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ABSTRACT

The reversal of subject and predicate terms in quantified, categorical expressions was studied as an operation that is potentially important in issues of representation and comprehension of quantified relations. In two experiments students were asked to evaluate the relation between two quantified expressions. The salience of reversal in the verification of expressions was shown in the first experiment, but quantifier encoding was not flawless. The second experiment examined whether the reversals could be blocked by simple semantic/syntactic manipulation. Blocking was shown to interact meaningfully both with quantifier type and the combined effect of quantifier and conqruity. A three-stage model for the observed latencies was developed, based on the experimental results. Verification profiles showed that students make errors which are attributed to faulty encoding, without discriminating between symmetrical and proper inclusion relations. Alternately, the encoding might be weakly specified. In this way constraints upon subject-predicate order are minimal and low priority, except where the semantic and syntactic aspects of relations show significant asymmetries. (CM)

INFERENCES FROM QUANTIFIED EXPRESSIONS

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Inferences from Quantified Expressions

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How to represent people's interpretation of quantified relations is important to issues concerned with semantic retrieval (e.g., Glass & Holyoak, 1974; Holyoak & Glass, 1978; Just, 1974), language comprehension (e.g., Anderson, 1979), and categorical inference (e.g., Erickson, 1978; Johnson-Laird, 1975; Revlin, 1975a; Guyote & Sternberg, 1978; Sternberg & Tur..er, 1981). While the current theoretical treatment has come largely from comprehension research, reasoning studies can inform us about critrial operations that the current stock of theories must permit. We would like to discuss one such operation that is potentially important to issues of representation and comprehension of quanitified relations.

The operation is the reversing of subject and predicate terms in quantified, categorical expressions (e.g., Revlis, 1975b). For example, when students are asked to reason with premises of the form, <u>All A are B</u>, they appear to systematically reverse the relation such that <u>All of the A's are B's</u> and also that <u>All of the B's are A's</u> (<u>see Figure 1</u>). Such reversals can change the logical import of the expressions and are termed illicit conversions (e.g., Cohen & Nagel, 1934). For example, if the sentence were <u>All dogs are animals</u>, reversal would lead to an expression counter to nexperience. So too with sentences of the form <u>Some A are not B</u> (e.g., <u>Some animals are not dogs</u>). However, reversals are appropriate with two types of expressions, <u>No A are B</u> and <u>Some A are B</u>.

Insert Figure 1 about here

The applicability of this operation extends beyond reasoning paradigms. In semantic retrieval, for example, these kinds of reversals occur in the guise of what Meyer (1970) called "semantic interchanges". The errors found in semantic retrieval tasks are quite telling. That a student might reverse the False sentence stones are rubies" to be "All the True sentence, "All rubies are stones" implies that the reversal of subject and predicate terms must be accomplished without a keen awareness of the logical implications of such an operation. The presence of conversion in non-inferential tasks such as semantic retrieval and sentence-picture verification (e.g., Revlin & Leirer, 1980) argue that it reflects a general comprehension mechanism rather than an artifact of problem solving paradigms. It provides a potential challenge to models that posit flawless encoding of quantifiers (e.g., Sternberg & Turner, 1981) ; it also obliges current models to address how such reversals may be realized within the models.

The study we will describe examines this reversal operation using a sentence-sentence verification task. Our purpose is to test whether such reversals occur in a comprehension context, if so it would suggest the generality of the operation.

The task is illustrated in Figure 2. A student is shown two quantified expressions, one above the other. The top expression is to be construed as the given information, the bottom one, the to-be-verified expression. Depending on the instructions, the student's task is to determine whether (a) the bottom expression logically follows from the top or (b) whether the bottom must be true, given the top one. The two expressions may vary with respect to quantifier and subject-predicate order as illustrated in Figure 2.

Insert Figure 2 about here

The paradigm contrasts with that of Sternberg & Turner (1981) in that the students' judgments here will be measured by discrete Yes/No response rather than plausibility statements. The paradigm also contrasts with that of Anderson (1981) in that we will employ categorical relations rather than comparative ones that Abelson & Kanous (1966) have shown entail implicit quantifiers.

Experiment I

Method

Materials.

Four groups of students (n=30) were asked to judge whether a "new" sentence followed from or was semantically consistent with a "given" sentence. The four groups resulted from the orthogonal pairing of two factors:

Concreteness of the quantified expressions (Symbolic vs Concrete) and Instructions (Inference vs Semantic Entailment). The Symbolic sentences were of the form All A are B; the concrete ones were of the form All large squares are filled.

The quantifiers used were All, No, Some, and Some are not. Each student examined 160 pairs of quantified sentences. The sentences were displayed on a computer terminal controlled by a PDP 11/34. Sessions were self-paced with a 2 sec ISI.

Half of the students were told that the first sentence would define a hypothetical domain. Their objective was to determine whether or not the second sentence was necessarily TRUE of that domain by virtue of its relation to the first sentence. The remaining students were first shown the solution to a sample syllogism and were told that they were to judge whether the second sentence was logically required by virtue of the truth of the first.

Results

The rationale for this experiment was to determine whether students would erroneously accept the converse of quantified expressions within the context of a single sentence inference task. The central focus is on those sentence pairs with identical quantifiers, but reversed subject-predicate relation (All and Some are not). The prediction is that students will verify All B are A follws from All A are B and that Some B are not A follows from Some A are not B. The decisions and decision latencies are presented in Table 1. To simplify the presentation, we will focus on the decision/comprehension errors here and then take-up the latency findings when we sketch a process model of quantifier verification in Experiment II.

Insert Table 1 about here

Homogeneous Pairs

The effect of conversion should be most salient in the comparison between congruent pairs--those with matching quantifier and subject-predicate order— and incongruent ones that have the same quantifier, but with a different subject-predicate order. The motivating hypothesis is supported by these data. Congruent pairs are more accurately verified than inconruent pairs [$F(1,107)=882.9$, p .001]. While this effect is seen for every quantifier pair (All-All: $F(1,107)=265.4$, p .001; No-No: $F(1,107)=57.5$, p .001; Some-Some: $F(1,107)=11.8$, p .001; Some not-Some not: $F(1,107)=378.4$, p .001), the effect is substantially greater for the critical pairs All-All and Some not-Some not where reversal of their quantified expression leads to a conversion error (Congruity x Quantifier: $F(3,321)=77.8$, p .001).

Language comprehension appears to be important for the effect: there were not differences occuring between reasoning and semantic entailment instructions. The only other main effect is due to the Concreteness of the materials. Concrete sentences are more accurately verified than symbolic ones [F(1,107)=17.0, p .001]. However, concrete sentences show the same effects of subject-predicate order as the symbolic ones.

Heterogeneous Pairs

Every type of quantified expression was contrasted with every other type (e.g., see example (c) in Figure 2). These are heterogeneous pairs since they have different quantifiers. This condition provides an opportunity to assess a number of encoding models. However, more to the point of the present purpose, heterogeneous pairs should show no effect of reversal of subject and predicate terms. Table 2 presents the verification accuracy of the heterogeneous pairs. It rreveals that only one of the 32 different pairs in the entire design shows a reversal effect exceeding five percent.

Insert Table 2 about here

Overall, the heterogeneous pairs are less accurately verfied than the homogeneous ones. This appears to reflect the contribution not so much of the pure heterogeneity of the pairs, but rather the necessity to process them more deeply than the homogeneous pairs. This is illustrated by the contribution of particular quantifiers to decision accuracy. For heterogeneous pairs, accuracy declines with increasing presence of particular relations (0,1, or 2 particularly quantified expressions in a pair): [F(2,214)=67.5, p .001]. In contrast, there is no such effect of particular relations for the homogeneous pairs, contributing to an interaction between Degree of Universality of quantifiers and Homogeneity of pairs

[F(2,214)=103.8,p .001]. When only a less entailed encoding of the expressions is required for a judgment, accuracy is high even in the presence of particular relations. When deeper processing is required, the more particular the relation, the greater the verification complexity.

Discussion

These findings illustrate the salience of the subject-predicate reversal in the verification of quantified expressions. They also argue against the notion that quantifier encoding is flawless. The encoding component contains at least two error-contributing factors: (a) conversion of the expression and (b) ambiguity of the particular quantifiers.

Experiment II

It is possible that these findings could be accounted for by positing simple response biases or an erroneeous decision rule. For example, rather than treating the sentences as expressions of class-inclusion relations, students may interpret the sentences as expressing degree of similarity between categories and make their verification judgments in terms of "relatedness" (similar arguments have been made concerning the interpretation of categorical expressions in memory paradigms by Potts, 1978; though see rejoinder by Griggs, 1978). Or, more simply, students may simply be "biased" to say YES for all sentence pairs.

Our intention in this experiment is to address these issues by examining whether the reversals previously shown can be blocked by means of a simple semantic/syntactic manipulation. If so, then the previous findings are informative concerning quantifier encoding per se rather than response biases or strategies.

Revlin & Leirer (1980) successfully blocked reversals by replacing the usual copula, is a with the less ambiguous, is included in. In this way, they manipulated the semantics of the relational terms and enhanced the apparent assymetry in the intended relations. The present experiment employs the same manipulation to examine whether the encoding phenomenon observed in Experiment I could reasonably be ascribed to comprehension mechanisms or to idiosyncratic and task-dependent stategies.

Method

Materials and Procedures

A single group of 30 students was asked to evaluate the relation between two quantified expressions just as with the Reasoning Group in Experiment I. The conditions for the present group was similar except that the quantified expressions contained the copula is included in, which contrasts with the copula in Experiment I, is a.

Subjects The students were 30 volunteers from the same introductory psychology course as those in Experiment I. The two experiments were run concurrently.

Results

The effect of the semantic/syntactic manipulation can be seen from Table 3 which presents the decision accuracy for both the is a (Experiment I) and is included in (Experiment II) conditions.

Insert Table 3 about here

Homogeneous Pairs.

Inspection of the table shows that blocking interacts meaningfully both with the type of quantifier [F(3,150)=2.7,p .05] and the combined effect of Quantifier and Congruity [F(3,150)=3.8,p=.01]. So, for example, blocking significantly improves the verification accuracy for All-All pairs when the first and second sentences are incongruent (Blocking x Congruity: F(1,50)=8.4, p<.01). No similar blocking effect is shown for any of the other homogeneous pairs. While this is consistent with the predictions for No-No and Some-Some problems, where reversal of subject-predicate order is said not to play a significant role in the students' decisions, the findings for Some not-Some not problems are not completely in accord with the conversion framework. However, there is a modest reduction in the frequence of conversion errors for Some not-Some not pairs in Experiment II (t(50)=1.6, p=.05). The selective blocking is more tersely illustrated in Table 4 which summarizes the effects for All-All and Some not-Some not pairs.

Insert Table 4 about here

Heterogeneous pairs.

The same regularities that characterized heterogeneous pairs in Experiment I are also found in Experiment II: (a) the absence of a strong Subject-Predicate congruity effect and (b) the complexity of particularly quantified relations. As expected, neither of these were influenced by the semantic/syntactic manipulations in the present experiment.

The Model

We propose a three stage model to account for the observed latencies. In Stage 1, the student encodes the given and new expressions and tests for an identical match. If the two expressions match, the flow of control passes to Stage 3 which outputs a rapid and accurate "YES" response. In Stage 1, superficial discrepancies may be noticed resulting in a deeper analysis of the relations by Stage 2. The results of Stage 2 analysis is registered in Stage 3 where the output response categories are selected.

Stage 2 includes a number of operations that are commonly supposed to be part-and-parcel of sentence verification, including comparisons of quantifiers and Affirmation-Negation tags. For our purposes, the most critical operation is a test for and a reversal of the subject-predicate order. This is done with impugnity unless it is specifically blocked by the semantic constraints imposed by the copula.

Evaluation

These predictions were subjected to a general linear model regression analysis with five parameters associatd with the encoding of the quantified expressions in Stage 1 and a parameter for each component stage. Verification accuracy relies on the encoding/conversion parameter and a sixth one that assumes a response "bias" towards YES responses adding a constant error when sentence pairs are incongruent.

Verification accuracy is predicted based on two of the six parameters. A general linear model was used to assess the predictions and found that this model accounts for 92.1% of the variance for the data presented in Table 1. Most of this (97%) is accounted for by the encoding/conversion parameter. The model is most successful in accounting for the data in the symbolic verification condition (99.7%) and least successful in account for the data in the concrete reasoning condition (90.4%).

With respect to latency measures, the model posits five parameters: It accounts for 82% of the variance of the data in Table 1. It also captures previously obscured regularities among the decisions and decision latencies.

General Discussion

The verification profiles show clearly that students make errors which may readily be attributed to faulty encoding. These errors are systematic and, among other factors, substantially implicate the representation's inability to discriminate between symmetrical and proper inclusion relations. One explanation for this is to assume that encoding, is indeed flawed. Alternately, the encoding of quantified expressions might be viewed as flawless, but weakly specified. In this way, constraints upon Subject-Predicate order are minimal and given a low priority except in those cases where the semantic and syntactic aspects of quantified relations make asymmetries in the relation glaring.

This formulation places emphasis then on the nature of the task demands. For example, in reasoning studies, students are frequently required to construct inference chains that may entail reversal of sentential terms in order to place the given information in a canonical form (see for examples conceptions of linear reasoning by Hunter (1957); categorical reasoning by Johnson-Laird & Steedman, 1978). In such contexts, weak constraints on Subject-Predicate order may easily become subservient to the higher order demands of the task. Notice that this is one way in which reasoning research could develop quite different ways of considering quantifier encoding than memory paradigms, with their potentially different task demands.

The ultimate representation of quantifiers as semantic features (e.g., Holyoak & Glass 1978; Revlin & Leirer, 1980), scalar values (e.g., Griggs & Warner, 1981; Holyoak & Glass, 1978; Ekberg & Lopes, 1979), or propositions (e.g., Anderson, 1981; Just & Carpenter, 1971) of course is undecideable here. However, data structures alone do not inform us concerning how the information is to be accessed and applied. The purpose of the present study was to provide at least one criterial operation for the formulation of constraints on models of quantifier representation.

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Table 1

Percent Correct on Homogeneous Sentence-Pairs

	Abstract		Concrete	
Relation	Reason	Verify	Reason	Verify
All-All(C)	99.0 (2438)	99.1 (1791)	99.5 (2853)	99.6 (2492)
All-All(I)	38.5 (5442)	25.0 (4926)	41.8 (7130)	46.7 (7890)
No-NO(C)	99.0 (2491)	99.6 (2023)	99.5 (2837)	99.2 (2711)
NO-NO(I)	75.5 (5156)	78.9 (3535)	77.9 (9405)	78.8 (9717)
SM-SM(C)	95.2 (1916)	99.6 (1418)	93.8 (2356)	97.5 (2125)
SM-SM(I)	82.2 (6064)	82.8 (4601)	94.2 (8638)	98.3 (7613)
SMN-SMN(C)	95.7 (3096)	100.0 (2323)	95.2 (3342)	98.3 (3100)
SMN-SMN(I)	23.6 (11927)	19.4 (7377)	59.1 (10911)	33.3 (10395)

Table 2

Percent Correct Verification for Heterogeneous Pairs

	Abstract		Concrete	
Relation	Reason	Verify	Reason	Verify
ALL-NO(C)	92.3 (4089)	99.1 (4274)	97.1 (5535)	98.3 (4687)
ALL-NO(I)	94.2 (5990)	92.2 (6032)	92.3 (10882)	90.0 (8889)
NO-ALL(C)	95.2 (5072)	96.6 (4014)	94.2 (6785)	99.2 (5839)
NO-ALL(I)	93.3 (5637)	92.2 (4463)	90.4 (8792)	95.8 (8821)
ALL-SM(C)	86.5 (5123)	81.9 (4494)	80.3 (5304)	94.2 (4759)
ALL-SM(I)	79.3 (6248)	80.6 (6125)	81.7 (8602)	95.4 (7576)
SM-ALL(C)	79.8 (5355)	71.6 (4585)	66.3 (5927)	66.3 (5007)
SM-ALL(I)	78.8 (7002	72.4 (5691)	73.6 (8825)	63.3 (7167)
NO-SMN(C)	78.9 (6925)	65.1 (6848)	68.3 (9703)	81.3 (9241)
NO-SMN(I)	76.9 (9279)	63.8 (6839)	68.3 (11137)	75.8 (11218)
SMN-NO(C)	74.0 (8260)	71.9 (7173)	78.4 (10869)	67.1 (11189)
SMN-NO(I)	74.5 (9083)	70.3 (8148)	74.0 (11801)	72.5 (13069)
SM-SMN(C)	58.7 (7183)	42.2 (6609)	48.1 (7704)	45.0 (7266)
SM-SMN(I)	56.7 (8154)	32.7 (6256)	46.2 (10621)	47.0 (8918)
SMN-SM(C)	58.7 (7563)	42.2 (6786)	47.1 (7994)	48.3 (7390)
SMN-SM(I)	68.3 (9236)	44.8 (9287)	47.1 (11601)	44.2 (13576)

Table 3

Percent Correct Verifications and Convertibility

Relation	Unblocked	Blocked
ALL-ALL(C)	99.0 (2438)	98.6 (2614)
ALL-ALL(I)	38.5 (5442)	70.7 (5345)
NO-NO(C)	99.0 (2491)	100.0 (2656)
NO-NO(I)	75.5 (5156)	68.8 (5574)
SM-SM(C)	95.2 (1916)	100.0 (2327)
SM-SM(I)	82.2 (6064)	74.0 (5543)
SMN-SMN(C)	95.7 (3096)	97.1 (3237)
SMN-SMN(I)	23.6 (11927)	37.9 (7266)

Table 4

Summary of Conversion Effect

Relation	Unblocked	Blocked
Congruent	97.4% (2767)	97.9% (2926)
Incongruent	31.1% (8685)	54.3% (6306)

FIGURE CAPTIONS

Figure 1: Reversible Categorical Expressions

Figure 2: Single Sentence Inference Problems

ALL A ARE B ------> ALL B ARE A

ALL STONES ARE RUBIES ------> ALL RUBIES ARE STONES

(1) All A are B

All A are B

(2) All A are B

All B are A

(3) All A are B

No B are A