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ABSTRACT

Two experiments investigated the role of capacity in children's comprehension of relative clause sentences. Sentences varied in number of participant roles, focus (object, subject), and embeddedness (center-embedded, right-branching). Center-embeddedness and object-focus were expected to constrain individuals toward assigning more nouns to their roles in the same decision. Estimates of sentences' processing loads were based on number of roles assigned in parallel and quantified in terms of a relational complexity metric (binary, ternary relations). In experiments 1 and 2, 135 children (4 to 8 years) and 48 children (4 to 7 years) respectively, responded to comprehension probes. As predicted, 3-role sentences were more difficult than 2-role sentences if sentences were center-embedded, object-focused or both, but not if sentences were right-branching. Comprehension improved with age. Children's working memory capacity (listening span) and their capacity to process complex relations (hierarchical classification, transitivity) were also assessed. Age-related improvements in performance were observed on all tasks. Regression analyses showed that Relational Complexity tasks accounted for variance in comprehension independently of age and listening span. The processing load involved in comprehension of relative clause sentences seems due to, in part, the complexity of the relational information entailed in the role assignment process. (Contains five tables and two figures of data.) (Author/RS)

Processing Load and Children's Comprehension of Relative Clause Sentences

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Abstract

Two experiments investigated the role of capacity in children's comprehension of relative clause sentences. Sentences varied in number of participant roles (2; 3), focus (object, subject) and embeddedness (centre-embedded, right-branching). For example: 2-role, object-focused, right branching "... the pig that the cow bumped"; 2-role, subject-focused right-branching "... the cow that bumped the pig"; 3-role, object-focused, centre-embedded "The cow that the pig bumped ate"; 3-role, subject-focused, right-branching "The cow bumped the pig that ate". A fifth type, 3-role, subject-focused, centre-embedded "The cow that bumped the pig ate" was included in Experiment 2. Centre-embeddedness and object-focus were expected to constrain individuals toward assigning more nouns to their roles in the same decision. Estimates of sentences' processing loads were based on number of roles assigned in parallel, and quantified in terms of a relational complexity metric (binary, ternary relations). In Experiments 1 and 2, 135 children (4 to 8 years) and 48 children (4 to 7 years) respectively, responded to comprehension probes (e.g., "Who bumped?"). As predicted, the 3-role sentences were more difficult than 2-role sentences if sentences were centre-embedded, object-focused or both, but not if sentences were right-branching. Comprehension improved with age. Children's working memory capacity (listening span), and their capacity to process complex relations (hierarchical classification, transitivity) were also assessed. Age-related improvements in performance were observed on all tasks. Regression analyses showed that Relational Complexity tasks accounted for variance in comprehension independently of age and listening span. The processing load involved in comprehension of relative clause sentences seems to due, in part, to the complexity of the relational information entailed in the role assignment process.

Processing Load and Children's Comprehension of Relative Clause Sentences

Two experiments investigated the processing demands involved in children's comprehension of five types of relative clause sentences. Loads were quantified using a general metric of relational complexity (Halford, Wilson & Phillips, in press). Predictions derived from the metric referred to the relative difficulty of the sentence types, and the relationship between comprehension and performance on two additional tasks (hierarchical classification, transitivity) whose items were known to entail the same level of relational complexity as the sentences.

Previous research with adults (e.g., King & Just, 1992) and children (e.g., Crain, Shankweiller, Marcaruso, & Bar-Shalom, 1990) suggested that comprehension of relative clause sentences involves verbal working memory (i.e., capacity to simultaneously maintain and process information). Therefore, working memory capacity (listening span) was assessed and the relationship with comprehension examined.

Relational Complexity metric (Halford et al, in press)

Relational complexity refers to the arity of relations (i.e., number of arguments or entities related). Each argument corresponds to a dimension and an *N*-ary relation is a set of points in *N*-dimensional space. The number of dimensions corresponds to the number of interacting variables that constrain responses or decisions.

A relational complexity metric is defined. Unary relations have a single argument as in class membership, dog(fido). Binary relations have 2 arguments as in larger-than(elephant, mouse). Ternary relations have 3 arguments as in addition(2,3,5). Quaternary relations such as proportion have 4 interacting components as in 2/3 = 6/9. Quinary relations entail 5 interacting components.

Processing load increases with complexity. Complexity can be reduced by segmenting the task into several less complex steps which can be processed in succession, or by chunking which can result in loss of information about relations among entities. Normative data suggests that children process unary relations at a median age of 1 year, binary relations at 2 years, ternary relations at 5 years, quaternary relations at 11 years.

Complexity Analysis of Relative Clause Sentences

Assigning noun phrases to their thematic roles (e.g., agent, patient) to determine *who did what to whom* is a key process in comprehension. Sentence complexity corresponds to the number of role assignments that must be made in a single decision. Sentences that require two role assignments in a single decision have the complexity of a binary relation. Sentences that require three role assignments in a single decision have the complexity of a ternary relation.

Two characteristics of relative clause sentences prevent segmentation of sentences and constrain individuals toward simultaneous assignment of roles. These are centre-embeddedness (CE) and object focus. In CE sentences, the relative clause separates the main clause subject from the main clause verb. This delays the assignment of subject noun to its role until the verb is encountered, at which point other role assignments must also be made. In right branching, RB sentences, there is no separation of main clause subject and verb, so the nouns can be assigned one at a time.

In object-focused sentences, the noun to which the relative clause refers is the object of the relative clause verb. The word order is noncanonical, i.e., noun-noun-verb, NNV. Two nouns precede the verb and the noun that fills object role occurs before the subject noun. Both nouns must be assigned to their roles when the verb is encountered. In subject-focused sentences the noun to which the relative clause refers is the subject of the relative clause verb and the word order is canonical, NVN. Each noun can be assigned to its role as soon as it is encountered. Table 1 contains examples of CE, RB, object-focused, and subject-focused sentences.

Research questions / predictions

If processing load increases with sentence complexity and complexity corresponds to the number of role assignments made in a single decision, then increasing the number of role assignments (from 2 to 3) should increase the difficulty of object-focused sentences which are difficult to segment to a greater extent than for subject-focused sentences which are easily segmented. Thus a Roles × Focus interaction was predicted.

If comprehension of relative clause sentences requires processing of complex relational information, then performance on tasks (hierarchical classification, transitivity) that entail the same level of complexity should correlate with comprehension. If comprehension of relative clause sentences requires working memory resources, then listening span should correlate with comprehension.

The extent to which working memory and the relational complexity account for age related improvements in comprehension will be evaluated.

Method

Participants

In Experiment 1, the 134 participants ranged in age from 3 years, 8 months (3;8) to 8;11 (mean 6;5, SD = 1;7). In Experiment 2, there were 48 participants who ranged in age form 4;0 to 7;8 (mean = 5;10, SD = 1;2).

In each experiment, all children completed 4 tasks.

Materials & Stimuli

Sentences. Each child received 6 instances of each of four types (Exp. 1) and five types (Exp. 2) of relative clause sentences. The sentences varied in terms of the number of roles assignments (2, 3) and focus (object, subject) and embeddedness (CE, RB). For each sentence, there were 2 picture cards (10 cm × 15 cm) each containing a line drawing of a noun from the sentence.

Comprehension questions. These referred to one noun-verb binding. There were 3 question forms in Exp. 1: Who *verbed*? Who was *verbed*? What did the *noun* do? and 2 question forms in Exp. 2: Who *verbed*? Who was *verbed*? One question was presented for each sentence.

Procedure (Experiment 1)

Prior to the 2-role sentences, the experimenter said,

"I want to tell you about a boy (girl)[1] *called Mark (Sally). It was Mark's (Sally's) birthday and he (she) got a present. It was a set of binoculars. Do you know what binoculars are? ... You hold them up to your eyes and look through them. You can see things that are far away. Mark (Sally) really liked his (her) binoculars and he (she) spent a lot of time looking through them. I will tell you about some of the things he (she) saw. I will give you some pictures to help you remember what Mark (Sally) saw. Listen carefully and see if you can say what I say, OK?"*

Prior to the 3-role sentences, children who had received the 2-role sentences first were told, *"This time, we don't have Mark (Sally), but you do just the same thing as before, OK?"* Children who received the 3-role sentences first were told, *"In this game,*

[1] Depending on sex of participant.

I read you a little story. I will give you some pictures to help you remember the story. Listen carefully and see if you can say what I say, OK?"

The picture cards were placed in random left-right order on the table in the child's view. The sentence was read aloud and the child repeated the sentence. Extra presentations (max of 4) were provided as required. The comprehension probe question was presented. Children responded verbally by stating a noun or verb, or nonverbally (pointing to a picture).

Procedure (Experiment 2)

This was similar to Experiment 1 except that no repetition of sentences was required.

Listening Span (Exps 1 & 2)

Siegel's (1994) procedure was used. Sets of 2, 3, 4 and 5 sentences were presented. The final word of each sentence was missing and children supplied a suitable word to complete each sentence (e.g., *There were six candles on the birthday* ______. Final word is *cake*). After hearing each set, children attempted to recall the final word of each sentence.

Up-down method of presentation was used. Set size was 2 for the trial 1. Set size on subsequent trials increased by 1 following accurate recall, and decreased by 1 (min set size of 2) if recall was incorrect. Listening Span score was the total number of sentences presented on the 7 test trials plus the estimate for trial 8 (min score = 16).

Hierarchical Classification (Exps. 1 & 2)

Inferences based on classification hierarchies require recognition of the asymmetric nature of the relations between a superordinate class and two or more non-empty subclasses (Markman & Callanan, 1984). Asymmetry exists because all members of a subclass are included in the superordinate class, but not all members of the superordinate class are included in a particular subclass. Relations among three classes (superordinate, subclass 1, subclass 2) are entailed so complexity is equivalent to a ternary relation.

Materials. Displays consisted of eight coloured shapes. For binary relation items, the colour and shape categories in the displays were non overlapping (i.e., red squares, blue circles). In displays used for ternary relation items, overlap between the colour and shape categories formed 2 inclusion hierarchies: superordinate class *squares* with subclasses, *blue* and *red*; superordinate class *blue things* with subclasses, *squares* and *circles*. An example display is shown in Figure 1.

Procedure. Children evaluated *Some-All* and *Alternate* statements made by a toy frog. Examples of the questions are shown in Figure 1. Complexity analyses revealed that false items were critical to understanding asymmetry. Scores were computed by combining scores for the false binary and ternary items for each question type.

Transitivity (Exps. 1 & 2)

Transitive reasoning is demonstrated when an inference A *R* C is deduced from premises A *R* B and B *R* C, where *R* is a transitive relation, and A, B, C are the elements related. Determining the A-C relation involves integrating A *R* B and B *R* C into an ordered triple, A *R* B *R* C, and has the complexity of a ternary relation.

Materials. The premise displays consisted of 4 pairs of coloured squares in which one colour was higher than another. An example display is shown in Figure 2. The four pairs together defined a unique vertical ordering of five coloured squares in a tower. For the example given, the correct top-down order is red, blue, green, purple, yellow. More generally A > B > C > D > E where A is top and E is bottom. A different assignment of colours to ordinal positions was used on each trial. Sets of five coloured squares were used for tower construction.

Procedure. In the binary relation items, children constructed 5-square towers, beginning with an internal pair, either BC or CD. Ordering elements B and C, required consideration of a single premise, the binary relation, B *above* C. Adding each subsequent square (e.g., D) also required consideration of a single premise, C *above* D.

In the ternary relation items, children predicted which of 2 squares, corresponding to positions B and D, would be higher up in the tower. Two premises, B *above* C and C *above* D must be integrated into the ordered set, B *above* C *above* D, from which B *above* D can be concluded. As a check on guessing, C was placed after B and D. If the child had integrated BC and CD to conclude B *above* D, the correct position of C should have been apparent. Credit was given for responses where B, D, and C were placed correctly.

Results and Discussion (Experiment 1)

Table 2 shows the means for the four sentence types all of which exceeded chance level (3), smallest $t(133) = 2.87$, $p < .01$. The 3-role, object-focused sentences were most difficult. Analyses of variance with focus (object, subject) and number of roles (2, 3) as within subject variables revealed main effects of focus, $F(1, 133) = 295.47$, $p < .001$, number of roles, $F(1, 133) = 117.12$, $p < .001$, and a significant Focus × Number of Roles interaction, $F(1, 133) = 42.25$, $p < .001$. Increasing the number of roles had a greater effect for object-focused sentences $F(1, 133) = 89.91$, $p < .001$, in which the roles are assigned ion the same decision, than for subject-focused sentences, $F(1, 133) = 17.22$, $p < .001$ in which the roles can be assigned in succession.

Table 3 shows the correlations among sentence comprehension, transitivity, hierarchical classification, listening span and age. Hierarchical regression was used to determine whether the age related variance in sentence comprehension could be accounted for by the predictor tasks.

Age and listening span entered in step 1 accounted for 11% variance in sentence comprehension, Multiple $\underline{R} = .33$, $\underline{F}(2,128) = 7.74$, $\underline{p} < .001$. Listening span accounted for all the age related variance and in addition accounted for significant variance (3%) independently of age. Entering transitivity and hierarchical classification on step 2 significantly increased total variance accounted for to 23%, $\underline{F}(3, 125) = 6.48$, $\underline{p} < .001$, for the change. Hierarchical classification (Alternate statements) contributed unique variance (4%), with the remaining variance (19%) being shared by the predictors. When all predictors had been entered, Multiple $\underline{R} = .48$; $\underline{F}(5,125) = 7.38$, $\underline{p} < .001$.

The analysis was repeated with the order of entry of the predictors reversed. Age, transitivity, and hierarchical classification entered on Step 1 accounted for 21% variance, Multiple $\underline{R} = .46$; $\underline{F}(4,126) = 8.44$, $\underline{p} < .001$. All the age related variance in sentence comprehension was accounted for by the relational complexity tasks. Hierarchical classification (Alternate statements) contributed unique variance (4%), as did transitivity (3%) with the remaining variance (14%) being shared. Entering Listening span on step 2 failed to produced a significant increase in Multiple $\underline{R}$.

Older children's comprehension of the CE object-focused sentences was poorer than expected, possibly because they gave priority to sentence repetition to the detriment of comprehension. In Experiment 2, repetition was not required.

Experiment 2 provided a further test of the relational complexity analysis by including an additional sentence type, 3-role, CE, subject-focused sentences. Because of their canonical, NVN word order, these were expected to be easier than 3-role, CE, object-focused sentences. Furthermore, as shown in Table 1, in the CE, subject-focused sentence, the head noun *monkey* plays the same role (agent) with respect to both verbs, therefore its assignment made be made once, effectively reducing the number of role assignments.

Results and Discussion (Experiment 2)

Table 4 shows the means for the five sentence types all of which exceeded chance level (3), smallest $t(47) = 2.46$, $p < .05$. The 3-role, object focused sentences were most difficult. The 3-role CE, subject-focused sentences (mean = 4.31, SD = 1.26) were easier than 3-role CE, object-focused sentences, $F(1,47) = 16.55$, $p < .001$, and approximately equal in difficulty to the 2-role, object focused sentences.

Analyses of variance with focus (object, subject) and number of roles (2, 3) as within subject variables revealed main effects of focus, $F(1, 47) = 79.46$, $p < .001$ and number of roles, $F(1, 47) = 4.69$, $p < .05$ and a significant Focus × Number of Roles interaction, $F(1, 47) = 7.92$, $p < .01$. Increasing the number of roles increased processing load only for object-focused sentences, $F(1, 47) = 8.90$, $p < .01$, in which roles must be assigned in a single decision. For subject-focused sentences in which roles can be assigned in succession, the number of roles effect was not significant.

Table 5 shows the correlations among sentence comprehension, transitivity, hierarchical classification, listening span and age. Unlike Experiment 1, the transitivity-hierarchical classification correlations were nonsignificant. The reason is unclear, but could be related to differences in sample size and age range.

Hierarchical regression was used to determine whether the age related variance in sentence comprehension be accounted for by the predictor tasks. Age and listening span entered on Step 1 accounted for 15% of variance in comprehension, 8% was shared variance and 7% was unique to age, Multiple $R = .38$, $F(2, 45)= 3.93$, $p < .05$. The relational complexity variables entered on step 2 increased variance explained to 34% variance, $F(3,42) = 4.03$, $p < .013$, for the change. After step 2, Multiple $R = .58$;

$F(5,42) = 4.30$, $p < .01$. All the age related variance was accounted for. Hierarchical classification (Some-All) contributed variance (15%) independently of the other predictors.

The analysis was repeated with the order of entry of the variables reversed. The relational complexity variables and age entered on step 1 accounted for 34% of variance in comprehension, Multiple $R = .58$; $F(4,43) = 5.42$, $p < .01$. Hierarchical classification (Some-All statements) (15%) and to a lesser extent transitivity (5%) contributed variance independently of the other predictors. All the age related variance was accounted for. Entering listening span on step 2 failed to produce a significant change

Conclusions

In both experiments, comprehension difficulty varied with the relational complexity of the sentences, that is, the number of role assignments made in the same decision. The 3-role, CE, object-relative sentences in which three role assignments had to be made in the same decision were most difficult. In Experiment 2, the 3-role, CE, subject-focused sentences and 2-role, RB, object focused sentences, each of which required two role assignments in the same decision, were comprehended at about the same level. The 2-role and 3-role, RB, subject-focused sentences in which the roles assignment could be made in succession were easiest.

Comprehension improved with age and was related to working memory capacity (listening span) and the ability to process complex relations (transitivity, hierarchical classification). The variance in comprehension accounted for by listening span was subsumed by the relational complexity tasks which also accounted for 100% of age-related variance in comprehension. Results were consistent with the view that the capacity to process complex relations increases with age during childhood and seems to underlie cognitive development in many different content domains, including comprehension of relative clause sentences.

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Table 1.

Sentence types included in Experiment 1 (4 types) and Experiment 2 (5 types)

Roles	CE-RB	Focus	Example sentence	Relational information
2[a]	RB	Object	*Sally saw* the gorilla that the zebra kicked	KICK(zebra,gorilla)
2[a]	RB	Subject	*Sally saw* the zebra that kicked the gorilla	KICK(zebra,gorilla)
3	CE	Object	The duck that the monkey touched sat.	TOUCH(monkey,duck);SIT(duck)
3	RB	Subject	The monkey touched the duck that sat.	TOUCH(monkey,duck);SIT(duck)
3[b]	CE	Subject	The monkey that touched the duck sat	TOUCH(monkey,duck);SIT(monkey)

[a] The words *Sally saw* were common to all 2-role sentences. They provided a context for the constituents of interest (i.e., the object of the main clause and the relative clause).

[b] The 3-role, CE, subject-focused sentences were used in Experiment 2 only.

Table 2

Mean Comprehension Scores by Sentence type in Experiment 1 (max = 6)

	Focus	
Roles	Subject	Object
2	5.63	4.72
	(0.68)	(1.19)
3	5.34	3.33
	(0.75)	(1.33)

Correlations among Sentence Comprehension, Listening Span, Transitivity, Hierarchical Classification (2 types) and Age with Descriptive Statistics in Experiment 1

	Sentence Comp	Listening Span	Transitivity	H.C. Some-All	H.C. Alternate	Age
Sentence Comp[a]	1.00					
Listening Span[b]	-.32**	1.00				
Transitivity[c]	.37**	-.65**	1.00			
H.C Some-All[c]	.31**	-.20*	.35**	1.00		
H.C Alternate[c].	.39**	-.29**	.44**	.50**	1.00	
Age (months)	.27**	-.66**	.69**	.32**	.41**	1.00
Mean	19.02	0.050	16.13	3.35	3.67	76.86
SD	2.41	0.001	3.56	0.78	0.81	18.50

[a] 4 sentences types combined; [b] Listening span scores were transformed. Negative correlations were the result of this transformation; [c] Binary and ternary items combined. * $p < .05$ ** $p < .01$

Table 4

Mean Comprehension Scores by Sentence Type in Experiment 2 (max = 6)

	Focus	
Roles	Subject	Object
2	5.25	4.29
	(0.98)	(1.34)
3	5.25	3.48
	(1.04)	(1.35)

Correlations among Sentence Comprehension, Listening Span, Transitivity, Hierarchical Classification (2 types) and Age with Descriptive Statistics in Experiment 2

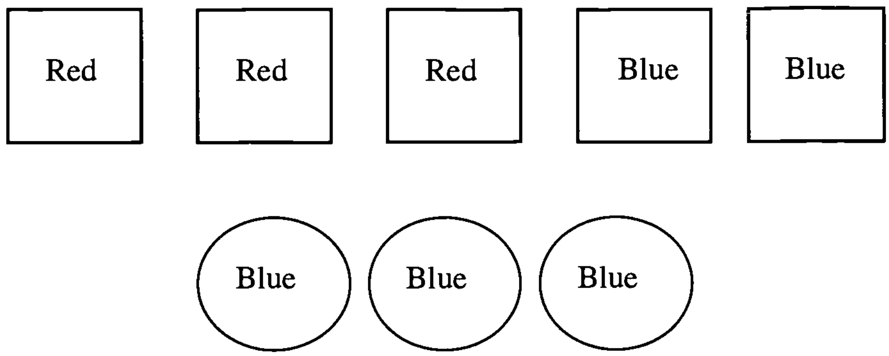
	Sentence Comp	Listening Span	Transitivity	H.C. Some-All	H.C. Alternate	Age
Sentence Comp[a]	1.00					
Listening Span	.29*	1.00				
Transitivity[b]	.28*	.39**	1.00			
H.C Some-All[b]	.48**	.34**	-.04	1.00		
H.C Alternate[b]	.25*	.35**	.17`	.24*	1.00	
Age (months)	.38**	.63**	.42**	.37**	.26*	1.00
Mean	22.58	18.81	10.13	6.94	6.35	69.21
SD	3.57	2.32	2.01	1.33	1.41	13.92

[a] 5 sentence types combined; [b] Binary and ternary items combined. * $p < .05$; ** $p < .01$

Figure Captions

Figure 1. An example display used for ternary relation hierarchical classification items with relevant questions.

Figure 2. An example premise display for the transitivity task



<u>Some -All statements</u> *All the squares are red.* *(False)*
All the circles are blue. *(True)*

<u>Alternate statements</u>
Froggie picks up all the circles. He says "I have red ones and blue ones." (False)
Froggie picks up all the squares. He says "I have red ones and blue ones." (True)

Blue	Red	Green	Purple
Green	Blue	Purple	Yellow

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