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ABSTRACT

This study examined the hypothesis that age-related increases in reasoning ability are associated with the ability to represent relations of increasing complexity, defined as the number of entities related. The study's purpose was to determine the extent to which this ability to process relations with three entities increased between ages 4 and 8 years, and whether this ability is domain-general. A total of 136 children, ages 3 to 8 years, performed relational tasks in 6 content domains: (1) transitivity; (2) hierarchical classification; (3) cardinality; (4) comprehension of relative clause sentences; (5) hypothesis testing; and (6) class inclusion. Relational complexity was manipulated within each domain. Tests of working memory and fluid intelligence were also given. Results showed significant correlations among tasks from different domains. The age by which 50 percent of the children processed relations with three entities was between 5 and 6 years. In a factor analysis, all tasks loaded on a single factor labeled Relational Complexity. Relational Complexity factor scores were estimated and interpreted as a content-independent measure of the ability to process relations. Relational Complexity was significantly correlated with age, fluid intelligence, and working memory. (Contains 12 references.) (Author/KDFB)

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Assessment of Relational Reasoning in Children aged 4 to 8 years.

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Paper presented at XIVth Biennial Meetings of the International Society for the Study of Behavioural Development held in Quebec City, Quebec on August 12 -16, 1996.

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Abstract

Relational processing is inherent in many reasoning tasks. This project tested the proposition that age-related increases in reasoning ability are associated with the ability to represent relations of increasing complexity (defined as the number of entities related). The purpose of this study was to determine the extent to which the ability to process relations with three entities increases between ages 4 years and 8 years and whether this ability is domain-general. 136 children (age range 3;5 to 8;11) performed relational tasks in six content domains: transitivity, hierarchical classification; cardinality, comprehension of relative clause sentences, hypothesis testing and class inclusion. Relational complexity was manipulated within each domain. Results showed significant correlations among tasks from different domains. In a factor analysis, all tasks loaded on a single factor which was labelled Relational Complexity (R.C.). R.C. factor scores were estimated and interpreted as a content independent measure of the ability to process relations. R.C. was significantly correlated with age (r = .80), fluid intelligence (r = .79) and working memory (r = .66).

Assessment of relational reasoning in children aged 4 to 8 years.

The aim of this research is to develop a test of processing capacity based on the view that relational complexity is a major source of processing load. The study presented here is a step in that direction. As described by the previous speaker in this symposium, relational complexity refers to the number of entities that are related (Halford, 1993). Unary relations such as class membership have one argument, for example DOG (fido). Binary relations such as LARGER-THAN (elephant, mouse) have two arguments. Ternary relations such as the arithmetic operation of addition, ADDITION (2,4,6) have three arguments and so on.. The prediction is that, other things being equal, tasks of greater complexity should be more difficult than less complex tasks. It is further proposed that the capacity to process relations increases with age during childhood such that children under five years of age can handle binary relations but experience difficulty with ternary relations.

Some general considerations underlying our approach to assessing processing capacity will be described. First, a capacity test should be independent of domain specific knowledge. Content-free measures do not exist, but they can be approximated through the use of multiple content-specific measures (Chapman, 1990), so that the test as a whole approaches content-independence. To this end, six content domains were sampled. They were transitivity; hierarchical classification; class inclusion; cardinality; sentence comprehension and hypothesis testing.

A second consideration refers to the relationship between demands imposed by storage and those imposed by processing. Storage capacity is viewed as being at least partly independent of processing capacity (Klapp, Marshburn & Lester, 1983). The relational complexity metric is concerned with processing load, therefore tasks were designed to have minimal storage loads. Third, the assignment of tasks to complexity levels was based on task analyses which were informed by process models when such models were available.

Finally consideration was given to reliability and validity issues. Age-appropriate assessment procedures and stimuli were used. Tasks were usually presented in a story or game context which helped to convey the instructions and goals of the task to participants. Various techniques were incorporated to detect and estimate the extent to which children relied on simpler strategies, or on guessing. To facititate interpretation of negative results, binary and ternary relation items were included in each domain. The binary and ternary items were comparable in all respects, except their complexity. If children succeeded on binary but not ternary items, their failure on ternary items was unlikely to be due to the aspects of the task procedure since these were comparable for both levels of complexity.

Several theorists including Case (1985) have proposed that age related increases in the capacity or efficiency of working memory underlie cognitive development. Working memory is conceptualised as simultaneous processing and storage of information. Tests measuring fluid intelligence also show age related increases in during childhood (Cattell, 1987). Fluid intelligence is descibed by Cattell (p.297) as "a generalised inherent capacity to perceive relations". To elucidate the correspondence (if any) between these two

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constructs and relational complexity, tests of working memory and fluid intelligence were included in the current study.

Method.

Participants.

136 children aged from 3;5 to 8;11 participated. The sample was partitioned into five age groups whose age ranges and sizes were as follows: group 4, n = 31, age range 3;5 to 4;11; group 5, n = 30, age range 5;0 to 5;11; group 6, n = 24, age range 6;0 to 6;11; group 7, n = 21, age range 7;0 to 7;11; group 8, n = 30, age range 8;0 to 8;11.

Procedure

Children completed six relational complexity tasks (transitivity, hierarchical classification, class inclusion, counting-cardinality, sentence comprehension, hypothesis testing) and the two reference tests of working memory and fluid intelligence.

<u>The transitivity task</u> was adapted from Pears & Bryant's (1990) procedure. A different set of premise information was presented on each trial. An example is shown in Figure 1. Each set of premise information consisted of four pairs of coloured squares in which one colour was higher than another, for example BLUE higher than PURPLE; RED higher than BLUE; YELLOW higher than GREEN; GREEN higher than RED. The four pairs together define a unique ordering of five coloured squares in a tower. In this example the correct top-down order would be: YELLOW, GREEN, RED, BLUE, PURPLE.. Alphabetic letters (A, B, C, D, E) will be used here to refer to the coloured squares by their ordinal positions, where A is topmost and E is bottom. Color names were used in the actual procedure.

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Insert Figure 1 about here.

In the binary items, children used the premise information to construct a five-square tower, beginning with an internal pair, either BC or CD (green-red or red-blue in Figure 1). To order elements B and C, they need to consider one binary relation, B above C. To add the next square D, they need to consider the binary relation between C and D. Each step entails a single binary relation. In the ternary items, children predicted which of two colours, would be "higher up" in the tower. The colours corresponded to positions B and D (green and blue in Figure 1). Two premise relations, B above C and C above D must be integrated to form the ordered set, B above C above D. From this ordered triple, it can be concluded that B would be higher than D. As a check on guessing, square C (red) was also placed. If the child had integrated BC and CD to respond that B would be higher than D, then she should know that the correct position of C is between B and D.

Hierarchical classification. Inferences based on classification hierarchies require recognition of the asymmetric nature of the relations between a superordinate class and its two subordinate classes (Markman & Callanan, 1984). Asymmetry refers to the fact that all members of a subclass are included in the superordinate class, but that not all members of the superordinate class are included in a particular subclass. To understand asymmetry, the relations among three classes (superordinate, subclass 1, subclass 2) must be considered, so the relation is ternary.

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Insert Table 1 about here.

On the ternary items, children were shown displays which contained two inclusion hierarchies, for example, 2 red squares, 3 blue squares and 3 blue circles. Displays for the binary items were similar except that the sets were not overlapping, for example 5 red squares, 3 blue circles. Children evaluated two types of statements regarding the displays. The statements, examples of which are shown in Table 1 were purportedly made by a toy frog who was learning about shapes and colours. The Some-All statements each incorporated a universal affirmative proposition and are similar to those used by Inhelder and Piaget (1964). When the ternary display was used, evaluation of the first statement *All the squares are red* requires children to take three classes into account: squares, red and blue. When the binary display is used, only two classes, squares and red are involved. In the Alternate format, the experimenter described an action that the frog had performed, then children evaluated the frog's statement. A task analysis indicated that the negative items are critical to tapping the notion of asymmetry.

Class inclusion. Understanding the implications of hierarchical structures was also assessed via the class inclusion task. The procedure was adapted from Hodkin (1987). The display contained coloured geometric shapes which together formed an inclusion hierarchy (e.g. three yellow squares and two blue squares). Children responded to three questions per display. Question A required comparison of the subclasses, *Are there more yellow things or more blue things?*. This involves a single binary relation between two

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entities, the subclasses. Question C required comparison of the superordinate class and the major subclass, *Are there more squares or more yellow things?*. This requires inclusion reasoning which entails the ternary relation between the three sets. Question B, *Are there more squares or more blue things?* was included so that Hodkin's (1987) method could be used to estimate and correct for guessing responses to the inclusion question.

Counting/cardinality. It has been argued (English & Halford, 1995) that understanding of cardinality involves having a mental model in which numerals are assigned to sets and the relation between sets is one of inclusion. Such a model would allow children to recognise the cumulative nature of counting, that is. that the cardinal value corresponds to a set of elements that includes the set of previously counted elements and the set of one representing the current element. They would also realise that the order in which objects are counted is irrelevant to the set's cardinal value. Displays contained line drawings of 4, 5 or 7 familiar stimuli (e.g. frogs, trees, pigs). After counting each array, children responded to one of three questions: *How many (stimuli) are there? Show me X by drawing a circle around X,* where *X* refers to the count total given by the child; and *How many would there be if you counted from the other end?*

Scoring of the cardinality items was independent of counting accuracy. On questions of the first and third type, children were scored as correct if they responded with the count total without recounting the set. Reliance on a mental model as described, ensures success on all three questions. Reliance on a simpler model in which there is a successor relation between sets, is insufficient for a complete understanding of cardinality.

Comprehension of relative clause sentences. Sentence comprehension involves the assignment of nouns to the agent and patient roles of verbs. Relational complexity corresponds to the number of participant roles that have to be filled to understand the sentence. Four relative clause constructions were used as shown in Table 2. The relational information is expressed in propositional format. In binary sentences, comprehension depends on two role assignments. In ternary sentences, it depends on three role assignments. The first two words *Sally saw* were common to all binary relation sentences. Within each complexity level, the centre embedded (CE) sentences were expected to be more difficult because these involve a constraint toward simultaneous role assignment whereas in right branching (RB) sentences, the opportunity exists for segmenting the sentence into less complex parts which can be processed sequentially.

Insert Table 2 about here.

The experimenter read each sentence aloud, and the child attempted to repeat it. A maximum of four presentations per sentence was provided. A memory aid, in the form of cards containing line drawings of the nouns was also provided. Comprehension was tested by a question referring to one noun-verb relation from each sentence.

Hypothesis testing. A task was designed to test children's ability to assess the relevance of a dimension, clothes colour, to determining the ownership of four bears. The four bears and their respective owners (John, Sarah) were depicted as line drawings. Two presentation formats were used. In the passive format, the four bears in the displays were

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already "dressed". Children judged whether or not clothes colour, differentiated John's from Sarah's bears. In the active format, children were given the clothes and were asked to dress the bears so that discrimination between John's and Sarah's bears either was or was not possible.

Complexity of the items depended on the interaction of several factors: passive versus active format; number of different colours included (1 to 4); whether the bears within a set had the same colour (opportunity for chunking in 0,1 or 2 sets); degree of overlap between sets (none, partial, complete). The ability to consider 2 binary relations in a single decision ensures correct responses to all items, whereas reliance on a single binary relation would yield less than perfect performance.

Fluid intelligence was assessed using 4 subtests of the Culture Fair Intelligence Test, Scale 1 (Cattell, 1950). Four subtests: Substitution; Classification; Mazes; and Similarities were administered using the standard instructions.

Working memory was assessed using Siegel's (1994) Listening span procedure whereby children hear a series of sentences. The final word of each sentence was missing and children were asked to supply a suitable word to complete each sentence. After hearing all the sentences in the set, children attempted to recall the final words. Set size was two at the outset of testing and was increased by one following accurate recall and decreased by one if recall was incorrect. Minimum set size administered was two.

Results.

A general finding across the relational complexity tasks was that binary relation items were easier than ternary relation items for the sample as a whole and within each age group. Scores on the binary items were generally at or close to ceiling for age groups 5, through 8, and well above chance level for the youngest group 4. Scores for binary and ternary items within each task were combined and the total scores analysed. There were significant age group effects on all tasks.

The percentages of children in each age group who were able to process ternary relations in each domain were computed. Competence within a domain was defined as above chance scores on both binary and ternary items. Table 3 shows the percentage of children in each age group who met this criterion for each task. Averaging over the six tasks, it appears that the age by which 50% of children processed ternary relations was between five and six years.

Insert Table 3 about here.

Correlational analyses were used to examine cross task correspondences. Table 4 shows the pairwise correlations among the six tasks. All were significant at $p < .01$. In a Principal Axis factor analysis the six variables loaded on a single factor (eigenvalue = 2.63; 43.8% common variance accounted for; Commumalities ranged from .21 to .56) indicating that the tasks were tapping a common construct. This factor was labelled Relational Complexity (RC). Factor loading are shown in Table 5. RC factor scores were computed using the regression approach. They were interpreted as a content-independent measure of the capacity to process ternary relations.

Insert Tables 4 & 5 about here.

Mean RC factor scores for each age group are shown in Table 6. Analysis of variance revealed a significant effect of age group, $F(4, 127) = 63.35$, $p < .001$. Scheffe tests showed that the mean for age group 4 was significantly lower than for all older groups. The mean for age group 5 was signficantly lower than for age groups 6, 7 and 8. Age group 6's mean was sigificantly lower than the mean for age group 8. Thus the greatest amount of change occurred between the ages of four and six years.

Insert Table 6 about here.

Table 7 shows that RC factor scores, fluid intelligence, and listening span were significantly correlated with one another and with age. Multiple regression analyses summarized in Table 8, revealed that 77% of the variance in fluid intelligence was accounted for by RC, listening span and age. Much of this variance was age related. RC accounted for 80% of the age related variance in fluid intelligence. When listening span was predicted, less than half (47%) of the total variance was accounted for by RC, fluid intelligence and age. Most of this variance was age related. RC accounted for 88% of the age related variance in Listening Span.

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Insert Table 7 about here.

It seems that there is considerable overlap among the three constructs and their age related variance. The overlap is especially strong between RC and fluid intelligence. Cattell (1987 p.297) has defined fluid intelligence as "a generalised inherent capacity to perceive relations". We interpret the RC factor scores as a domain general measure of the capacity to process complex relations, so the correlation between RC and fluid intelligence supports the construct validity of our items. It also suggests an explanation as to a major source of difficulty underlying the intelligence test items.

In future work we will investigate the relation between RC and other criterion measures including concept of mind tasks and other working memory measures. We will also extend the relational complexity battery to include items at higher levels of complexity.

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Table 1.

Hierarchical Classification Questions.

Some-All questions (Inhelder & Piaget, 1964)	
1. All the squares are red?	Wrong
2. All the red ones are squares?	Right
3. All the blue ones are circles?	Wrong
4. All the circles are blue?	Right
Alternate questions	
1. Froggie picks up all the squares.	Right
He says "I have red ones and blue ones."	
2. Froggie picks up all the blue ones.	Right
He says "I have squares and circles."	
3. Froggie picks up all the circles.	Wrong
He says "I have red ones and blue ones."	
4. Froggie picks up all the red ones.	Wrong
He says "I have squares and circles."	

Table 2.

Sentence Comprehension task: Example sentences and questions

Type	Example	Relational information	Question
Binary CE	(Sally saw) the girl that the boy hugged.	HUG(boy, girl)	Who hugged?
Binary RB	(Sally saw) the goat that bit the pig.	BITE(goat, pig)	Who was bitten?
Ternary CE	The clown that the boy scared spoke.	SCARE(boy, clown) SPOKE(clown).	Who scared?
Ternary RB	The monkey touched the duck that sat.	TOUCH(monkey, duck) SIT(duck).	Who sat?

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Table 3.

Percentage of children in each age group processing ternary relations.

Task	Agegroup 4 n=31	5 n=30	6 n=24	7 n=21	8 n=30
Transitivity	6	47	67	71	83
Hierarchical Classification.	23	33	46	48	70
Class Inclusion	10	30	68	95	87
Cardinality	14	57	80	86	93
Sentence comp	17	30	30	38	47
Hypoth. testing	20	47	87	95	97
Average % across 6 tasks	15	41	63	72	80

Table 4.

Correlations among Relational Complexity tasks

Variables	1	2	3	4	5	6
1.Transitivity	1.00					
2.Hierarchical Classif.*	.41	1.00				
3.Class Inclusion	.54	.43	1.00			
4.Count/cardinality*	.54	.41	.53	1.00		
5.Sentence comp.	.37	.30	.33	.34	1.00	
6.Hypothesis testing *	.53	.37	.55	.47	.24	1.00
Mean	16.13	7.02	9.26	27.19	19.02	6.74
Standard deviation	3.56	1.37	2.90	4.36	2.41	1.62
Maximum score	24.00	8.00	12.00	30.00	24.00	8.00
Sample size	136	135	133	134	134	134

All p's $< .01$

* Indicates transformed variables.

Table 5.

Factor matrix: Loadings on Relational complexity factor.

Variable	Loading on RC factor
Transitivity	.75
Hierarchical Classification	.57
Class Inclusion	.75
Counting/Cardinality	.72
Sentence Comprehension	.45
Hypothesis Testing	.68

Reproduced correlation matrix:one residual > .05. (Value = .066)

Table 6.

Mean RC factor scores by age group.

	Age groups				
	4	5	6	7	8
Mean	-1.13	-0.36	0.34	0.57	0.86
Std.dev.	0.54	0.54	0.63	0.56	0.44
n	29	30	22	21	30

Table 7.

Zero order correlations among relational complexity R.C. factor scores, fluid intelligence, listening span and age.

	1	2	3	4
R.C. factor scores	1.00			
Listening span*	-.66	1.00		
Fluid intelligence	.79	-.67	1.00	
Age	.80	-.66	.85	1.00

*Negative signs resulted from the transformation of listening span scores.

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Table 8.

Summary of multiple regression analyses with fluid intelligence and listening span as predicted variables.

Dependent variable	Total variance Adjust. R^2	Total Age related variance (ARV)	% ARV in DV explained by each predictor alone.	% ARV in DV explained by two predictors jointly.
Fluid Intelligence	.77	.71	RC[a] 80% Span 58%	RC + Span[b] 86%
Listening Span	.47	.44	RC 88% Fluid 95%	RC + Fluid[c] 100%

[a] Relational Complexity factor scores

[b] Listening span

[c] Fluid Intelligence

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Figure Caption.

Figure 1. Example of premise display for binary and ternary items in the transitivity task.

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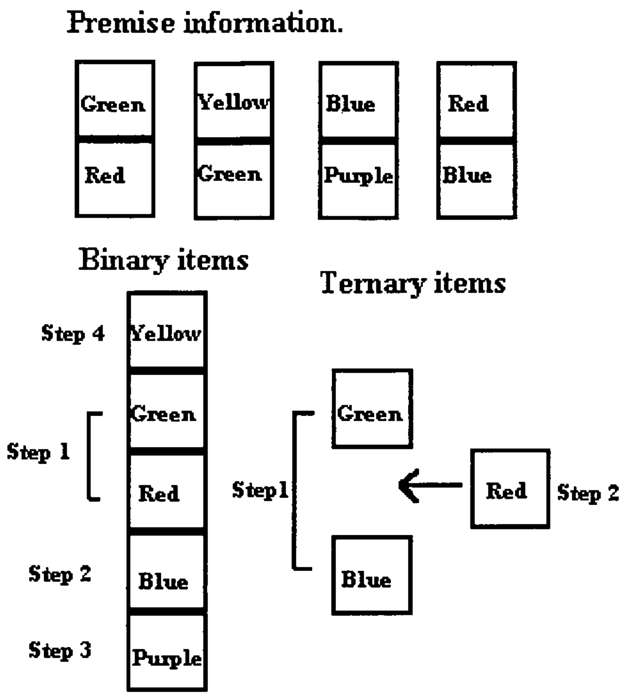
Premise information.
Green
Red
Yellow
Green
Blue
Purple
Red
Blue
Binary items
Step 4
Yellow
Step 1
Green
Red
Step 2
Blue
Step 3
Purple
Ternary items
Step1
Green
Blue
Red
Step 2

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