Two Sources of Age-Related Decline in Comprehension of Complex Relative Clause Sentences

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TWO SOURCES OF AGE-RELATED DECLINE IN COMPREHENSION OF COMPLEX RELATIVE CLAUSE SENTENCES

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Running head: AGEING AND COMPLEXITY

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ABSTRACT

Working memory capacity is thought to underlie many higher cognitive processes including sentence comprehension. Sentences that contain object-extracted relative clauses are more complex and impose higher demands on working memory than comparable sentences that contain subject-extracted relative clauses. We report two experiments examining the role of the central executive component of working memory in adult age-related declines in comprehension of these sentences. Two different conceptualizations of executive capacity were employed. One approach quantifies load in terms of simultaneous storage and computational demands of the task and assesses this capacity using complex span tasks such as Reading Span. The other (newer) approach quantifies load in terms of the complexity of the relational information in the task and assesses capacity using relational processing tasks such as n-term premise integration. Participants aged 20 years to 88 years read object- and subject-cleft sentences (Study 1) and subject- and object-relative clause sentences (Study 2) at their own pace then responded to comprehension questions. As expected, object-extracted sentences were more difficult to understand than subject-extracted sentences. Multiple regression analyses showed that after controlling for subject-clefts/relatives, N-term premise integration task accounted for age-related and age-independent variance in object-clefts/relatives whereas Reading Span accounted for age-related variance only. The findings suggest that both N-term and Reading Span tap processes that are required for comprehension of object-extracted sentences. Moreover, relational processing (N-term) and simultaneous storage and computation (Reading Span) are partly independent. Both are vulnerable to age-related decline, but relational processing declines earlier than capacity for simultaneous storage and computation.
INTRODUCTION

Object-cleft sentences as shown in Table 1 are known to be more difficult to understand than comparable subject-clefts (Caplan, Alpert, & Waters, 1999; Gordon, Hendrick, & Levine, 2002; Waters & Caplan, 2001). Similarly, for sentences containing restrictive relative clauses (Table 2) the object-relative form is more difficult than the subject-relative form (e.g., Blaubergs & Braine, 1974; Blumenthal, 1966; Fodor & Garrett, 1967; Ford, 1983; King & Just, 1991; Marks, 1968; Miller & Isard, 1964; Traxler, Morris, & Seely, 2002; Traxler, Williams, Blozis, & Morris, 2005). The greater difficulty of object-clefts and object-relatives has been attributed to the higher demand they impose for working memory (WM) resources (King & Just, 1991), where WM is conceptualised in terms of the resources that can be allocated to simultaneous storage and computational demands. By extension, age-related declines in comprehension of object-extracted sentences in later adulthood have been attributed to reductions in this capacity (Carpenter, Miyake & Just, 1994). While it is generally agreed that sentence comprehension imposes simultaneous storage and computational demands, recent evidence suggests object-clefts and object-relative sentences also involve complex relational information (Andrews, Birney, & Halford, 2006). The current research examined the relative importance of the capacity for simultaneous storage and computation and relational processing capacity in accounting for age-related and age-independent variance in comprehension of object-cleft and object-relative sentences.

Working memory and sentence comprehension

The notion that sentence comprehension demands short-term memory (STM) or WM resources has a long history (e.g., Miller & Isard, 1964). Early approaches emphasised the higher storage demands of object-extracted as compared to subject-extracted sentences. More recent approaches have also recognised the computational (processing) functions of WM and their involvement in comprehension (Baddeley & Hitch, 1974; Just & Carpenter, 1992). Thus Just and Carpenter defined WM as the resources used for the simultaneous storage and computation of information. They use complex span tests to assess WM capacity. In the Reading Span task (Daneman & Carpenter, 1980) participants attempt to retain a number of sentence-final words (storage) while reading and judging a set of sentences (computation). Based on their meta-analysis, Daneman and Merickle (1996) concluded that complex span measures are stronger predictors of language comprehension than simple span tests, which are primarily measures of short-term storage capacity.
Table 1.

*Examples of Object-cleft and Subject-cleft Sentences with 2, 3, 4 Roles used in Study 1*

<table>
<thead>
<tr>
<th>Roles</th>
<th>Form</th>
<th>Example sentence</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Object</td>
<td>It was the rat that the dog hit</td>
</tr>
<tr>
<td></td>
<td>Subject</td>
<td>It was the dog that hit the rat</td>
</tr>
<tr>
<td>3</td>
<td>Object</td>
<td>It was the cook that the king sent the man to</td>
</tr>
<tr>
<td></td>
<td>Subject</td>
<td>It was the king that sent the man to the cook</td>
</tr>
<tr>
<td>4</td>
<td>Object</td>
<td>It was the doctor that the farmer that the politician helped liked</td>
</tr>
<tr>
<td></td>
<td>Subject</td>
<td>It was the farmer that liked the doctor and it was the politician that helped the farmer</td>
</tr>
</tbody>
</table>

Table 2.

*Examples of Object-relative and Subject-relative Sentences with 3, 4, 5 Roles used in Study 2*

<table>
<thead>
<tr>
<th>Roles</th>
<th>Form</th>
<th>Example sentence</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Obj</td>
<td>The duck that the monkey touched walked</td>
</tr>
<tr>
<td></td>
<td>Subj</td>
<td>The monkey touched the duck that walked</td>
</tr>
<tr>
<td>4</td>
<td>Obj</td>
<td>The artist that the waiter warned the chef about talked</td>
</tr>
<tr>
<td></td>
<td>Subj</td>
<td>The waiter warned the chef about the artist that talked</td>
</tr>
<tr>
<td>5</td>
<td>Obj</td>
<td>The clown that the teacher that the actor liked watched laughed</td>
</tr>
<tr>
<td></td>
<td>Subj</td>
<td>The actor liked the teacher that watched the clown that laughed</td>
</tr>
</tbody>
</table>

Carpenter et al., (1994) characterized the demands of sentence comprehension in terms of simultaneous storage and computational load. WM demand is directly related to syntactic complexity. They noted five sources of complexity, which along with sentence length determine WM load. One is the number of thematic roles associated with a single verb. Verbs with three roles (agent, patient, recipient) are more complex than verbs with two roles (agent, patient). Sentences with two verbs are more complex than sentences with a single verb. Sentence complexity is higher if the noun that occupies the patient role precedes the noun in the agent role (i.e., role order is non-canonical). Sentences in which the relative clause interrupts the main clause are more complex than those in which there is no interruption. Finally, complexity is greater when nouns have non-parallel functions (Sheldon, 1974), that is, when a single noun plays different thematic roles in different clauses. To the
extent that sentences incorporate these five factors, they are more complex and impose a higher WM demand. King and Just (1991) tested this hypothesis by contrasting object-relatives (1) and subject-relatives (2).

1. The reporter that the senator attacked admitted the error.
2. The reporter that attacked the senator admitted the error.

Object-relatives impose a higher WM demand because they incorporate non-parallel function and non-canonical order, which are not present in subject-relatives. Comprehension was assessed using end-of-sentence true-false questions. Participants with High Reading Spans had better comprehension overall than Low Reading Span participants, but the difference was greater for object-relatives. The findings were consistent with the claim that object-relatives impose a higher verbal WM demand than subject-relatives (King & Just, 1991). Reductions in WM capacity have been proposed to underlie age-related declines in comprehension of syntactically complex sentences (for a review, see Carpenter et al., 1994).

While there is a consensus that WM is involved in sentence comprehension and the age-related declines therein, the precise nature of its role remains unclear. For example, Caplan and Waters (1999; Waters & Caplan, 2004) proposed that two separate WM systems are involved. There is a specialised WM sub-system dedicated to interpretive processing of sentences and a more general verbal WM (similar to Carpenter et al., 1994) used for post-interpretive processing. Interpretive processing is used to extract initial meaning from the linguistic signal. It is described as first-pass, obligatory, and unconscious. Post-interpretive processing involves using meaning for other purposes. It is conscious and controlled. Thus reductions in general WM capacity should account for age-related declines in sentence comprehension only when post-interpretive processing is tapped.

Waters and Caplan (2001) investigated the links between age-related declines in WM capacity (Reading Span), interpretive, and post-interpretive processing in 127 individuals aged from 18 years to over 80 years. Subject- and object-clefts and subject- and object-relatives were presented using Ferreira, Henderson, Anes, Weeks, and MacFarlane’s (1996) self-paced auditory moving windows technique. On-line listening times (assumed to reflect interpretive processing) and end-of-sentence acceptability judgments (assumed to reflect post-interpretive processing) were obtained. Reading Span was related to off-line measures but not to on-line listening times. Furthermore, age was significantly correlated with the off-line measures, and these correlations were reduced when Reading Span was partialled. DeDe, Caplan, Kemtes and Waters (2004) reached a similar conclusion based on their reanalysis using structural equation modelling of data from several earlier studies. On their on-line
processing measure, there was a direct effect of age that was not mediated by Reading Span. However on their off-line measures of sentence and text comprehension, the age effect was mediated by Reading Span. Thus, the off-line measures provided support for Carpenter et al’s (1994) claim that reductions in simultaneous storage and computational capacity account for age-related declines in comprehension, but this was not the case for on-line measures.

Traxler et al., (2005) also questioned the role of general WM in comprehension of complex sentences, specifically the extent to which complex span tasks accurately reflect the demands imposed by object-extracted sentences. They proposed that the object-subject difference stems from the binding of constituents to positions in the syntactic tree and the assignment of thematic roles, rather than the maintenance of information. Readers experience difficulty assigning thematic roles, either because of competition between nouns for argument slots or because an initial incorrect assignment must be abandoned and the sentence re-analysed. By default, readers treat the sentential subject as the subject of the relative clause verb. This yields the correct assignment of thematic roles for subject-relatives, but not for object-relatives, which then require re-analysis. On this view, object-extracted sentences impose a higher computational rather than storage demand. Other evidence (Haarmann, Just, & Carpenter, 1997; Linebarger, Schwartz, & Saffran, 1983) also indicates that role assignment is an effortful process that imposes high computational load.

If we accept that thematic role assignment in object-extracted sentences is effortful and that it demands computational rather than storage resources, then measures of computational processing should be better predictors of comprehension of object-relatives than complex span tasks (e.g., Reading Span), in which item difficulty reflects the increasing storage load imposed as set size increases. Tasks in which storage load is minimised while computational complexity is manipulated have been developed. The basis for these manipulations is the relational complexity metric (Halford, Wilson, & Phillips, 1998).

Relational Complexity theory (Halford, et al., 1998)

In relational complexity theory, the distinction between processes that are automatic, unconscious, and dedicated on the one hand versus controlled, conscious, effortful and domain-general on the other, is captured by the distinction between processing based on associations versus relations (Halford, et al., 1998). Higher cognitive processes involve complex relations. Complexity is defined in terms of the number of arguments related in a single decision. Each argument corresponds to a dimension or variable. Complexity corresponds to the number of interacting variables that constrain responses or decisions. A metric of relational complexity is proposed. Unary relations such as class membership,
dog(fido) have a single argument. They are less complex than binary relations such as larger-than(elephant, mouse) which have two arguments. Ternary relations have three arguments as in arithmetic addition(2,3,5) and are more complex than binary relations. Quaternary relations have four interacting components (e.g., proportion 2/3 = 6/9). Quinary relations entail five interacting components. Examples at this level are rare, but recent evidence suggests that interpretation of statistical interactions involving five independent variables is quinary-relational (Halford, Baker, McCredden & Bain, 2005).

Processing load increases with relational complexity therefore quinary relations impose a higher load than quaternary relations, which impose a higher load than ternary relations, and so on. The effective complexity of a task is the least complex relation required to represent it. Where tasks have multiple steps, task complexity reflects the most complex step performed using the least demanding strategy available (Halford et al., 1998, Section 2.1). Relational complexity theory specifies that human processing capacity is limited. Adult humans can (on average) process quaternary relations, that is, four variables can be related in a single cognitive representation. A minority can also process quinary relations under optimal conditions (Halford et al., 1998; Halford, et al., 2005).

Processing of very complex concepts depends on reducing effective complexity so that optimal use can be made of the available capacity. There are two strategies for complexity reduction. Conceptual chunking occurs when concepts are recoded into fewer dimensions. For example, velocity can be represented as a ternary relation, \( velocity = \frac{distance}{time} \). It can also be recoded and represented as a unary relation as when speed is indicated by the position of a pointer on a dial. Recoding reduces processing load, but there is a cost because access to the relations that make up the concept is lost. Changes in velocity as a function of time and/or distance cannot be computed if velocity is represented as a unary relation. The principle is that variables can be chunked if the relations between them do not need to be considered. Complexity can also be reduced through segmentation of tasks into less complex steps, which can be processed serially (Halford et al., 1998).

mathematics education (English & Halford, 1995) and in industrial contexts (Boag, Neal, Loft & Halford, 2006).

Andrews, Birney, and Halford (2006) applied the approach to sentence comprehension. They proposed that subject-clefts and subject-relative sentences are less difficult than object-clefts and object-relatives because subject forms are easier to segment, whereas object forms are less conducive to segmentation. The reasoning is as follows. The aim of comprehension is to discover sentence meaning, that is, to determine who did what to whom (Caplan & Waters, 1999). This involves assigning nouns to thematic roles (e.g., agent, patient, recipient) of the verbs. Thus thematic role assignment is central to comprehension, but as noted above it is a demanding process. Thematic role assignment was characterised in terms of processing the noun-verb relations, and it was proposed that the complexity of these relations captures the difficulty of object-relatives.

To illustrate, consider the 5-role subject- and object-relative sentences in Table 2. The meaning of both forms can be expressed as the propositions: like(actor, teacher); watch(teacher, clown); laugh(clown). There are three verbs and five roles to be filled (3 agents, 2 patients). The nouns teacher and clown appear in two propositions. In the object-relative form, the three nouns occur prior to any of the verbs. Patient nouns, teacher and clown occur before the agent nouns (i.e., in non-canonical order). Role assignments cannot be finalized until the verbs are encountered. When the first verb, liked, is encountered there are three nouns waiting to be assigned to their roles. There are no semantic constraints, therefore each noun would be equally acceptable (on semantic grounds alone) as the agent or patient of liked and of watched and laughed, which occur immediately afterwards. This concentration of verbs toward the end of the sentence and the fact that two nouns are related to two verbs means that it will be difficult to reduce complexity by segmenting the sentence. If segmentation is precluded there will be pressure to assign the nouns to their roles in the same step. This means that complexity and processing load will be high.

By contrast, the nouns and verbs in subject-relatives are distributed throughout the sentence. Agent and patient roles occur in canonical order. Segmentation is easier because the propositions can be processed one at a time. The nouns, actor and teacher can be assigned to the agent and patient roles of liked before the subsequent propositions, watch(teacher, clown) and laugh(clown) are encountered. The noun-verb relations can be processed serially, thereby avoiding concentration and the concomitant processing load.

Thus in the relational complexity approach, the load imposed by sentence comprehension depends on the extent to which the thematic role assignment task can be
segmented. Object-relatives are resistant to segmentation, so the effective complexity of the noun-verb relations is higher in the object-relative than in subject-relatives.

This analysis captures important aspects of other approaches to sentence complexity. It incorporates the five sources of sentence complexity identified by Carpenter et al., (1994) either as the total number of role assignments or the ease of segmentation. Segmentation difficulty can be related to Lewis’ (1996) analysis in which stacking of verbs at the end of object-relatives makes them more difficult than comparable sentences in which there is no verb stacking. Verb stacking overloads the limited storage capacity of a short-term memory system that is specialised for syntactic relations. Items are lost due to similarity-based interference because the buffer cannot store more than two or three constituents under the same syntactic relation. Segmentation difficulty is also consistent with Hawkins’ (1994) Early Immediate Constituents (EIC) theory in which the object-subject difference is attributed to the size of the constituent recognition domain. For object-relatives, more words are required before the reader can identify the material as a phrasal constituent than for subject-relatives. This results in an increase in the number of items within current WM and in the number of computations that must be performed on them.

Gibson’s (2000) Dependency Locality Theory (DLT) includes two metrics, memory cost and integration cost, both of which impose demands on a single WM resource, similar to Just and Carpenter’s (1992). Memory cost reflects storage of information about the structure that has already been processed, whereas integration cost is imposed as new discourse referents (e.g., nouns and verbs) are incorporated into the mental representation constructed during sentence processing. Integration cost fluctuates across the sentence but is highest at the verbs. It is quantified in terms of the distance between the noun and its point of integration. There is some commonality between integration cost in DLT and processing load in relational complexity theory.

Relational complexity theory differs from each of these approaches in that it quantifies computational demand only, rather than storage demands or simultaneous storage and computational demands. In this sense it is more consistent with Traxler et al.,’s (2005) view that the object-subject difference stems from the computational demands imposed by binding of constituents to positions in the syntactic tree and the assignment of thematic roles rather than in the maintenance of information (Halford, Cowan, & Andrews, 2007).

Relational processing corresponds most closely to the functions of the central executive in Baddeley’s (1986) WM model. Just and Carpenter (1992) also likened their WM construct to the central executive. However, Baddeley (1993) has countered that complex
span tests might not be good measures of the capacity of the central executive because they also involve the Phonological Loop and aspects of long-term memory. The relational complexity metric quantifies central executive capacity only (Halford, et al., 2007).

Support for the relational processing hypothesis comes from two correlational studies. In Andrews, Halford, and Prasad’s (1998) research children aged 4 to 8 years listened to object- and subject-relative sentences with 2 and 3 roles, and responded to a comprehension question (e.g., *Who walked?*) after each. WM capacity was assessed using a Listening Span task, the auditory analogue of Reading Span. Relational processing was assessed using hierarchical classification and transitivity tasks, which have been shown to entail ternary relations, and to cause difficulty for young children (Andrews & Halford; 1998, 2002; Breslow, 1981; Halford, 1984, 1993; Halford, et al., 2002; Markovits, Dumas, & Malfait, 1995). As expected, object-relatives (especially those with three roles) were more difficult than subject-relatives. The relational processing tasks predicted comprehension independently of age and Listening Span. The comprehension questions assessed understanding of the noun-verb relations, whereas hierarchical classification and transitivity involved relations of a different type, but of similar complexity.

Further support was provided by Andrews et al., (2006). Across three studies, young adults read object- and subject-extracted relative clause sentences at their own pace then responded to end-of-sentence comprehension questions. WM capacity was assessed using Reading Span in two studies and forward and backward digit span tests in a third study. Relational processing was assessed using an $N$-term premise integration task in two studies and a Latin Square task in the third study. These tasks included items at three levels of relational complexity, with storage demands minimized. Thus the tasks imposed computational, rather than storage loads. Performance on the $N$-term and Latin Square tasks predicted comprehension object-relatives/clefts before and after controlling for subject-relatives/clefts. Performance on the WM tasks predicted comprehension of object-relatives/clefts before but not after controlling for subject-relatives/clefts. Thus individual differences in relational processing ability better accounted for the greater complexity of object-relatives/clefts than did individual differences in Reading Span, forward digit span, and backward digit span.

*The current research*

The two studies presented here provide a further investigation of the roles of relational processing ($N$-term task) and WM (Reading span) in comprehension of object-
extracted sentences assessed in the same manner as Andrews et al., (2006). However, the participants in the current research were older (age range, 20 to 88 years).

When selecting the sentence types our main requirement was to have sentences that varied in their ease of segmentation. To the extent that segmentation is difficult, participants will need to assign more roles in same decision. The object-clefts and subject-clefts (Table 1) and object-relatives and subject-relatives (Table 2) provide strong manipulations of this variable. Use of end-of-sentence comprehension questions allowed assessment of participants’ capacity to construct an explicit representation of the entire thematic structure. To the extent they did so, individuals should have access to any component of that structure (any noun-verb relation). If relational complexity were reduced (e.g., by chunking), access to the component relations would be lost.

Age-related declines in WM measures such as Reading Span are well documented. Based on their review, Carpenter et al., (1994) concluded that the correlations with age typically range from -.40 to -.70. We expected to replicate these findings and to observe a wider range of Reading Spans than in Andrews et al.’s (2006) research involving young adults. If the greater difficulty of object-extracted sentences stems from their higher WM loads, evidence for the WM hypothesis should be demonstrated in this older sample.

There is less research relevant to age-related declines in the capacity to integrate complex relations. Salthouse (1992) reported significant adult age differences in integrative reasoning. The task involved sequential presentation of premises for 4 seconds each, followed by a question. Age differences were interpreted in terms of the WM demands of the task and older participants’ reduced ability to maintain information during active processing. Salthouse’s task is similar to the N-term task in that correct responses depend on integration of the premises. However it differs in that premises were presented sequentially for a fixed duration in Salthouse’s procedure but simultaneously with no time limit in the N-term task. Thus Salthouse’s procedure incorporates two potential sources of age-related decline: maintaining premises in STM, and integrating the premises.

Viskontas, Morrison, Holyoak, Hummel, and Knowlton (2004) investigated age-related declines in relational integration using a version of Sternberg’s (1977) People Pieces Analogy task, in which short-term storage load was minimized, and the relational complexity of the items was manipulated. Results showed that young (mean age 19.8 years) and middle-aged (mean age 50 years) participants performed with a high level of accuracy on all except the most complex items. Older participants (mean age 75 years) responded less accurately
than the younger groups even on items at low and medium levels of complexity. Thus the capacity to integrate complex relations appears to decline with increasing age.

Other evidence supports this conclusion. Brain imaging studies indicate that relational processing involves prefrontal regions of the brain (Christoff, et al., 2001; Kroger, et al., 2002). Furthermore, the findings of Waltz et al., (1999), who investigated the effects of brain damage due to dementia suggest that successful integration of premises in a transitive inference task depends on an intact dorsolateral prefrontal cortex. Thus the pre-frontal regions appear crucial for processing complex relations. However, these are the very brain regions that are most vulnerable to deterioration associated with normal ageing according to neurophysiological (Raz, 2000; West, 1996) and neuropsychological (Dempster, 1992; MacPherson, Phillips & Della Sala, 2002) evidence. Thus it seems likely that performance on the N-term task, which involves complex relations, will decline with age in later adulthood.

STUDY 1

Study 1 investigated comprehension of object-clefts and subject-clefts. Based on previous research, object-clefts should be more difficult than subject-clefts. This will be referred to as the sentence complexity hypothesis. To the extent that older persons are more affected by sentence complexity (Obler, Fein, Nicholas, & Albert, 1991) the age-related decline in comprehension of object-clefts should remain significant after comprehension of subject-clefts and control variables are accounted for. This is the age-complexity hypothesis. The WM hypothesis predicts that Reading Span will account for significant age-related variance and independent variance in object-clefts after controlling for subject-clefts. The relational processing hypothesis predicts that N-term scores will account for significant age-related and independent variance in object-clefts, after controlling for subject-clefts.

Method

Participants

Sixty individuals (33 females, 27 males) aged from 20 to 82 years ($M = 49.15$ years; $SD = 17.83$) participated in Study 1. There were 10 participants in each of six age bands (20 to 29, 30 to 39, 40 to 49, 50 to 59, 60 to 69, 70 to 82). All were native English speakers. The younger participants were students enrolled in first year psychology courses. They were recruited through announcements in lectures and on course websites and participated in return for course credit. Older participants were all healthy individuals living independently in the community. Some were university employees or relatives or friends of students. They were recruited by personal contacts, word of mouth, or approaches to community groups.
Procedures and Materials

Participants completed a questionnaire eliciting demographic details including date of birth, gender, years of education, and current health status. Health was rated on a 5-point scale where 1 meant very poor and 5 meant excellent. Verbal ability was assessed using the Vocabulary subtest of the Wechsler Adult Intelligence Scale-III (WAIS-III), which was administered individually, using standard procedures.

Sentence comprehension, Reading span, and N-term tasks were administered using Hewlett Packard 233 MHz Pentium 2 personal computers with Ultra VGA 1024, 15-inch monitors. Up to four participants were tested at a time. Some older participants were tested individually because they were unfamiliar with computers and required assistance on one or more tasks. These participants were given the option of spoken responses, which were typed by the experimenter. Because of these procedural variations we restricted our analyses to accuracy measures.

Sentence comprehension. There were 96 semantically reversible sentences, divided into two sets of 48 (Appendix A). Each set contained eight instances of object-cleft and subject-cleft sentences requiring two, three, and four role assignments, as shown in Table 1. Across the sets, each sentence content was used in both object- and subject-cleft forms. Each comprehension question referred to a single noun-verb relation. There were two, four and six question types for the 2-, 3-, and 4-role sentences respectively. For example, for the 3-role sentences shown in Table 1 the questions were, Who sent? Who was sent? Who was the man sent to? What did the king do? As far as possible, each question type was used with equal frequency for object-clefts and for subject-clefts, and for each participant. Instances of the six sentence types were intermixed and presentation order was randomised for each participant. Sentences were displayed, one at a time, on the upper half of the computer screen in red Times Roman lettering (font size 24) on a grey background. Participants read each sentence at their own pace and then pressed ENTER, at which point a comprehension question replaced the sentence. Participants responded by typing a single noun or verb, or by giving a spoken response, which was typed by the experimenter. Each participant received one of the two 48-item sets, which were administered equally often to participants in each 10-year age band.

Reading Span. This task was identical to that used by Andrews et al., (2006) which was based on Turner and Engle (1989). Stimuli were 44 sentences, 11 to 16 words in length. The final words were one-syllable, high frequency, concrete nouns. Half the sentences were made nonsensical by reversing the order of four to six pre-terminal words. For example, The
The possum took the apple from the sill and then disappeared into the night. Sentences were randomly assigned to three sets at each of four set sizes (2, 3, 4, 5) and a practice set of 2 sentences.

The task was programmed using DMDX software (Forster & Forster, 1999). Instructions were displayed in green lettering on a dark blue screen. Participants were instructed to read each sentence as it was presented, judge whether it made sense, and record their judgements by pressing one of two keys labelled "Yes" and "No". Sentences were presented one at a time in white lettering. Each sentence was displayed until a key press was registered or until 10 seconds had elapsed, whichever occurred first. Following the final sentence in each set, a "Recall" signal appeared on the screen. Participants then attempted to write the final word of each sentence in the set on the sheet provided. A practice set of two sentences was presented followed by feedback to ensure participants understood the requirements. In the test phase, three 2-sentence sets were presented first, and set size was increased systematically thereafter. Reading Span scores were calculated by deducting the number of errors on make sense judgements from the number of final words correctly recalled. We used this continuous scaling rather than WM classifications (e.g., high span, low span) because the latter are known to be unstable (Waters & Caplan, 2003). According to a recent study (Murphy & Andrews, in preparation) involving 69 participants this version of Reading Span has a test-retest reliability of .70 over a 2-week interval. This is comparable to the values reported by Waters and Caplan (2003) for their simple (.73) and complex (.76) Sentence Span tasks. It meets Nunnally’s (1978) criterion for minimum reliability adequacy.

N-term. This task was identical to that used by Andrews et al., (2006). The procedure was designed to minimize storage load and to preclude complexity reduction through segmentation. The task incorporated a manipulation of computational load in that items at three levels of complexity were included. The items were generated in the following manner. Sequences of \( n \) letters (where \( n = 3, 4, \) or 5) were formed by selecting letters at random without replacement. A greater-than (>) relation was imposed on adjacent elements such that the first letter was greater than the second, the second greater than the third, and so on. These were the correct descending sequences that participants were required to construct. A set of premises containing \( n-1 \) adjacent pairs and one pair of non-adjacent letters was constructed for each sequence. A mixture of < and > signs was used in the premises. Example premises sets and 3-, 4-, and 5-term sequences are shown in Figure 1.

The screen display was divided into two sections by a white vertical line approximately 8 cm (3 in) from the left. The premise relations were presented in the left
section in white upper case letters (Times Roman, font size 24) on a grey background, in a
different randomly determined vertical order for each participant. Premises remained visible
for the duration of the item. In the right section was a row of \( n \) boxes with white outlines, and
white \( \rightarrow \) signs between them. Participants’ task was to mentally combine the premise relations
to construct a descending sequence of letters of length \( n \), and to report the sequence using the
keyboard. At the outset of each item, the left-most box was highlighted in white. The first
letter typed appeared in red in the highlighted box. It remained in view momentarily before
being replaced by an asterisk. Subsequent boxes were highlighted only when a valid letter
(one that appeared in the premises) was typed in the preceding box. This meant that during
construction of the sequence, a maximum of one letter was visible in the boxes at any one
time. When \( n \) letters had been entered, the entire sequence was displayed. Participants were
advised to construct the entire sequence mentally before beginning to type, because they
would be unable to reorder the letters once they had been entered. No time limit was
imposed. The items were blocked according to series length. Within each block, a practice
item was followed by 10 test items yielding maximum scores of 10 for each level and 30 for
the three levels combined.

<table>
<thead>
<tr>
<th>Premises</th>
<th>Correct sequences</th>
</tr>
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<td>L &lt; Q</td>
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<td>G &gt; L</td>
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*Figure 1.* Example items at three levels of complexity in \( N \)-term task. Premise information is
shown on the left and completed sequences on the right. Source: Andrews, Birney & Halford,
Results

Table 3 shows the means, standard deviations, and the zero-order correlations among age, the control measures, scores for the N-term and Reading span tasks, and comprehension accuracy (% correct) for the object-clefts and subject-clefts. Sex was not significantly correlated with any other measure, so it was not included in Table 3 or in further analyses. Consistent with the sentence complexity hypothesis, object-clefts were significantly more difficult than subject-clefts, \( t(59) = 8.36, p < .001 \).

The age-complexity hypothesis was tested in a hierarchical regression analysis with object-clefts as the dependent variable. Control variables (education, vocabulary, health) and subject-clefts were entered on Step 1 and together accounted for 39.1% variance in object-clefts, \( F(4, 55) = 8.84, p < .001 \). When age was entered on step 2, a further 5.4% variance was accounted for, \( F_{\text{change}}(1, 54) = 5.23, p < .05 \). After step 2, the unique contributions of vocabulary (4.8%), subject-clefts (8.9%) and age (5.4%) were significant, Multiple \( R = 0.67, F(5, 54) = 8.66, p < .001 \). Thus consistent with the age-complexity hypothesis, there is a significant age-related decline in object-clefts that is independent of subject-clefts and the control variables. Table 4 (central columns) summarises this and subsequent analyses.

The WM hypothesis was tested by entering Reading Span on step 3. See analysis 2 in Table 4. Steps 1 and 2 were the same as in the previous analysis. Entry of Reading Span resulted in no significant increase in variance accounted for, \( F_{\text{change}}(1, 53) = 1.07, p > .05 \). After step 3, the unique contribution of subject-clefts (5.2%) was reduced, but remained significant. The unique contribution of age was reduced to a marginally significant level (\( p = .051 \)). The unique contribution of Reading Span was not significant, Multiple \( R = 0.68, F(6, 53) = 7.40, p < .001 \). Thus Reading Span accounted for variance in object-clefts that was shared with verbal ability (vocabulary). It reduced the unique contributions of subject-clefts and age. Reading Span did not account for additional independent variance in object-clefts.

The relational processing hypothesis was tested in an analogous manner. See analysis 3 in Table 4. N-term scores entered on step 3 accounted for additional 5.5% variance, \( F_{\text{change}}(1, 53) = 5.78, p < .05 \). After step 3, the unique contributions of subject-clefts (6.7%) and N-term (5.5%) were significant, Multiple \( R = 0.71, F(6, 53) = 8.82, p < .001 \). Thus N-term accounted for the age-related variance in object-clefts, as well as for shared variance with verbal ability, and to a lesser extent, subject-clefts. In addition, N-term accounted for independent variance in object-clefts.

To evaluate whether Reading Span and N-term account for overlapping variance in comprehension of object-clefts, both Reading Span and N-term were entered on Step 3 and an
Table 3.

*Simple Correlations and Descriptive Statistics for Age, Control Variables, N-term, Reading Span, Comprehension of Object- and Subject-clefts in Study 1*

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Table 4
Hierarchical Regression of Control Variables, Comprehension of Subject-Clefts, Age, Reading Span and N-term on Comprehension of 2-, 3-, and 4-role (central columns) and 3- and 4-role (rightmost columns) Object-Clefts in Study 1.

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* p < .05; ** p < .01; *** p < .001

additional 6.2% variance was accounted for, $F_{\text{change}} (2, 52) = 3.25, p < .05$. After step 3, subject-clefts (4.0%) and N-term (5.1%) each made a significant unique contribution, Multiple $R = .71$, $F (7, 52) = 7.63, p < .001$. Comparison with analyses 2 and 3 shows that Reading Span had little impact on the unique contribution of N-term. However, there was
considerable overlap in the age-related variance accounted for by Reading Span and \(N\)-term, and both measures accounted for most of the age-related variance.

**STUDY 2**

In Study 2, we assessed comprehension of 3-role, 4-role, and 5-role object- and subject-relative sentences as shown in Table 2. An additional control measure, nonverbal ability, was also included. The hypotheses were analogous to Study 1.

**Method**

**Participants**

Seventy-three individuals (39 females, 34 males) aged from 20 to 88 years participated (\(M = 53.53\) years; \(SD = 21.47\) years). The number of participants in each age band differed slightly as follows 20 to 29 yrs (12), 30 to 39 yrs (10), 40 to 49 yrs (14), 50 to 59 (7), 60 to 69 yrs (10), 70 to 79 yrs (8), 80 to 88 yrs (12). None of these individuals had participated in Study 1. All were native English speakers. The younger participants were students enrolled in first year psychology courses, who participated in return for course credit. The older participants were all healthy individuals living independently in the community, who were recruited in the manner described in Study 1.

**Procedures and Materials**

Participants completed a demographic questionnaire, identical to that described in Study 1. Verbal ability was assessed using the Vocabulary subtest of the WAIS-III. Nonverbal ability was assessed using the Matrices subtest of WAIS-III. These tests were administered individually using standard procedures.

**Sentence comprehension task.** There were 96 semantically reversible sentences, divided into two sets of 48 (Appendix B). Each set contained eight instances of object-relative and subject-relative sentences requiring three, four, and five role assignments, as shown in Table 2. As in Study 1, each sentence content was used in both object- and subject-relative forms, and each comprehension question referred to a single noun-verb relation. There were five, six and eight question types for the 3-, 4-, and 5-role sentences respectively. For example, for 3-role sentences in Table 2 the five questions were, *Who touched? Who walked? Who was touched? What did the duck do? What did the monkey do?* The question types were selected randomly with the constraint that each question type was used at least once for each sentence type and for each participant. Sentence presentation and response modes were the same as in Study 1.

**Reading Span and \(N\)-term.** WM capacity and relational processing were assessed using the same Reading Span and \(N\)-term tasks as in Study 1.
Results

Table 5 shows the means, standard deviations and the zero-order correlations among age, the control measures, N-term and Reading span, and comprehension accuracy (% correct) for the object-relatives and subject-relatives. Means for vocabulary, Reading Span, and N-term tests were lower than in Study 1, consistent with the higher mean age of the sample. Mean levels of comprehension were lower than in Study 1, consistent with the inclusion of 5-role sentences, and the extended age range. The sentence complexity hypothesis was supported in that, object-relatives were significantly more difficult to comprehend than subject-relatives, \( t(72) = 10.32, p < .001 \).

To test the age-complexity hypothesis, control variables (education, sex, health, vocabulary, matrices) and subject-relatives were entered on Step 1 and together they accounted for 50.2% variance in object-relatives, \( F(6, 66) = 11.07, p < .001 \). When age was entered on step 2 it accounted for a further 4.4% variance, \( F_{change}(1, 65) = 6.25, p < .05 \). After step 2, the unique contributions of vocabulary (4.3%), subject-clefts (21.3%) and age (4.4%) were significant, Multiple \( R = 0.74, F(7, 65) = 11.14, p < .001 \). The unique contribution of subject-relatives was somewhat larger than in Study 1, but those of vocabulary and age were comparable. Consistent with the age-complexity hypothesis, there is an age-related decline in object-relatives that is independent of subject-relatives, verbal ability, non-verbal ability, and education. This and subsequent analyses are summarised in Table 6.

To test the WM hypothesis (analysis 2 in Table 6) Reading Span was entered on step 3. The increase in variance was not significant, \( F_{change}(1, 64) = 2.66, p > .05 \). After step 3, the unique contribution of subject-relatives (16.65%) was significant, Multiple \( R = 0.75, F(8, 64) = 10.33, p < .001 \). As in Study 1, Reading Span accounted for the variance associated with verbal ability, and reduced the unique contribution of subject-relatives. Reading Span reduced the age-related variance in object-relatives to non-significance in Study 2. As in Study 1, Reading Span did not account for independent variance in object-relatives.

To test the relational processing hypothesis (analysis 3 in Table 6), N-term was entered on step 3. It accounted for an additional 3.5% variance, \( F_{change}(1, 64) = 5.35, p < .05 \). After step 3, the unique contributions of vocabulary (3.6%), subject-relatives (18.6%) and N-term (3.5%) were significant, Multiple \( R = 0.76, F(8, 64) = 11.07, p < .001 \). Thus as in Study 1, N-term reduced the age-related variance in object-relatives to non-significance and reduced the unique contributions of verbal ability and subject-relatives somewhat. In addition, N-term accounted for a small, though significant amount of independent variance.
Table 5

**Simple Correlations and Descriptive Statistics for Age, Control Variables, N-term, Reading Span, Comprehension of Object- and Subject-relatives in Study 2**

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Table 6
Hierarchical Regression of Control Variables, Comprehension of Subject-Relatives, Age, Reading Span and N-term on Comprehension of 3-, 4-, and 5-role (centre columns) and 3- and 4-role (rightmost columns) Object-Relatives in Study 2

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*p < .05; **p < .01; ***p < .001
To examine whether Reading Span and N-term account for overlapping variance in comprehension of object-relatives, Reading Span and N-term were entered on step 3 and resulted in an additional 5.6% variance being accounted for, $F_{\text{change}} (2, 63) = 4.44, p < .05$. After step 3, subject-clefts (13.9%), N-term (3.8%) and nonverbal ability (2.9%) made significant unique contributions, Multiple $R = .78$, $F (9, 63) = 10.57, p < .001$. Comparison with analyses 2 and 3 shows that Reading Span had little impact on the unique contribution of N-term, however as in Study 1, there was considerable overlap in the age-related variance in object-relatives accounted for by Reading Span and N-term.

**Working Memory and Relational Processing**

A further question is the independence or otherwise of WM capacity and relational processing ability. Previous research suggests that the correlations observed might depend on the age range investigated. Andrews et al., (1998) observed significant correlations between Listening Span and relational processing tasks in young children, however in an age-restricted sample of young university students, Reading Span and N-term scores were not significantly correlated (Andrews et al., 2006, Experiments 1 and 2). In the current research, Reading Span and N-term scores were positively correlated and each was negatively correlated with age. It is possible for variables that have substantial unique variance to be similar in terms of the overlap in their age-related variance (Salthouse, 1994, p. 419). Thus, we computed the proportions of shared variance in Reading Span and N-term that are related and unrelated to age. The Venn diagrams in Figure 2 depict the relations between the relevant variables, Reading Span, N-term, age (Salthouse, 1994). For these analyses, data from Studies 1 and 2 were combined ($N = 133$).

Of the age-related variance in N-term, 0.64 was shared with the age-related variance in Reading Span. This corresponds to $(b / (b + d))$ in Figure 2. Of the age-related variance in Reading Span, 0.61 was shared with the age-related variance in N-term. This corresponds to $(b / (b + c))$. The corresponding proportions for age-independent variance $(a / (a + f))$ or $(a / (a + e)$ were considerably lower at .08. Thus the significant zero-order correlation between Reading Span and N-term ($r = .50, N = 133$) reflects common age-related variance more so than common age-independent variance. A similar picture emerged when variance associated with control variables (education, vocabulary and health) was removed and analyses were based on residual variance. The proportions for age-related variance were .49 $(b / (b + d))$ and .47 $(b / (b + c))$; and for age-independent variance were .02 $(a / (a + f))$ and $(a / (a + e))$. 
Despite the overlap in age-related variance, there were significant amounts of age-related variance that were unique to Reading Span (region c) or to N-term (region d). This unique age-related variance might reflect different patterns of decline. To examine this the sample was divided into four age groups: Group 1 (n = 32, mean age = 25.75 years, range 20 to 36 years), Group 2 (n = 34, mean age = 42.91 years, range 37 to 49 years), Group 3 (n = 33, mean age = 58.70 years, range 51 to 68 years); Group 4 (n = 34, mean age = 77.56 years, range 69 to 88 years). As would be expected given the correlations reported above, ANOVA revealed significant age group effects for N-term, $F(3, 129) = 15.55, p < .001$, and for Reading Span, $F(3, 129) = 25.09, p < .001$. For N-term, post-hoc Scheffe tests showed significant differences between Groups 1 and 2 versus Groups 3 and 4. Group 1 ($M = 23.41; SE = 1.46$) did not differ significantly from Group 2 ($M = 20.41; SE = 1.42$). Group 3 ($M = 13.36; SE = 1.44$) did not differ significantly from Group 4 ($M = 11.47; SE = 1.42$). For Reading Span, there were no significant differences among Groups 1 ($M = 28.59; SE = 1.51$), 2 ($M = 30.91; SE = 1.47$), and 3 ($M = 27.88; SE = 1.49$). However Group 4 ($M = 14.62; SE = 1.47$) performed significantly worse than the three younger groups. Thus the age-related decline began later for Reading Span (after 69 years) than for N-term (after 50 years). When the effects of education, vocabulary, and health were covaried, additional group differences indicating earlier onsets of age-related decline emerged. For N-term, the difference between Groups 1 and 2 reached significance. For Reading Span, the difference between Groups 2 and

![Diagram](image-url)

*Figure 2.* Illustrations of the relevant regions of variance in Reading Span, n-term, and age.
3 reached significance. However, the conclusion that the capacity to process complex relations declines earlier than WM capacity is unchanged.

**GENERAL DISCUSSION**

Consistent with the *sentence complexity hypothesis*, object-clefts were more difficult to comprehend than the corresponding subject-clefts (Study 1) and object-relatives were more difficult than the corresponding subject-relatives (Study 2). This replicates many previous findings comparing object-extracted with subject-extracted forms. There is a consensus that the greater difficulty of object-sentences stems from their greater complexity.

The studies demonstrated age-related declines in comprehension of both subject-clefts/relatives and also object-clefts/relatives. While there was much shared variance, there was also evidence of an age-related decline in object-extracted sentences that is independent of subject-clefts/relatives, and the control variables. Thus consistent with the *age-complexity hypothesis*, older adults were particularly susceptible to the higher loads imposed by object-clefts and object-relatives (Obler et al., 1991).

The research investigated whether WM capacity and relational processing ability account of the age-related declines in comprehension of object-clefts/relatives. Study 1 provided support for the WM account in that inclusion of Reading Span reduced the age-related variance in object-clefts to a marginally significant level. Study 2 provided stronger support with Reading Span reducing age-related variance to a nonsignificant level ($p = .10$). This slight discrepancy appears to be due to the higher mean age of participants and the inclusion of more complex sentences in Study 2 (3-, 4-, and 5-role sentences) as compared to Study 1 (2-, 3-, and 4-role sentences). This is supported by a supplementary set of regression analyses in which the comprehension variables in both studies were recomputed based on 3-role and 4-role sentences only, and the age range in Study 2 was restricted to participants aged up to 80 years. This resulted in sample size ($N = 62$) and mean age ($M = 48.06; SD = 18.49$) in Study 2 that was comparable to Study 1. The results are reported in the rightmost columns in Tables 4 and 6. The analyses involving Reading Span are more consistent when complexity and age ranges are equated in this way. In both studies, Reading Span reduced the unique contribution of age to a marginally significant level ($p = .07$). These findings are consistent with Carpenter et al.’s, (1994) *WM hypothesis*. They are also consistent with Waters and Caplan’s (2001) approach if it is assumed that the comprehension questions require post-interpretive processing, but not interpretive processing.

There was consistent support for the *relational processing hypothesis*. In both studies, $N$-term reduced the unique contribution of age to a nonsignificant level. This was also the
case when the analyses were restricted to participants aged up to 80 years and to 3 and 4-role sentences only.

Whereas both Reading Span and N-term tests accounted for age-related variance in object-clefts/relatives, a different picture emerges when the variance unrelated to age is considered. In both studies, N-term accounted for variance in object-clefts/relatives independently of age and the other variables, whereas Reading Span never did so. This is reminiscent of our previous findings with young adults, where Reading Span did not account for individual differences in comprehension of object-relatives/clefts after subject-relatives/clefts were entered, whereas relational processing tasks (including N-term) predicted comprehension of object-relatives/clefts both before and after controlling for subject-relatives/clefts. The relational processing tasks captured the greater complexity of object-clefts/relatives, whereas Reading Span did not (Andrews et al., 2006).

As in many previous WM studies, Reading Spans declined with increasing age. The magnitude of the decline ($r = -.50, N = 133$) was consistent with previous research (Carpenter et al., 1994). As individuals age, simultaneous computation and storage of information becomes increasingly difficult. Significant age-related declines were also observed on the N-term task ($r = -.50, N = 133$), which involved integration of relational premises. The items varied in their relational complexity (number of premises to be integrated), but short-term storage load was minimal, because premise information was available continuously. In these respects, the N-term task resembles the reasoning task used by Viskontas et al., (2004), and the findings are interpreted in a similar way. Both studies suggest that relational processing capacity is vulnerable to decline with increasing age in later adulthood. The current results suggest that age-related decline begins earlier for relational processing than for WM capacity (Reading Span). As such, tasks requiring relational integration might be useful inclusions in cognitive aging research.

The positive correlations between Reading Span and N-term that were observed in both studies appear to reflect common age-related variance (region b in Figure 2) rather than common age-independent variance (region a). Salthouse (1994) interpreted common age-related variance as evidence for a single causal factor that underlies age-related declines on many tasks. However, the presence of age-related variance that is unique to N-term (region d) and to Reading Span (region c) suggests some degree of independence between the capacity for simultaneous storage and computation and relational processing capacity. As such the findings have implications for unitary WM models that incorporate a single pool of resources
that can be flexibly allocated to storage and computational demands. If computation and storage draw on the same resources, similar onsets of age-related decline would be expected.

The differential patterns of age-related decline observed on Reading Span and \( N \)-term tasks might reflect the involvement of different brain regions within the frontal lobes. Christoff and Gabrieli (2000) proposed a hierarchical model of the prefrontal cortex in which the ventrolateral, dorsolateral, and frontopolar regions are involved in storage, manipulation, and evaluation functions, respectively. The Reading Span and \( N \)-term tasks differ in terms of their storage, manipulation and evaluation demands and therefore the involvement of the three regions. Reading Span involves a high storage load (maintaining final words) and a lesser manipulation load (judging the sentences). Thus the ventrolateral regions and (to a lesser extent) the dorsolateral region would be involved. \( N \)-term has a minimal storage load (premises were continuously available), a high manipulation load (integrating premises), and opportunities for evaluation (checking responses against the premises). Thus dorsolateral and frontopolar regions would have been involved. The earlier onset of age-related decline for \( N \)-term than Reading Span might indicate that more anterior brain regions are more vulnerable to degenerative processes associated with normal ageing.

CONCLUSION

Overall the results suggest that the difficulty of object-clefts/relatives and the age-related decline in comprehension stems from at least two sources. First, there are the demands that are common to both object-clefts/relatives and subject-clefts/relatives. Subject-clefts/relatives accounted for significant unique variance in the prediction of object-clefts/relatives in all analyses. Clearly, understanding the subject forms of these constructions is a prerequisite for comprehending the more complex object forms. While both Reading Span and \( N \)-term reduced the unique variance attributable to the subject forms when entered on Step 3 of the analyses, the reductions tended to be larger for Reading Span than for \( N \)-term. This might reflect the verbal nature of the Reading Span task and/or the fact that Reading Span itself involves comprehending sentences.

Second, there is the extra demand imposed by the complexity of the object-clefts/relatives as compared to the subject-clefts/relatives. Both Reading Span and \( N \)-term accounted for the age-related component of this variance. The part correlations for age (analyses 2 and 3 in Tables 4 and 6) suggest that \( N \)-term did so more convincingly, perhaps because of the earlier onset of age-related decline in \( N \)-term than Reading Span. Thus reductions in either WM capacity or relational processing capacity (or both) disadvantaged older participants in their efforts to cope with the additional demands of the object-
clefts/relatives. There was also age-independent variance in the additional demands imposed by object-clefts/relatives. That $N$-term captured this additional complexity whereas Reading Span failed to do so provides more support for the relational processing hypothesis (that the object-clefts/relatives involve more complex relations) than for the WM hypothesis (that the object-clefts/relatives involve more for simultaneous storage and computation).
REFERENCES


Appendix A - Cleft Sentences Used In Study 1

Set A
It was the monkey that the lion pushed.
It was the doctor that the lawyer phoned.
It was the giraffe that the camel kicked.
It was the baker that the policeman hit.
It was the dancer that the artist kissed.
It was the man that the dog dragged.
It was the teacher that the parent reported.
It was the lion that the tiger mauled.
It was the crow that attacked the magpie.
It was the mechanic that contacted the plumber.
It was the journalist that shot the photographer.
It was the possum that chased the rabbit.
It was the scientist that liked the politician.
It was the cow that followed the horse.
It was the teenager that thanked the woman.
It was the sergeant that buried the corporal.
It was the banker that the pilot told the tailor about.
It was the Alsatian that the Labrador chased the terrier toward.
It was the zebra that the donkey pushed the goat onto.
It was the pastor that the dentist introduced the nurse to.
It was the dog that the cat dragged the monkey to.
It was the lecturer that the student warned the librarian about.
It was the hairdresser that the waiter contacted the chef about.
It was the plane that the truck towed the car toward.
It was the novelist that approached the reporter about the spy.
It was the sailor that left the airman for the soldier.
It was the squirrel that bumped the possum toward the chimp.
It was the philosopher that rejected the biologist for the historian.
It was the boat that transported the plane to the semitrailer.
It was the kangaroo that drove the dingo toward the emu.
It was the assistant that delivered the waiter to the doctor.
It was the lawyer that interviewed the manager about the clown.
It was the duck that the monkey that the rabbit touched kicked.
It was the aeroplane that the helicopter that the rocket passed hit.
It was the count that the king that the duke slapped killed.
It was the banker that the model that the photographer hugged liked.
It was the canary that the budgerigar that the wren pecked nudged.
It was the actor that the producer that the writer stalked dismissed.
It was the farmer that the reporter that the singer punched caught.
It was the rooster that the cow that the mule followed bit.
It was the cat that bit the pig and it was the pig that pushed the mule.
It was the dancer that liked the waiter and it was the waiter that photographed the pilot.
It was the labourer that watched the shearer and it was the shearer that punched the farmer.
It was the magpie that attacked the hawk and it was the hawk that swooped the crow.
It was the murderer that phoned the thief and it was the thief that helped the rapist.
It was the goose that bumped the duck and it was the duck that followed the swan.
It was the actor that thanked the teacher and it was the teacher that saved the pilot.
It was the barman that followed the cheerleader and it was the cheerleader that hated the editor.
Set B
It was the magpie that the crow attacked.
It was the plumber that the mechanic contacted.
It was the photographer that the journalist shot.
It was the rabbit that the possum chased.
It was the politician that the scientist liked.
It was the horse that the cow followed.
It was the woman that the teenager thanked.
It was the corporal that the sergeant buried.
It was the lion that pushed the monkey.
It was the lawyer that phoned the doctor.
It was the camel that kicked the giraffe.
It was the policeman that hit the baker.
It was the artist that kissed the dancer.
It was the dog that dragged the man.
It was the parent that reported the teacher.
It was the tiger that the lion mauled.
It was the spy that the novelist approached the reporter about.
It was the soldier that the sailor left the airman for.
It was the chimp that the squirrel bumped the possum toward.
It was the historian that the philosopher rejected the biologist for.
It was the semitrailer that boat transported the plane to.
It was the emu that the kangaroo drove the dingo toward.
It was the doctor that the assistant delivered the waiter to.
It was the chimp that the lawyer interviewed the manager about.
It was the pilot that told the tailor about the banker.
It was the Labrador that chased the terrier toward the Alsatian.
It was the donkey that pushed the goat onto the zebra.
It was the dentist that introduced the nurse to the pastor.
It was the cat that dragged the monkey to the dog.
It was the student that warned the librarian about the lecturer.
It was the waiter that contacted the chef about the hairdresser.
It was the truck that towed the car toward the plane.
It was the mule that the pig that the cat bit pushed.
It was the pilot that the waiter that the dancer liked photographed.
It was the farmer that the shearer that the labourer watched punched.
It was the crow that the hawk that the magpie attacked swooped.
It was the rapist that the thief that the murderer phoned helped.
It was the swan that the duck that the goose bumped followed.
It was the pilot that the teacher that the actor thanked saved.
It was the editor that the cheerleader that the barman followed hated.
It was the rabbit that touched the monkey and it was the monkey that kicked the duck.
It was the rocket that passed the helicopter and it was the helicopter that hit the aeroplane.
It was the duke that slapped the king and it was the king that killed the count.
It was the photographer that hugged the model and it was the model that liked the banker.
It was the wren that pecked the budgerigar and it was the budgerigar that nudged the canary.
It was the writer that stalked the producer and it was the producer that dismissed the actor.
It was the singer that punched the reporter and it was the reporter that caught the farmer.
It was the mule that followed the cow and it was the cow that bit the rooster.
Appendix B – Relative Clause Sentences Used In Study 2

Set A
The giraffe that the horse kicked ate.
The man that the child bit read.
The dog that the cat chased died.
The duck that the monkey touched walked.
The fireman that the woman kissed spoke.
The aeroplane that the helicopter passed crashed.
The nurse that the dentist scared smoked.
The woman that the man helped sang.
The pig bumped the cow that ate.
The emu passed the kangaroo that slept.
The girl kissed the woman that smiled.
The boy scared the clown that drank.
The rhino feared the tiger that slept.
The pig bit the goat that yelled.
The waiter liked the pilot that coughed.
The bus towed the truck that crashed.
The cook that the king sent the man to yelled.
The hairdresser that the butcher took the princess to helped.
The bear that the ox pushed the horse onto slept.
The baker that the fireman introduced the doctor to died.
The banker that the butcher told the tailor about laughed.
The Alsatian that the Labrador chased the terrier toward barked.
The journalist that the editor warned the politician about absconded.
The coach that the player brought the manager to drank.
The woman drove the teacher to the postman that smiled.
The clown informed the queen of the singer that collapsed.
The waiter warned the chef about the artist that talked.
The lorry carried the truck to the boat that left.
The lawyer took the barrister to the judge that sneezed.
The host introduced the reporter to the spy that shivered.
The sheep bumped the pig toward the goat that ate.
The sailor left the airman for the soldier that moved.
The boy that the girl that the man saw met slept.
The car that the truck that the taxi followed towed crashed.
The clown that the teacher that the actor liked watched laughed.
The kangaroo that the dog that the rabbit saw followed ate.
The customer that the chef that the waitress left thanked sneezed.
The photographer that the model that the publisher kicked fed danced.
The rabbit that the duck that the lamb bumped pestered left.
The salesperson that the senator that the parent contacted interviewed lied.
The boy watched the woman that thanked the child that danced.
The tiger caught the mouse that annoyed the horse that ran.
The canoe passed the boat that rammed the yacht that sank.
The girl helped the nurse that attacked the doctor that left.
The ringmaster liked the keeper that noticed the acrobat that shouted.
The Chihuahua confronted the poodle that bit the terrier that played.
The electrician divorced the painter that helped the singer that stuttered.

Set B
The writer fed the ratepayer that watched the mechanic that complained.
The cow that the pig bumped ate.
The kangaroo that the emu passed slept.
The woman that the girl kissed smiled.
The clown that the boy scared drank.
The tiger that the rhino feared slept.
The goat that the pig bit yelled.
The pilot that the waiter liked coughed.
The truck that the bus towed crashed.
The horse kicked the giraffe that ate.
The child bit the man that read.
The cat chased the dog that died.
The monkey touched the duck that walked.
The woman kissed the fireman that spoke.
The helicopter passed the aeroplane that crashed.
The dentist scared the nurse that smoked.
The man helped the woman that sang.
The postman that the woman drove the teacher to smiled.
The singer that the clown informed the queen of collapsed.
The artist that the waiter warned the chef about talked
The boat that the lorry carried the truck to left.
The judge that the lawyer took the barrister to sneezed.
The spy that the host introduced the reporter to shivered.
The goat that the sheep bumped the pig toward ate.
The soldier that the sailor left the airman for moved.
The king sent the man to the cook that yelled.
The butcher took the princess to the hairdresser that helped.
The ox pushed the horse onto the bear that slept.
The fireman introduced the doctor to the baker that died.
The butcher told the tailor about the banker that laughed.
The Labrador chased the terrier toward the Alsatian that barked.
The editor warned the politician about the journalist that absconded.
The player brought the manager to the coach that drank.
The child that the woman that the boy watched thanked danced.
The horse that the mouse that the tiger caught annoyed ran.
The yacht that the boat that the canoe passed rammed sank.
The doctor that the nurse that the girl helped attacked left.
The acrobat that the keeper that the ringmaster liked noticed shouted.
The terrier that the poodle that the Chihuahua confronted bit played.
The singer that the painter that the electrician divorced helped stuttered.
The mechanic that the ratepayer that the writer fed watched complained.
The man saw the girl that met the boy that slept.
The taxi followed the truck that towed the car that crashed.
The actor liked the teacher that watched the clown that laughed.
The rabbit saw the dog that followed the kangaroo that ate.
The waitress left the chef that thanked the customer that sneezed.
The publisher kicked the model that fed the photographer that danced.
The lamb bumped the duck that pestered the rabbit that left.
The parent contacted the senator that interviewed the salesperson that lied.