribution, the addition of working memory over and

Table 19. Hierarchical regression models predicting 1 or more errors on all passages Search-for-Answer latency performance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Perceptual Speed Model				
Perceptual Speed	.221	.221	151.50*	
Working Memory	.333	.112	89.59*	14.4%
Working Memory Model				
Working Memory	.267	.267	195.30*	
Perceptual Speed	.333	.065	52.10*	8.9%

$*p < .01$. N = 537.

above perceptual speed accounted for a further 11.2% of the variance. This increment was statistically significant, $p < .01$. In comparison, by reversing the order of entry, working memory accounted for 26.7% of variance associated with participants' errors across passages. This estimate represents 4.6% more variance than perceptual speed accounted for in block 1. Moreover, the 26.7% of variance working memory accounted for represents an increase of 13.4% over its contribution to the prediction of variance associated with perfect performance for all passages. Perceptual speed accounted for an additional 6.5% of passage errors variance after partialing the effects of working memory. Although significant, $p < .01$, patterns of variance accounted for in these passage errors prediction models underscore the primary predictive importance of working memory. Indeed, as hypothesized, response latency for participants who performed perfectly on all passages versus participants who made 1 or more errors was differentially predicted by cognitive resource measures: perceptual speed was the better predictor of perfect passage performance while working memory was the superior predictor of latency associated with 1 or more passage errors.

Adding semantic speed to the prediction of performance for perfect and error passage groups. Working memory and perceptual speed were the only two predictors entered in the previous analyses based on theoretical rationale. However, an additional predictor requires consideration based on a statistical rationale. Results examining total latency variance (Table 9) indicated that semantic speed was the most influential predictor of performance latency. Thus, further hierarchical analyses assessing the influence of semantic speed for perfect and error passage performance would prove useful. We turn now to consider how the addition of semantic speed influences the importance of latency prediction for these 2 groups of participants.

Table 20 shows results for the revised hierarchical regression models including semantic speed. The results indicated that semantic speed accounted for the largest proportion of latency variance associated with perfect performance across all passages. Entered on block 1, semantic speed accounted for 56.2% of latency variance. In relative terms, this represented 20.7% and 42.9% more variance than either perceptual speed or working memory respectively accounted for. Further, semantic speed uniquely accounted for 24.3% of the latency variance over and above perceptual speed and 24% over and above both perceptual speed and working memory. Both of these increments were statistically significant, $p < .01$. Despite some obvious differences, these results do however support our previous findings indicating the predictive importance of perceptual speed over working memory for perfect performance on all passages.

Table 20. Revised hierarchical regression models predicting correct on all passages Search-for-Answer latency performance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Perceptual Speed Model				
Perceptual Speed	.355	.355	32.54*	
Semantic Speed	.598	.243	35.08*	37.7%
Working Memory	.600	.002	.22	.5%
Semantic Speed Model				
Semantic Speed	.562	.562	75.64*	
Perceptual Speed	.598	.037	5.28*	8.4%
Working Memory	.600	.002	.22	.5%
Working Memory Model				
Working Memory	.133	.133	9.01*	
Perceptual Speed	.360	.228	20.65*	26.3%
Semantic Speed	.600	.240	34.13*	37.5%

*$p < .01$. N = 61.

Similar to the results presented in table 9, semantic speed accounted for the most Search-for-Answer latency variance: variance associated with perfect performance across passages in the present case.

Semantic speed also accounted for the most variance associated with participants who made 1 or more errors across Search-for-Answer passages. Patterns of variance accounted for in Table 21 indicated that semantic speed alone predicted 35.6% of passage error variance. Although this represented a decrease from its contribution in the perfect on all passages analysis, the influence of semantic speed still accounted for more variance than either perceptual speed (22.1%) or working memory (26.7%). Further, semantic

Table 21. Revised hierarchical regression models predicting 1 or more errors on all passages Search-for-Answer latency performance

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Perceptual Speed Model				
Perceptual Speed	.221	.221	151.50*	
Semantic Speed	.396	.176	155.33*	22.6%
Working Memory	.467	.071	71.04*	11.8%
Semantic Speed Model				
Semantic Speed	.356	.356	295.28*	
Perceptual Speed	.396	.041	35.95*	6.4%
Working Memory	.467	.071	71.04*	11.8%
Working Memory Model				
Working Memory	.267	.267	195.30*	
Perceptual Speed	.333	.065	52.10*	8.9%
Semantic Speed	.467	.135	134.81*	20.2%

*$p < .01$. N = 537.

speed contributed an additional 17.6% and 13.5% respectively over and above perceptual speed and perceptual speed and working memory, $p < .01$. However, not to be overlooked, the contribution of working memory actually doubled for the prediction of response latency associated with 1 or more errors across passages (26.7% compared with 13.3%). Moreover, working memory explained an additional 7.1% of variance associated with passage errors after partialing the effects of both speed composites. This increase in the predictive importance of working memory supports the differential prediction hypothesis. Although semantic speed accounted for the most latency variance associated with both perfect and 1 or more errors in performance, the relative influence of the various predictors changed in magnitude. Both perceptual and semantic speed decreased in importance as predictors of passage errors whereas working memory became increasingly important.

Comparing the prediction of perfect passage performance and reading speed. In an indirect fashion, comparing prediction equations for two separate measures can inform us of underlying similarities or differences. For our purposes, the distinction between prediction patterns on perfect passage performance versus performance characterized by 1 or more errors across passages is potentially an important one. To the extent that perfect passage performance analyses demonstrate the importance of perceptual speed as opposed to working memory, the Search-for-Answer task may not be substantially different from other speeded tasks. That is to say, if analyzing overall Search-for-Answer latency variance artificially inflates the influence of working memory, then perhaps the prediction of only perfect passage performance will coincide with prediction equations for other speeded measures. Evidence suggesting similar patterns of prediction would imply that similarities exist between the speed measures examined. In order to test this possibility, prediction equations were specified for both perfect passage Search-for-Answer latency as well as latency for a reading speed test. As the research goal was simply to compare general patterns of variance accounted for, only a perceptual speed model was assessed for each dependent measure (see Table 22).

Results indicated that the overall variance accounted for in each dependent measure was not remotely similar. Together, perceptual speed, semantic speed, working memory, and episodic memory accounted for 60.7% of perfect on all passages variance.

Table 22. Perceptual speed model predicting correct on all passages Search-for-Answer latency and reading time latency

Order of Variable Entry	Cumulative R^2	Increment in R^2	F for Increment	PRE
Correct On All Passages				
Perceptual Speed	.355	.355	32.54*	
Semantic Speed	.598	.243	35.08*	37.7%
Working Memory	.600	.002	.22	.5%
Episodic Memory	.607	.007	.97	1.8%
Reading Latency				
Perceptual Speed	.093	.093	6.07*	
Semantic Speed	.126	.032	2.15	3.5%
Working Memory	.139	.013	.87	1.5%
Episodic Memory	.155	.016	1.05	1.9%

**$p < .05$. N = 61.

In comparison, the same hierarchical model accounted for only 15.5% of the variance in reading speed latency for the same participants. Given the large difference in total variance accounted for, it makes little sense to further interpret the contributions of individual predictors. Although both dependent measures were measured in the same latency units, the predictors of performance differed markedly in magnitude of influence. Previous findings indicated that the importance of working memory may be partly predicated on the type of variance analyzed. However, even after attenuating the influence of working memory, patterns of variance in the current analysis failed to demonstrate any increase in similarity between prediction of perfect performance on all Search-for-Answer passages and prediction of performance on another speed measure.

Chapter VI

DISCUSSION

The comprehension speed path model (Hultsch et al., 1998) presented a most interesting finding; comprehension speed mediated the influence of a variety of cognitive measures, including processing speed and working memory, on episodic memory performance. However, it is not well understood why comprehension speed acts as a pivotal mediator. To this end, the underlying focus of this investigation was to gain a better understanding of the Search-for-Answer comprehension speed task. Results from the present investigation provide ample empirical evidence with which to evaluate the three primary research objectives. For each of these objectives, the findings, interpretations, and implications are considered in turn.

Identifying Mean Age Differences

The first research objective considered whether mean age differences were present for both Search-for-Answer latency response and error performance. Identifying predictors of age differences is contingent upon first detecting reliable mean level differences. Results from this analysis clearly indicated that significant age differences exist for both response latency and error criterion variables. Older adults take longer to find the correct response and make more errors in the process. For latency, all pairwise comparisons were significant among the Young-Old, Mid-Old, and Old-Old age groups. Mean differences for error performance indicated that only the Old-Old age group differed significantly from the Young, Young-Old, and Mid-Old age groups. These results are consistent with previous findings documenting age differences for complex cognitive tasks (e.g., Hultsch & Dixon, 1990; Salthouse, 1991a). Moreover, the fact that age-sensitive basic resources such as working memory (Hultsch et al., 1998) exert their influence through comprehension speed is consistent with finding mean level differences on the Search-for-Answer task. Although the Tukey post hoc tests provided a rough estimate of the locus of age differences, these findings represent only global indicators of mean performance differences.

Specific age difference analyses provided a better understanding of the more general mean level differences. In particular, these specific analyses identified potential factors associated with mean level age differences. The first specific analysis considered whether increases in performance latency simply reflect more performance errors for older adults. Missing the correct response at the end of each passage entails a rather large penalty in the Search-for-Answer task; the participant must reread the passage from the beginning. It was hypothesized that although errors might exert an influence, factors other than response accuracy would contribute to mean level latency differences. In line with the hypothesis, the findings show that even after partialing all accuracy variance, a significant age difference remains. Mean level age differences in response latency reflect more than decreasing accuracy of performance. Consider, however, that partialing the effect of errors attenuated a sizeable 53.1% of age-related latency variance. Although not the only influence of age differences in response latency, response accuracy does exert considerable influence.

As performance accuracy alone failed to account for all age differences, additional influences need be considered. Given older adults' difficulty with more demanding tasks (e.g., the age-complexity effect, Salthouse, 1991a), one such influence deserving consideration is the length of the target passage. Longer passages with a greater number of words to be processed may particularly influence response latency performance for older age groups. It was hypothesized that age differences would be accentuated for longer passages in favour of younger age groups. The results clearly supported this hypothesis. A significant Age x Passage Length interaction indicated that age differences in response latency increased for longer compared with shorter passages. Further, results from Tukey pairwise comparison tests indirectly supported the contention that older age groups experience more difficulty with longer passages. On short passages, only the Old-Old age group differed in latency performance. However, pairwise comparisons for long passages indicated that all possible combinations of mean age group latencies differed significantly, save for differences between the Young and Young-Old age groups. As previous research has suggested (e.g., Salthouse, 1991a), placing more demands on available resources often produces an interaction accentuating age differences in favour of younger adults.

In addition to response latency, specific analyses were also examined for age differences in response accuracy. Assessment of response accuracy is important given its contribution to the prediction of age differences in response latency. Age differences in response accuracy may be a function of numerous factors. In keeping with research suggesting older adults perform more poorly for more involved tasks, several passage characteristics believed related to performance accuracy were identified. It was hypothesized that passages characterized by longer lengths, higher reading grade levels, longer target sentences, greater distances to target sentence responses, and more syntactically complex target sentence structures would be associated with more response errors, particularly for older adults. Of primary importance then was the Age x Passage Characteristic interaction for each separate analysis.

Interestingly, the results for these analyses provided mixed support for the common interaction hypothesis. The interaction considering the association between passage length and age did not support the hypothesis that response errors increase as a function of both age and passage length. Although the Age x Passage Length interaction was significant, the mean level trends for individual age groups were paradoxical. Contrary to prediction, performance errors for the Young and Old-Old age groups were significantly higher for shorter as opposed to longer passages. It was anticipated that longer passages would require more processing thereby overtaxing the available resources of older age groups. Based on these findings, it appears that passage length does not influence response accuracy as hypothesized. In fact, given the opposite relationship of passage length to response accuracy for several age groups, it is imperative to consider additional passage characteristics potentially associated with response accuracy and age.

As a further attempt to more clearly differentiate age differences in response accuracy as a function of passage characteristics, passages were examined with reference to reading grade level. Passage reading grade level is often calculated with reference to number of syllables, sentences, and words per average passage length. Thus, it is a more precise indicator than passage length as it reflects roughly the amount of processing effort that might be required based on passage characteristics more specific than just number of words. Higher reading level passages require more processing effort. Thus, the length of a passage (general indicator) may share little relation with its reading grade level (more precise indicator). Two such indices, Fry reading grade and Flesch-Kinkaid reading grade level were examined. By categorizing passages according to lower and higher reading grade levels, it was possible to determine whether response accuracy was influenced as a function of passage readability and age. Specifically, it was hypothesized that passages that are more difficult to read (i.e., higher reading grade level) will be associated with more performance errors for older adults.

Interestingly, these two indices provided different results. The results for the Fry reading grade analysis closely mirrored those for length of passage. Although the Age x Fry Reading Grade interaction was significant, the trends within this interaction were not clearly differentiated. Simple effects analyses indicated that response accuracy did not differ for either the Young-Old or the Old-Old age group. Although more errors were associated with higher Fry grade estimates for the Young age group, the Mid-Old age group actually made significantly more errors for lower Fry reading grades. In stark contrast, the results considering the Flesch-Kinkaid reading grade level clearly supported the hypothesis. The Age x Flesch-Kinkaid reading grade level interaction was significant indicating there were more response errors for passages reflecting higher reading grade levels, particularly for older age groups. Further, the mean level trends comprising this interaction were in the expected direction. Although Young adults made approximately the same number of errors for both higher and lower readability passages, all three older age groups made significantly more response errors for higher readability passages.

One possible reason for the divergence of findings between the Fry and Flesch-Kinkaid reading grade level indices concerns the manner in which their respective reading grade scores are calculated. Fry reading grade level is determined by plotting the average number of sentences per 100 words as a function of the average number of syllables per 100 words on a graph (Fry, 1977). Where the point falls on the plot determines reading grade level. Thus, Fry reading grade is determined in relation to the "smoothed mean of the plots of sample passages" (Fry, 1977, p. 243). However, conversely, the Flesch-Kinkaid reading level index is derived directly using a mathematical formula (Schuyler, 1982). Further, the Flesch-Kinkaid calculation takes into account not only the number of sentences and syllables but the number of words as well. Thus, in some respects, the difference between these reading grade level indices may represent a function of their derivation. In support of subtle differences between these measures of passage readability, the Fry index significantly correlates with passage length (-.55) whereas the Flesch-Kinkaid index does not (-.35).

To this point, the influence of target characteristics on response accuracy has centered on the entire passage. However, characteristics of the target sentence itself containing the response may more clearly provide clues as to the source of age differences in response accuracy. Target sentence length, distance to target sentence response, and complexity of target sentence structure were considered. It was hypothesized that longer target sentences, more words in the target sentence prior to the response, and left-branching sentence structure would differentially influence response accuracy as a function of age. Specifically, it was hypothesized that older adults would make more response errors for each of these target sentence characteristics.

The results supported all but the target sentence complexity hypothesis. Significant results were found for the Age x Target Sentence Length and Age x Distance to Target Sentence Response interactions. These results indicate that older adults produce significantly more errors for longer target sentences and for longer distances to target sentence responses. However, age differences were far more differentiated for the distance to target sentence response analysis. For short distances to response, the mean level trends indicated that the Young, Young-Old, and Mid-Old age groups performed equivalently. Only the Old-Old age group made significantly more errors for shorter distances to target sentence response. In comparison, longer distances to response reflected marked performance differences with older age groups making progressively more response errors. In order to further differentiate the trends in this interaction, four length to response categories were assessed as compared to the original two categories. Of considerable interest, the decomposition of the significant Age x Distance to Target Sentence Response interaction suggested that the interaction is largely a function of more errors committed by older adults for only the longest length to response category. In particular, specific contrast results indicated that the short, medium-short, and medium-long distance to response categories did not significantly differ from one another as a function of age. However, these three categories did significantly differ from the long length to response category indicating marked increases in response errors for older adults. Finally, the target sentence complexity hypothesis was not supported. Although more complex passages did yield more response errors, this pattern did not change as a function of age. For both simple and complex target sentence structure, an increased number of response errors were made across age groups.

To summarize, these results suggest that age differences are indeed present for both Search-for-Answer latency and error performance. As a direct path was present from age to comprehension speed in the comprehension model (Hultsch et al., 1998), this finding was not surprising. However, several other interesting findings did surface from the mean age difference analyses. In particular, it was determined that differences in response latency are not just a consequence of response accuracy. Significant age variance remained to be accounted for after partialing accuracy thus underscoring the presence of true age differences in speed of performance. As variance associated with performance differences for these two criterion measures does not completely overlap, a further implication is that variance associated with these tasks is perhaps a function of different predictors. As will be reviewed in the following section, perhaps age differences in response latency reflect individual differences in perceptual speed (e.g., generalized slowing), whereas age differences in response accuracy reflect individual differences in working memory (e.g., less processing efficiency).

Further, the examination of the relationship between age, passage characteristics, and latency and error performance proved quite informative. Of interest was not so much the fact that a number of the age by passage characteristic interactions were significant. Rather, more importantly, we were able to gain a better understanding of the point at which age differences become pronounced as well as pinpoint aspects of the Search-for-Answer task that accentuate age differences. For response latency, the length of passage clearly exerted an influence that changes as a function of age. Similarly, distance to target sentence response most clearly accentuated age differences for response accuracy.

It is important to consider that all of the passage characteristics examined and the influences they exerted on age differences in the criterion measures can be accounted for using specific construct or general resource accounts. That is to say, irrespective of the amount of variance passage characteristics accounted for, age differences for both response latency and accuracy may actually reflect individual differences in cognition. For example, although longer distances to target sentence responses resulted in well differentiated age trends for response accuracy, this investigation was merely exploratory and is subject to third variable hypothesis accounts. What would further assist understanding of these age differences requires examining what distance to target sentence response might be a proxy for. As mentioned, these passage characteristics were selected to influence age differences in a fashion similar to the age-complexity analysis. Perhaps distance to target sentence response is but one example of many passage characteristics that are spuriously related to age as a function of restricted resources. It may be that longer distances to target sentence responses accentuate age differences due to the increasing demands placed on working memory resources.

Further research is required to truly understand why characteristics such as length of passage, length of target sentence, and target sentence complexity result in noticeable age differences. Although we have successfully pinpointed specific locuses of age-related differences, factors responsible for these differences in latency and accuracy remain unclear. Determining what underlies age differences requires prediction equations. We turn now to address predictors of total and age-related variance associated with Search-for-Answer task performance.

Predicting Search-for-Answer Response Latency and Accuracy

Although age differences were clearly identified, the mean level analyses obviously did not indicate what underlies these differences. The second major research objective of this investigation concerned identifying individual differences in cognitive abilities that predicted both total and age-related Search-for-Answer task variance.

Total latency variance prediction. Interest in total variance prediction stems from the comprehension model findings (Hultsch et al., 1998). In this model, comprehension speed mediated the influence of many cognitive measures as well as age on episodic memory. Predicting total latency and accuracy variance associated with Search-for-Answer performance will provide insight into the complex nature of this task. It was hypothesized that the prediction of total latency and error variance would be significantly influenced by individual differences in perceptual speed. Further, the predictive importance of perceptual speed was expected regardless of order of entry in the hierarchical prediction model. However, in light of the Hultsch et al. (1998) comprehension model findings, other predictive influences including working memory and episodic memory were also expected to make significant contributions.

In order to examine the differential contributions of predictors to total latency variance, four hierarchical models were specified. Results from these models indicated that individual differences in general cognitive resource abilities accounted for a significant amount of total Search-for-Answer latency variance. In general, the entry of perceptual speed, semantic speed, working memory, and episodic memory accounted for just over 50% of total latency variance. However, of greater interest, by strategically varying the order of predictors within the theoretically driven prediction equations, we were able to discriminate the predictive importance of cognitive abilities.

A particularly interesting finding is that semantic speed represented the best predictor of total Search-for-Answer latency performance. Comparing and contrasting variance accounted for in both the perceptual and semantic speed models provided a means of assessing which composite measure exerted the most influence on total Search-for-Answer task variance. Specifically, by reversing the order of variable entry, estimates of overlapping and unique variance were determined for these speed composites. Although perceptual speed represented a general resource construct, semantic speed accounted for more comprehension speed variance over and above perceptual speed than vice versa. Thus, based on reversing the order of entry, we can infer that semantic speed accounted for more total variance in comprehension speed performance than perceptual speed. Moreover, although perceptual and semantic speed certainly share overlapping variance, the specific influences of semantic speed impacted Search-for-Answer performance to a greater extent (22.3% proportional reduction in error) than unique influences of perceptual speed (6.6% proportional reduction in error). In addition, the working memory composite also explained more total latency variance than perceptual speed. Moreover, working memory accounted for a significant proportion of variance even after both speed composites were partialed from the equation.

Such a pattern of variance accounted for supports the Hultsch et al. (1998)

findings outlining the central importance of comprehension speed as a mediator of semantic speed and working memory in the comprehension path model. The fact that the comprehension model findings are supported was even more impressive considering these results are based on an entirely separate sample. In addition, although we were predicting total Search-for-Answer latency variance and not simply age-related variance, these findings also provide evidence underscoring task specific speed influences. Specifically, semantic speed, a complex form of processing speed, represents the most important explanatory predictor of comprehension speed performance. This finding suggests that comprehension speed has multiple determinants including both specific semantic speed influences as well as more general perceptual speed influences common to a number of tasks. This is consistent with findings by Hertzog (1989) and Tomer and Cunningham (1993) which indicate the existence of multiple speed factors. The fact that semantic speed, and to a lesser extent perceptual speed, represent important predictors of Search-for-Answer comprehension speed performance supports the existence of independent speed factors, albeit indirectly.

A final model predicting total latency variance was specified to examine the LT-WM hypothesis. The construct of LT-WM postulates a relation between working memory and long-term memory. Based on the results of their comprehension model, Hultsch et al. (1998) suggested that Search-for-Answer comprehension speed may be an index of the LT-WM construct. Indirect support for this hypothesis requires that both working and episodic memory significantly predict total latency variance. Indeed, results from the LT-WM hierarchical model provide preliminary support for this hypothesis.

Both working and episodic memory significantly predicted Search-for-Answer response latency. Moreover, both of these measures made significant contributions over and above influences of perceptual and semantic speed. However, although related, the present findings provide little additional information regarding the relationship between working and episodic memory. Nonetheless, the Hultsch et al. (1998) comprehension model findings, and to a lesser extent the present findings, indicate that further investigation is warranted. In particular, a structural equation investigation specifically designed to assess expert performance (e.g., text comprehension) that ostensibly benefits from a LT-WM mechanism would be of considerable scientific importance. Until such time, the present findings merely indicate that such a construct is plausible based on patterns of variance.

Total error variance prediction. Identifying predictors of total error score (accuracy) variance required the specification of several hierarchical models including a perceptual speed model, a semantic speed model, and a working memory model. Similar to the prediction of response latency, it was hypothesized that perceptual speed would be an important predictor of performance errors. However, it was also hypothesized that several additional cognitive measures would make significant contributions, in particular working memory. In spite of the inclusion of basic resource measures, the results for this investigation indicated that individual differences in cognitive measures accounted for only 20% of the total variance associated with performance accuracy. This is somewhat surprising given the seemingly ubiquitous importance of these basic resources for predicting performance on complex cognitive tasks (Salthouse, 1991a).

Of interest, working memory emerged as the most important predictor of performance error variance. In fact, working memory alone accounted for the majority of the 20% of variance that was predicted. Further underscoring its importance, working memory uniquely accounted for variance over and above perceptual speed despite the overlapping variance it shared with this measure. Nonetheless, the fact that working memory represented the most important predictor of performance errors was intuitive for several reasons. First, performance errors can be considered a consequence of resource restrictions or reduced processing efficiency (Salthouse & Babcock, 1991). Working memory resources are required in Search-for-Answer performance for functions such as the maintenance of the target question in memory until the target response is found. In this sense, failure of working memory would be expected to be associated with increased performance errors. Forgetting the target question would most certainly reduce the odds of finding the target response. Although the primary importance of working memory was derived from varying its position in the hierarchical models, this finding should be interpreted with some caution. Previous research has indicated that working memory shares considerable variance with perceptual speed (Salthouse, 1992b). In fact, Salthouse (1991b) reported that the bulk of age differences for working memory performance can be attenuated by partialing the effects of perceptual speed.

Age-related latency variance prediction. Prediction equations were also specified to consider the influence of cognitive measures on age-related latency variance. The comprehension model (Hultsch et al., 1998) indicated that both basic resources as well as age exert their effects directly through comprehension speed. Given the relation of cognitive resources previously shown to be important predictors of age differences

(Salthouse, 1991a) as well as the direct influence of age itself, an investigation as to the relationship between comprehension speed and cognitive aging was a scientific necessity. As discussed previously, patterns of prediction for age-related variance could take several forms related to either general resource or specific construct accounts. Evidence in favour of a general resource account of age-related differences would come in the form of only one or several primary predictors. Conversely, evidence for specific accounts of age differences would be supported in the event of multiple predictors of age differences. Predicting age-related variance afforded insight into factors underlying age differences on the Search-for-Answer task.

Based on findings reviewed by Salthouse (1996b), it was hypothesized that perceptual speed would be a dominant predictor of age-related latency variance. However, given the previously documented importance of both semantic speed and working memory (Hultsch et al., 1998), it was suggested that these additional measures might also significantly predict age-related latency performance.

The present results support a general resource account of age-related decline. Of the 11.3% of age-related variance associated with Search-for-Answer task latency performance, perceptual speed fully attenuated 95.6%. Only .5% of the age-related variance remained to be accounted for. Further, this increment for age was not significant precluding the addition of further predictors. As regression models are dependent on the order of variable entry, we must rely on both a priori model specification as well as varying the order of entry of predictors to gain an understanding of patterns of overlapping and unique variance. Although semantic speed and working memory both attenuated significant proportions of age-related variance, neither predictor fully attenuated all age-related variance as in the case of perceptual speed. Moreover, even after attenuating both these measures, perceptual speed significantly accounted for the remaining age-related variance.

In contrast to the prediction of total response latency variance, the prediction of age-related variance underscores the primary importance of a single measure. Statistically, all of the age-related variance was attenuated by perceptual speed, a finding consistent with the processing speed theory of cognitive aging (Salthouse, 1996b). More than just support for this theory, these findings also speak to the issue of general versus specific speed influences on memory and cognitive aging. Consider Salthouse's (1996a) suggestion that multiple indicators of perceptual speed share significant amounts of overlapping variance. Empirical findings (Salthouse, 1996b) indicate that these measures partial the majority of age-related variance for a broad array of cognitive tasks. Evidence in favour of specific versus common age-related influences might take the form of multiple significant indicators of age-related variance. The present findings do not support a specific influence account of age-related decline. In fact, subsequent to the partialing of perceptual speed, testing the predictive capacity of additional specific influences was not required as no age-related variance remained to be accounted for. The importance of only perceptual speed as a predictor of age-related variance supports a general resource account of cognitive aging, a finding consistent with Salthouse's (1996b) general resource processing speed theory of cognitive aging.

A simple qualification to the above interpretation requires mention. Although perceptual speed alone accounted for the majority of age-related variance, this finding is still subject to third-variable hypothesis criticisms. In fact, support for such a criticism is already documented in the literature (Lindenberger & Baltes, 1994) suggesting that the predictive importance of perceptual speed actually reflects a higher-order common cause factor (e.g., Central Nervous System integrity). Future research is required to truly determine what underlies the importance of perceptual speed's contribution to age-related variance.

Age-related error score (accuracy) variance prediction. The present investigation was also directed toward determining the most important predictors of age-related variance associated with performance errors. Again, the focus concerned whether the patterns of variance accounted for by the predictors supported a general or specific influence account of age differences. Conceptualizing response errors as a possible consequence of resource limitations, three hierarchical resource prediction models were assessed: a perceptual speed model, a semantic speed model, and a working memory model. Based on the processing speed theory of cognitive aging, it was hypothesized that perceptual speed would account for a large proportion of age-related variance. However, given both the statistical importance of working memory to the Search-for-Answer task (Hultsch et al., 1998) as well as theoretical grounds for postulating the existence of this relationship (e.g., more errors associated with poorer working memory performance), it was further hypothesized that working memory would also represent a significant predictor.

Interestingly, the results indicated that both perceptual speed and working memory represented important predictors of age-related variance associated with performance errors. After assessing the perceptual speed model, it appeared as if this speed composite represented the best predictor of age-related error variance. In comparison to semantic speed at least, there can be no debate regarding the more important predictive influence; perceptual speed exerted a far greater influence on age-related Search-for-Answer error variance. However, upon comparing the perceptual speed and working memory models, determining the more important predictor represented a more difficult challenge. Several factors cloud interpretation. For instance, the fact that only 3.8% of the total performance error variance was related to age proved troublesome. With such a small amount of variance to be accounted for, several variables may account for the majority of variance alone as was the case here. Moreover, this finding was all the more interesting given that only 61 of 598 participants (10.2%) completed all 15 Search-for-Answer passages mistake free. Obviously, the majority of participants made errors in performance but these errors did not share a strong association with chronological age. A second factor clouding interpretation was the actual patterns of variance accounted for in the perceptual speed and working memory models. Although perceptual speed attenuated 100% of the age-related variance compared with 97.4% for working memory, the increment for remaining age-related variance was significant in neither instance. Effectively then, in both the perceptual speed and working memory models, no significant age-related variance remained to be accounted for. An argument can be made in favour of perceptual speed based on the slight difference in effect size, but statistically speaking there was little difference between the two models. Thus, both perceptual speed and working memory can be considered important predictors of age-related error score variance.

Although interesting, the implications of this finding are not clear. As mentioned, both perceptual speed and working memory alone attenuate all age-related variance. However, as no age-related variance remained to be accounted for, neither predictor made a significant contribution after partialing the effects of the other. One possibility is that the importance of both perceptual speed and working memory might simply represent a substantial proportion of shared variance between these resource measures. In support of this claim, Salthouse (1996b) suggests the speeded component of working memory actually reflects psychomotor speed and has presented findings indicating that age differences on working memory are attenuated after partialing the influence of perceptual speed (Salthouse, 1992b). As mentioned at the beginning of this thesis, it is not clear that working memory and perceptual speed should be considered separate general resource accounts. Thus, even though we found two measures that significantly attenuate age-related variance, these measures may both be related to age-related variance by virtue of the same mechanism of psychomotor slowing.

To summarize the findings, we can make no claims regarding specific prediction accounts of age-related variance associated with performance errors. Rather, as was the case for the prediction of age-related latency variance, it seems that a general resource account is also best suited to predicting age-related performance error variance. The importance of perceptual speed for predicting both age-related latency and accuracy variance supports Salthouse's (1996b) contention that perceptual speed accounts for the majority of age-related differences for a variety of cognitive tasks.

Predicting Performance Error Variance as a Function of Passage Characteristics

Very little age-related variability in response accuracy was found. However, the examination of Search-for-Answer response errors may benefit from additional analyses. To coincide with the investigation of mean age differences in performance errors as a function of passage characteristics, several hierarchical models were specified in order to determine whether the prediction of performance errors varied as a function of passage characteristics. As was evident from the mean age difference analyses, age differences as a function of passage characteristics assessed tended to be similar. Thus, rather than examine prediction analyses for all passage characteristics, only the Flesch-Kinkaid reading grade level index was examined. Age differences for the Flesch-Kinkaid index were among the most differentiated. Resource prediction models were specified for each Flesch-Kinkaid reading grade level. It was hypothesized that lower and higher passage reading grade levels would be differentially associated with individual differences in cognitive measures.

Prediction of passage reading grade level. Results for the models predicting both high and low passage reading grade level indicated that working memory was the best predictor. This finding is consistent with the previous finding indicating the importance of working memory for predicting total variance associated with response errors. Further, the findings support the shift in importance of predictors for more taxing passages hypothesis. Of note, for the high Flesch-Kinkaid reading grade level, the influence of perceptual speed increased substantially (3.8% of variance in low readability passages to 9.7% of variance in high readability passages). However, despite the increase in importance of perceptual speed, working memory remained the most important predictor of performance errors for both reading grade levels. Working memory also increased slightly in predictive importance for passages requiring higher reading grade levels.

Results indicating the differential importance of predictors as a function of passage reading grade level have several interesting implications. Of particular interest, working memory surfaced as the most important predictor of variance associated with Search-for-Answer performance errors. Recall that the initial mean age difference investigation of performance errors indicated that increased errors were closely tied to Flesch-Kinkaid reading grade level. In and of itself, this finding is quite interesting. Effectively, a 2 level passage characteristic markedly differentiates age differences in response errors. However, building on this finding, the present prediction analysis implies that performance errors increase for passages requiring a higher reading grade level partly as a function of individual differences in working memory. The importance of working memory in the performance error prediction equations suggests that restrictions in working memory resources are partly responsible for increased errors.

Parallels can be drawn between the present findings and previous research by Norman et al. (1991). The argument proposed by Norman et al. suggests that complex syntactic constructions place demands on elderly adults working memory that exceed available capacity. For the purposes of the present investigation, this hypothesis can be adapted to suggest that passages requiring a higher reading grade level might exceed the capacity of participant's working memory resources. Our findings support this hypothesis in several ways. Most notably, working memory represents the most important predictor of performance errors thereby underscoring its influence on response performance. The inference is that working memory is not only an important aspect of correct Search-for-Answer responses (as indicated by the importance of working memory in total response latency prediction equations) but also plays an important role for response errors (as indicated by its importance for predicting variance associated with performance errors). Arguably, the prediction results provide indirect evidence that poorer working memory function is related to more errors on the Search-for-Answer task. As further support of a fundamental relation between working memory and performance errors, we would expect working memory to be highly related to performance errors, particularly for older adults. Tables 5, 6, 7, and 8 indicated that working memory was the only cognitive indicator to be significantly related to error performance for all age groups. Further, the magnitude of this relationship was most noticeably accentuated for the Old-Old age group.

Although the importance of working memory for predicting errors as a function of passage characteristics appears promising, one caveat should be mentioned. Specifically, although some evidence exists in favour of the increase in importance of both working memory and perceptual speed for more cognitively demanding passage characteristics, these increases may simply be a function of increased age variance associated with these characteristics. Indeed, simple regression analyses indicated that more age-related variance was associated with passages requiring higher reading ability. Thus, it is conceivable that the increase in importance of perceptual speed for higher Flesch-Kinkaid reading grade levels may simply be a facet of an increase in overall age variance.

Although this was not tested, indirect support for such a relation was derived from the importance of perceptual speed as a predictor of age-related variance for performance errors. In effect, increasing the demands of the task also increased the amount of performance variability related to age. As age-related variability was largely accounted for by perceptual speed, it stands to reason that more demanding passage characteristics would be better predicted by perceptual speed due to increased age-related variance. In fact, the results support this notion. Although working memory represented the most important predictor for both low and high reading grade level, perceptual speed also exerted considerable influence. Further, given the lack of clarity regarding differences between working memory and perceptual speed as resource predictors, increases in the importance of predictors for more demanding passage characteristics may logically be a function of increases in age-related variance. The importance of both these resources for explaining age-related variance has already been demonstrated. In sum, the potential relation between increases in importance of predictors and increases in age-related variance for higher reading grade levels indirectly supports a general resource account of cognitive aging (Salthouse, 1991a).

As a final comment, the contributions of more specific measures such as episodic memory has been largely overlooked. The fact that very little total accuracy variance was accounted for even with the inclusion of multiple cognitive measures representing general resources was an important finding. At best, the models tested accounted for 20% of performance error variance. Further, the relation between performance errors and age was marginal. Obviously, a large proportion of variance associated with performance errors remained to be accounted for. Thus, the significance of episodic memory over and above all the general resource measures suggests that other more specific indicators of accuracy performance deserve attention in future research. Factors to further consider include task specific abilities such as familiarity with computers, practice trials, as well as other task specific abilities.

Predicting All Passages Correct Versus One or More Errors Response Latency Performance

The third and final research objective addressed by this investigation focused on determining whether predictors of Search-for-Answer performance would vary in importance as a function of perfect performance for all passages versus 1 or more errors across all passages. Understanding similarities and differences for predictors of perfect and error passage performance is an important issue to examine. To this point, analyses considering performance latency have analyzed variance associated with both correct responses and errors. Analyzing this composite measure of variance, however, may result in a biased prediction estimate artificially inflating the importance of certain response latency predictors. The importance of this analysis concerns whether Search-for-Answer performance errors unduly influence response latency as a function of predictors that differ from those that account for perfect performance on all passages. Specifically, it was suggested that the importance of working memory as a predictor of response latency may represent a biased estimate of influence. Although working memory most certainly reflects an important predictor of total latency variance, its importance may be a function of errors made on the task and not trial performance itself. Thus, it was hypothesized that cognitive measures would differentially predict perfect and error passage performance. In particular, it was suggested that working memory would share a stronger association with participants performance characterized by 1 or more errors whereas perceptual speed would share a stronger relation with performance for participants who responded perfectly on all 15 passages.

As hypothesized, the predictive importance of cognitive measures varied as a function of perfect versus error group performance. For perfect performance on all passages, comparison of the perceptual speed and working memory hierarchical models indicated that perceptual speed was the most influential predictor of response latency. Conversely, for the prediction of performance including errors on at least 1 passage, working memory represented the most influential predictor of response latency. Prior to discussing the implications of these differential patterns of prediction, an additional measure requires consideration. Given that semantic speed represented the best predictor of the composite measure of total latency variance, its influence must be considered in the present model. Of note, although perceptual speed accounted for a respectable 35% of variance associated with perfect performance on all passages, semantic speed accounted for an even more impressive 56% of perfect passage variance. Further, although accounting for a lesser 35% of the variance, the semantic speed composite also represented the best predictor of performance for participants who made 1 or more errors. However, in partial support of the differential prediction hypothesis, the predictive importance of working memory more than doubled for error passage performance compared with perfect passage performance.

Several implications surface based on these results that directly concern the interpretation of predictors of total latency performance. First, considering only the influence of perceptual speed and working memory, these results suggest obvious differences in patterns of variance prediction as a function of performance accuracy. These differences imply that processes related to individual differences in perceptual speed are more important for predicting perfect performance on all passages whereas processes related to individual differences in working memory are more important for predicting participants' performance that included 1 or more errors across passages. One possible interpretation of these results is that a failure to find the correct response for a particular passage seems more likely a function of failures in working memory as opposed to restrictions in processing speed. Our findings indirectly support such a claim as the predictive importance of working memory doubled for participants who made 1 or more errors. Interestingly, these findings are not consistent with resource restrictions proposed in Salthouse's limited time or simultaneity mechanism (1996b). According to the simultaneity mechanism, it might be expected that age differences in performance are a consequence of previously encountered information not being available for integration into later processing. For example, failure to process the target question prior to reading the first sentence in a passage would result in a failure to find the target response. In this example, performance differences are a consequence of limited time to process the requisite information. However, an equally plausible account suggests that the target question read at the beginning of each Search-for-Answer passage may be forgotten. In this instance, increases in performance errors are not the result of limited processing time but rather a breakdown in memorial processes. Albeit indirectly, the results indicate that the underlying mechanism may be more a function of restrictions in working memory as opposed to perceptual speed. Further, although the above analysis did not focus on age-related variance alone, previous results from this investigation indicated that working memory was of primary importance for the prediction of age-related variance in performance errors.

These findings support the hypothesis that the inclusion of error trials in latency variance being predicted impacts the relative importance of predictors. Thus, the importance of predictors may be partially a function of the variance being analyzed. It is imperative to consider this fact when interpreting the influence of predictors. Again, consider that errors on the Search-for-Answer task are penalized in the form of requiring each participant to reread the entire passage. Thus, it could be argued that the importance of working memory or processing speed for total latency prediction might partially depend on the ratio of participants who performed perfectly on all passages compared with those who made 1 or more errors. In the present case, only 10% of participants completing the Search-for-Answer task did so without making any errors across all 15 passages (the perfect passage performance group, n = 61). Thus, given the large number of participants who committed errors in this sample (90% reread at least 1 of the 15 passages), we might expect working memory to reflect a very important predictor of latency variance.

Ultimately, further understanding the prediction of latency performance must consider several issues. Without question, consideration must be given to whether individual differences in working memory truly predict Search-for-Answer response latency or whether they simply represent an important predictor of response errors which in turn impact Search-for-Answer response latencies. Recall that although response errors did not attenuate all age-related variance associated with Search-for-Answer latencies, a considerable 53% of the age-related variance was attenuated. Further, a closer examination of the similarities and differences between working memory and perceptual speed is required. The importance of working memory in the present case may simply reflect individual differences in the psychomotor speed component of the resource, as suggested by Salthouse (1996b). Finally, future research might consider more markedly varying demands placed on resources required for Search-for-Answer task performance. Experimentally manipulating resource requirements may provide a clearer picture of the most important predictors of performance.

The second implication of the differential importance of perceptual speed and working memory concerned the additional role semantic speed served in the prediction of perfect and error passage performance. Based on the comprehension model findings (Hultsch et al., 1998), it is necessary to consider the influence of semantic speed in addition to perceptual speed and working memory. As was implied for working memory in the previous analysis, the importance of semantic speed in the comprehension model (Hultsch et al., 1998) may be overestimated as a function of Search-for-Answer task variance analyzed. However, unlike the comprehension model, the present investigation included a measure of perceptual speed. Essentially, the inclusion of both perceptual speed and semantic speed in the same prediction model addresses both the absolute importance of semantic speed for predicting comprehension speed as well as indicates the relative importance of general versus task specific influences. Consistent with the finding that semantic speed represents the best predictor of total response latency, the addition of semantic speed to the perfect/error passage analyses indicated that it is the most important predictor for both performance groups. Thus, the dominance of semantic speed as a predictor of both perfect and error performance on Search-for-Answer passages is consistent with its importance as a resource in the comprehension model. Even with the inclusion of perceptual speed, the findings imply that semantic speed would remain a relatively strong influence on comprehension speed in a path model. However, the relative importance of semantic speed and working memory did shift for predicting performance of passage errors. Although still the strongest predictor, the importance of semantic speed decreased slightly whereas the importance of working memory dramatically increased. Future research needs to reconsider the mediational capacity of comprehension speed. Of particular interest will be both the direct and indirect path relations among working memory, semantic speed, perceptual speed, and age. As semantic speed was the most important predictor of all classes of latency variance, the present results indicate that its importance in the comprehension model is not without justification. However, as the relative importance of predictors changed for perfect compared with error passage performance, a more direct structural investigation including perceptual speed might shed further light on this issue.

In sum, prediction patterns for perfect versus error passage performance analyses support the mediation of semantic speed and working memory by comprehension speed in the Hultsch et al. (1998) structural model. However, the results also indicated that working memory was an important predictor of comprehension speed due in part to the variance analyzed. Interestingly, perceptual speed exerted a strong predictive influence for perfect passage performance even though semantic speed still accounted for the most variance associated with perfect performance.

Based on the differential patterns of prediction in the above findings, it seems prudent to evaluate whether predictors of perfect performance on all passages are really that different from predictors of other speeded measures. A final investigation examined similarities and differences between predictors of two separate speed measures. Previous structural equation models have indicated that comprehension speed and reading comprehension speed load well on a single latent factor (Hultsch et al., 1990; Hultsch et al., 1992). In an attempt to better understand whether perfect performance on Search-for-Answer passages was similar to other speeded measures, hierarchical prediction equations were specified for both perfect passage latency performance and reading comprehension latency. Response latency associated with reading comprehension is simply a function of the time it takes to read through a passage with the intent of preserving information (i.e, speed of reading for comprehension). Given the differential importance of predictors for perfect and error performance groups, it was hypothesized that predictors for perfect passage performance would be similar to predictors of reading comprehension speed. Thus, the main purpose of this analysis was to determine whether predictors of perfect Search-for-Answer performance are more similar to predictors of other speed measures compared with predictors of passage errors or total latency variance. As the general research goal was to simply compare general patterns of variance accounted for and not the relative influence of predictors, only a perceptual speed model was specified.

The results did not support the hypothesis. Whereas 60% of response latency variance was accounted for in perfect passage performance by perceptual speed, semantic speed, working memory, and episodic memory, only 15% of reading speed variance was accounted for by the same predictors for the very same participants. Thus, although predictors were found to differ in importance for perfect and error passage performance, the current results do not support the contention that predictors of perfect passage performance will more closely approximate predictors of other speed measures. Implications of this finding rebut criticisms of the comprehension model as simply an instantiation of basic resources. These findings underscore that indeed the Search-for-Answer task has a complex cognitive structure and not simply by virtue of the inclusion of variance associated with performance errors. Although predictors do differ for perfect and error passage performance groups, the present results indicate that the prediction of even perfect passage performance differs from the prediction of other conventional measures of speed. Thus, all results inclusive associated with the third research objective suggest that the importance of working memory and semantic speed as predictors of comprehension speed does not simply reflect a spurious relation driven by the inclusion of passage error variance. The Search-for-Answer task does indeed have a complex structure that is influenced by both general resources such as perceptual speed and working memory as well as more task specific influences such as semantic speed. However, it should be emphasized that these results are both preliminary and tentative. It is imperative that future research specifically identify in what way errors are influencing latency performance outcomes. Although previous research demonstrated similarities between reading speed and comprehension speed (Hultsch et al., 1990; Hultsch et al., 1992), comparison of perfect passage performance to other speeded measures might yield very different results.

Summary

In summary, the results of this investigation suggest that mean age differences in Search-for-Answer comprehension speed performance are accentuated as a function of varying passage characteristics. Generally speaking, more demanding passages result in poorer Search-for-Answer performance. However, passage difficulty appears to be inextricably linked with both age and available resources. In support of this hypothesis, results from hierarchical prediction models indicated that individual differences in cognitive processing variables were associated with both total and age-related Search-for-Answer task variance. However, of even greater interest was the differential importance of predictors depending on the type of variance analyzed. As addressed at the outset of this thesis, this investigation was concerned with both task specific and general influences of speed on Search-for-Answer performance. The results for total latency and error variance prediction suggest that semantic speed represents a more important predictor of Search-for-Answer performance than perceptual speed. Such a pattern of variance accounted for underscores the importance of task specific influences of comprehension speed performance. Conversely, the prediction of age-related latency and accuracy variance indicates that perceptual speed is the most important predictor. Thus, although task specific influences of Search-for-Answer performance exist in the form of semantic speed, general influences in the form of perceptual speed also serve an important role. Interestingly, these findings support both the Hultsch et al. (1998) comprehension model findings as well as Salthouse's (1996b) processing speed theory. Despite the inclusion of perceptual speed in these analyses, semantic speed represents the most important indicator of total latency consistent with the comprehension model findings. However, the fact that perceptual speed is the most important predictor of age-related variance is consistent with age differences in performance based on individual differences in processing speed.

The Search-for-Answer task is most assuredly a complex cognitive measure. Although the importance of predictors and influence of passage characteristics were examined, these findings only indirectly speak to the complexities of Search-for-Answer task performance. Future research needs to consider a componential analysis in which the task is decomposed into its constituent components (see Laux & Lane, 1985). Such an approach will provide a more precise indication of the relative influence of performance predictors. In addition, future investigations of Search-for-Answer performance might also consider looking more closely at the relation between performance errors and failures of working memory. This could be accomplished by asking participants to recall the initial question after reading and responding to the final sentence of the passage. As presently configured, participants either indicate that they have found the correct response or they indicate that they would like to see the next sentence. If they request the next sentence after reading the target sentence, they must read through the passage again. It would be interesting to ask all subjects after reading the last sentence (i.e., the target sentence of each passage) to recite back what the initial question was. Evidence in support of failures in working memory might indicate that participants who do not respond correctly are also less likely to remember the initial question for which they were in search of a response. Assessing the importance of attention as a predictor of Search-for-Answer performance must also be properly considered in future research. The inclusion of several multiple indicators of attention may indicate the importance of attentional processes (as opposed to working memory processes) and the role they play in response accuracy. Conceivably, errors on the Search-for-Answer task may in fact be related to attentional deficits. Additional studies such as these are required to truly understand the complexities of the Search-for-Answer task.

The present analysis was important for not only investigating age-related decline and examining component processes of comprehension speed, but to further promote investigations of age-related decline in general. Arguably, the Hultsch et al. (1998) comprehension model findings indicate that the story of cognitive aging is most likely more complex than the explanations several robust explanatory measures can provide. Indeed, the Search-for-Answer task may prove an invaluable key for the field of cognitive aging in this regard.

References

Babcock, R.L., Laguna, K.D., & Roesch, S.C. (1997). A comparison of the factor structure of processing speed for younger and older adults: Testing the assumption of measurement equivalence across age groups. Psychology and Aging, 12, 268-276.

Baddeley, A. (1986). Working Memory. Oxford: Clarendon Press.

Baltes, P.B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. Developmental Psychology, 23, 611-626.

Baltes, P.B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? Psychology and Aging, 12, 12-21.

Birren, J.E. (1965). Age changes in speed of behavior: Its central nature and physiological correlates. In A.T. Welford & J.E. Birren (Eds.), Behavior, Aging and the Nervous System (pp. 191-216). Springfield, Illinois: Charles C. Thomas.

Blanchard-Fields, F., & Hess, T.M. (1996). Perspectives on Cognitive Change in Adulthood and Aging. Printed in the United States: The McGraw-Hill Companies, Inc.

Burke, D.M. & Light, L.L. (1981). Memory and aging: The role of retrieval processes. Psychological Bulletin, 90, 513-546.

Cerella, J. (1994). Generalized slowing in brinley plots. Journal of Gerontology: Psychological Sciences, 49, 65-71.

Craik, F.I.M. & Salthouse, T.A. (Eds.). (In press). The handbook of aging and cognition. Hillsdale, New Jersey: Lawrence Erlbaum Associates

Cohen, J. (1969). Statistical power analysis for the behavioral sciences. New York, NY: Academic Press. Chapter 3 “The significance of a product moment r” (72-104).

Dixon, R. A., Hultsch, D. F., & Hertzog, C. (1989). A manual of 25 three-tiered structurally equivalent texts for use in aging research (CRGCA Technical Report No.2). Victoria, BC: University of Victoria, Department of Psychology.

Dixon, R. A., Wahlin, Å, Maitland, S. B., Hertzog, C., & Bäckman, L. (1998). Profiles of episodic memory change in late adulthood: Generalizability across samples and performance indices. Manuscript submitted for publication.

Ericsson, K.A. & Kintsch, W. (1995). Long-term working memory. Psychological Review, 102, 211-245.

Fry, E. (1977). Fry's readability graph: Clarifications, validity, and extension to level 17. Journal of Reading, 21, 242-252.

Giambra, L.M., Arenberg, D., Zonderman, A.B., Kawas, C., & Costa, P.T., Jr. (1995). Adult life span changes in immediate visual memory and verbal intelligence. Psychology and Aging, 10, 123-139.

Hartley, J.T. (1986). Reader and text variables as determinants of discourse memory in adulthood. Psychology and Aging, 1, 150-158.

Hasher, L., Stoltzfus, E.R., Zacks, R.T., & Rypma, B. (1991). Age and Inhibition. Journal of Experimental Psychology: Learning, Memory, and Cognition, 17, 163-169.

Hasher, L. & Zacks, R.T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology: General, 108, 356-388.

Hasher, L. & Zacks, R.T. (1988). Working memory, comprehension, and aging: A review and a new view. In G.G. Bower (Ed.), The Psychology of Learning and Motivation (Vol. 22, pp.193-225). San Diego, California: Academic Press.

Hertzog, C. (1989). Influences of cognitive slowing on age differences in intelligence. Developmental Psychology, 25, 636-651.

Hertzog, C., Raskind, C.L., & Cannon, C.J. (1986). Age-related slowing in semantic information processing speed: An individual differences analysis. Journal of Gerontology, 41, 500-502.

Howard, D.V. (1988). Aging and memory activation: The priming of semantic and episodic memories. In L.L. Light & D.M. Burke (Eds.), Language, Memory, and Aging (pp. 77-99). Cambridge, England: Cambridge University Press.

Hultsch, D.F., & Dixon, R.A. (1990). Learning and memory in aging. In J.E. Birren & K.W. Schaie (Eds.), Handbook of the Psychology of Aging (3rd ed., pp. 258-274)). San Diego, CA: Academic Press.

Hultsch, D.F., Hammer, M., & Small, B.J. (1993). Age differences in cognitive performance in later life: Relationships to self-reported health and activity life style. Journal of Gerontology: Psychological Sciences, 48, 1-11.

Hultsch, D.F., Hertzog, C., & Dixon, R.A. (1990). Ability correlates of memory performance in adulthood and aging. Psychology and Aging, 5, 356-368.

Hultsch, D.F., Hertzog, C., Small, B.J., McDonald-Miszczak, L., & Dixon, R.A. (1992). Short-term longitudinal change in cognitive performance in later life. Psychology and Aging, 7, 571-584.

Hultsch, D.F., Hertzog, C., Dixon, R.A., & Small, B.J. (1998). Memory Change in the Aged. Cambridge, Massachusetts: Cambridge University Press.

Hultsch, D.F., Hertzog, C., Small, B.J., & Dixon, R.A. (in press). Use it or lose it? Engaged life style as a buffer of cognitive decline in aging. Psychology and Aging.

Kausler, D.H. (1994). Learning and Memory in Normal Aging. San Diego, CA: Academic Press.

Laux, L.F., & Lane, D.M. (1985). Information processing components of substitution test performance. Intelligence, 9, 111-136.

Light, L.L. (1991). Memory and aging: Four hypotheses in search of data. Annual Review of Psychology, 42, 333-376.

Lindenberger, U. & Baltes, P.B. (1994). Sensory functioning and intelligence in old age: A strong connection. Psychology and Aging, 9, 339-355.

Lindenberger, U., Mayr, U., & Kliegl, R. (1993). Speed and intelligence in old age. Psychology and Aging, 8, 207-220.

Masson, M.E.J. (1983). Conceptual processing of text during skimming and rapid sequential reading. Memory & Cognition, 11, 262-274.

Masson, M.E.J. & Miller, J.A. (1983). Working memory and individual differences in comprehension and memory of text. Journal of Educational Psychology, 75, 314-318.

Mitchell, D.B., Brown, A.S., & Murphy, D.R. (1990). Dissociations between procedural and episodic memory: Effects of time and aging. Psychology and Aging, 5, 264-276.

Myerson, J., Wagstaff, d., & Hale, S. (1994). Brinley plots, explained variance, and the analysis of age differences in reaction latencies. Journal of Gerontology: Psychological Sciences, 49, 72-80.

Norman, S., Kemper, S., Kynette, D., Cheung, H., & Anagnopoulos, C. (1991). Syntactic complexity and adults' running memory span. Journal of Gerontology: Psychological Sciences, 46, 346-351.

Park, D.C. & Shaw, R.J. (1992). Effect of environmental support on implicit and explicit memory in younger and older adults. Psychology and Aging, 7, 632-642.

Park, D.C. , Smith, A.D., Lautenschlager, G., Earles, J., Frieske, D., Zwahr, M, & Gaines, C. (1996). Mediators of long-term memory performance across the life span. Psychology and Aging, 11, 621-637.

Rabbitt, P. (1996). Do individual differences in speed reflect global or local differences in mental abilities? Intelligence, 22, 69-88.

Salthouse, T.A. (1985). Speed of behaviour and its implications for cognition. In J.E. Birren and KW. Schaie (Eds.) Handbook of the Psychology of Aging (2nd ed., pp. 400-426). New York: Van Nostrand Reinhold.

Salthouse, T.A. (1988). Resource-reduction interpretations of cognitive aging. Developmental Review, 8, 238-272.

Salthouse, T.A. (1991a). Theoretical Perspectives on Cognitive Aging. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.

Salthouse, T.A. (1991b). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. Psychological Science, 2, 179-183.

Salthouse, T. A. (1992a). Mechanisms of Age-Cognition Relations in Adulthood. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.

Salthouse, T.A. (1992b). Influence of processing speed on adult age differences in working memory. Acta Psychologica, 79, 155-170.

Salthouse, T.A. (1992c). What do adult age differences in the digit symbol substitution test reflect? Journal of Gerontology: Psychological Sciences, 47, P121-128.

Salthouse, T.A. (1993). Speed mediation of adult age differences in cognition. Developmental Psychology, 29, 722-738.

Salthouse, T.A. (1994a). How many causes are there of aging-related decrements in cognitive functioning? Developmental Review, 14, 413-437.

Salthouse, T.A. (1994b). The nature of the influence of speed on adult age differences in cognition. Developmental Psychology, 30, 240-259.

Salthouse, T.A. (1996a). General and specific speed mediation of adult age differences in memory. Journal of Gerontology: Psychological Sciences, 51B, 30-42.

Salthouse, T.A. (1996b). The processing-speed theory of adult age differences in cognition. Psychological Review, 103, 403-428.

Salthouse, T.A. & Babcock, R.L. (1991). Decomposing adult age differences in working memory. Developmental Psychology, 27, 763-776.

Salthouse, T.A. & Coon, V.E. (1993). Influence of task-specific processing speed on age differences in memory. Journal of Gerontology: Psychological Sciences, 48, 245-255.

Salthouse, T.A., Hancock, H.E., Meinz, E.J., & Hambrick, D.Z. (1996). Interrelations of age, visual acuity, and cognitive functioning. Journal of Gerontology: Psychological Sciences, 51B, 317-330.

Salthouse, T.A. & Meinz, E.J. (1995). Aging, inhibition, working memory, and speed. Journal of Gerontology: Psychological Sciences, 50B, 297-306.

Schuyler, M.R. (1982). A readability formula program for use on microcomputers. Journal of Reading, 25, 560-591.

Smith, A.D. (1996). Memory. In J.E. Birren & K.W. Schaie (Eds.), Handbook of the Psychology of Aging (4th. ed., pp. 236-250). San Diego, California: Academic Press, Inc.

Smith, A.D. & Earles, J.L.K. (1996). Memory changes in normal aging. In F. Blanchard-Fields & T.M. Hess (Eds.), Perspectives on Cognitive Change in Adulthood and Aging (pp. 192-220). New York: The McGraw Hill Companies, Inc.

Stankov, L. (1988). Aging, attention, and intelligence. Psychology and Aging, 3, 59-74.
Statistics Canada. (1989a). Census of Canada, 1986: Population and dwelling characteristics: Occupations (Catalogue # 93-112). Ottawa: Statistics Canada.

Statistics Canada. (1989b). Census of Canada, 1986: Population and dwelling characteristics: Schooling and major field of study (Catalogue # 93-110). Ottawa: Statistics Canada.

Sticht, T.G. (1977). Comprehending reading at work. In M.A. Just & P.A. Carpenter (Eds.), Cognitive Processes in Comprehension. Hillsdale, New Jersey: Erlbaum.

Stine, E.A. & Wingfield, A. (1990). How much do working memory deficits contribute to age differences in discourse memory? European Journal of Cognitive Psychology, 2, 289-304.

Tipper, S.P. (1991). Less attentional selectivity as a result of declining inhibition in older adults. Bulletin of the Psychonomic Society, 29, 45-47.

Tomer, A., & Cunningham, W.R. (1993). The structure of cognitive speed measures in older and younger adults. Multivariate Behavioral Research, 28, 1-24.

Tulving, E. & Thomson, D.M. (1973). Encoding specificity and retrieval processes in episodic memory. Psychological Review, 80, 359-380.

Welford, A.T. (1958). Aging and Human Skill. Oxford: Oxford University Press.

Zelinski, E. M., Gilewski, M.J. & Schaie, K.W. (1993). Individual differences in cross-sectional and 3-year longitudinal memory performance across the adult life span. Psychology and Aging, 8, 176-186.

VITA

Surname: MacDonald Given Names: Stuart Warren Swain

Place of Birth: Winnipeg, Manitoba, Canada

Educational Institutions Attended:

The University of Victoria	1996 to 1999
The University of Winnipeg	1991 to 1996

Degrees Awarded:

B.A. (Honours)	University of Winnipeg	1996

Honours and Awards:

NSERC Postgraduate Scholarship (B)	University of Victoria	1999 - 2001
NSERC Postgraduate Scholarship (A)	University of Victoria	1996 - 1998
President's Research Scholarship	University of Victoria	1998 - 1999
President's Research Scholarship	University of Victoria	1997 - 1998
President's Research Scholarship	University of Victoria	1996 - 1997
Student of Highest Distinction	University of Winnipeg	1992 - 1996
The Academic Proficiency Scholarship	University of Winnipeg	1995 - 1996
Dr. C.J. Robson Scholarship in Psychology	University of Winnipeg	1994 - 1995
The Academic Proficiency Scholarship	University of Winnipeg	1994 - 1995
Dr. A.R. Cragg Scholarship in Psychology	University of Winnipeg	1993 - 1994
The Academic Proficiency Scholarship	University of Winnipeg	1993 - 1994
The Mature-Status Student Scholarship	University of Winnipeg	1992 - 1993

Conference Presentations and Invited Addresses:

MacDonald, Stuart, W.S. (1996, April). Correlational investigation of impulse control with causal and outcome variables mediated by inhibitory mechanisms. Paper presented at The 15th Annual Prairie Undergraduate Psychology Conference, Winnipeg, MB.

MacDonald, Stuart, W.S. (1997, August). A processing resource analysis of age-related decline in cognitive task performance. Paper presented as a featured speaker at the University of Winnipeg Colloquium Series, Winnipeg, MB.

MacDonald, Stuart, W.S., Maitland, S.B., Hertzog, C., Hultsch, D.F., & Dixon, R.A. (1998, November). Testing performance and structural characteristics in processing speed across age group and time. Poster session presented at the annual meeting of the Gerontological Society of America, Philadelphia, PA.

PARTIAL COPYRIGHT LICENSE

Title of Thesis: Understanding Performance on the Search-for-Answer Comprehension Speed Task: Delineating Determinants, Age Effects, and Complex Relations with Cognitive Resources

Author [redacted]

Stuart Warren Swain MacDonald
January 11, 1999