Empirical Justifications for the Universalness of the Mental Logic and Mental Models Paradigm

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Abstract

Though there is a long-standing controversy between mental logic theory and mental model theory in human deductive reasoning, the two theories do share one general hypothesis: that whether people reason by applying inference schemas or by constructing mental models, these mental representations and mechanisms should be universal across *homo sapiens*, which implies that they should be available to speakers of different languages. We examined this hypothesis by conducting a series of experiments in Chinese, parallel to the empirical research supporting mental logic (Yang, Braine, and O'Brien, 1998), and to that supporting mental models (Yang and Johnson-Laird, 2000). The results show that the Chinese data sets are significantly correlated with English data sets, indicating that performance in Chinese and performance in English are likely to be based on similar mental representations and mechanisms (in tasks of deductive reasoning with quantifiers and predicates).

Introduction

While logic tells us what reasoning is, psychology of reasoning studies how people reason. There are two major competing approaches in psychology of deductive reasoning: mental logic theory (Braine & O'Brien, 1998; Rips, 1994) claims that people reason by applying inference schemas, and mental model theory (Johnson-Laird & Byrne, 1991) claims that people reason by constructing mental models. Though there is a long-standing controversy between the two (O'Brien, Braine, & Yang, 1994; Johnson-Laird, Byrne, & Schaeken, 1994), they share one general normative hypothesis: viz., that whether people reason by applying inference schemas or by constructing mental models, these mental representations and mechanisms are universal across *homo sapiens*, which means they should be available to speakers of different languages. However, recently some researchers have argued that there is a cultural difference in systems of thought: a difference between Western analytical cognition versus Eastern holistic cognition (Nisbett, Peng, Choi, & Norenzayan, 2001).

There is a great deal of empirical evidence in the psychological literature supporting both mental logic theory (e.g., Yang, Braine, & O'Brien, 1998) and mental model theory (e.g., Yang & Johnson-Laird, 2000). Both sets of experiments in these examples were conducted in English. This paper reports two sets of experiments conducted in Chinese, strictly parallel to the above English counterparts. In the following two sections, we report on the set of experiments in Chinese based on mental logic theory first, and then based on mental model theory.

Mental Logic

The theory

Mental logic theory claims that people reason by applying inference schemas. An inference schema specifies the form of an inference: Given information whose semantic representation has the form specified in the schema, one can infer the conclusion, whose form is also specified. Below is an example:

All the children found some red beads.
The red beads were either round or square.
The round beads were plastic.
The square beads were wooden.
Did all the girls find either plastic or wooden beads?

Mental logic theory predicts that people solve this problem in steps. Step 1 is to infer from the first premise that all the girls got red beads. This step can be seen as a constant of the inference schema called quantified *modus ponens*. Step 2 is to consider the next three premises and infer that the red beads are either plastic or wooden. This step is an instance of another schema. Step 3 is to apply this schema again on the two intermediate conclusions in Steps 1 and 2, and infer that all the girls found either plastic or wooden beads; and this leads to answer Yes to the question.

English Study

Yang et al. (1998) provided empirical justifications for a mental predicate logic by Braine (1998). This study was conducted in English at New York University. It tested a set of 10 inference schemas (see Table 1) by using a set of 64 monadic predicate problems and a parallel set of 64 dyadic predicate problems (Appendix 1 and Appendix 2, in Yang et al., 1998) similar to the example above. All the test problems involved so-called *quantified predicate reasoning* soluble by applying the 10 inference schemas given in Table 1. The number of schemas required by the proposed solutions to these problems varies, from one-step to multiple steps. Subjects were instructed to rate the degree of relative difficulty right after solving each problem (on a 7-point scale). All the experiments were individually administered. The overall accuracy out of more than 13,000 responses was greater than 97%, which allowed using the introspective ratings to estimate the weight of the schemas. A parametrical model of 10 schema weights (see Table 2) generated from the perceived difficulty ratings using the least-square method proved to be highly reliable: the correlations between the predicted problem difficulty using schema weights generated from one sample and the perceived difficulty rating from other samples were on average .93, accounting for above 80% of variance.

Chinese Study

We conducted a set of 5 experiments in Chinese at Zhongshan University, China, by using the strict Chinese translations of the original English problems and by following precisely the same procedures as those used in the English experiments. The results show that the overall accuracy was 93%, and all the cross-language validations (i.e., correlations between English weights and Chinese ratings, between Chinese weights and English ratings, and between English weights and Chinese weights) are above .90, accounting for more than 80% of the variance. Table 2 shows the English weights and Chinese weights. Figures 1 and 2 should make the comparison more perspicuous.

Mental Models

The Theory

Mental model theory postulates that reasoners build models of the situations described in premises. One doctrine at the heart of model theory is the co-called Principle of Truth: Reasoners normally represent what is true but not what is false due to limited working memory. In one sense, mental models can be seen as partial selections from formal semantics in logic. For example, recall the familiar truth table for conditionals:

P	Q	If P then Q
True	True	True
True	False	False
False	True	True
False	False	True

Table 1: One example for each of the 10 schemas

Schema 1. Conjunction Introduction
Example: All the beads are blue; all the beads are plastic; therefore, all the beads are blue plastic beads.

Schema 2. Conjunction Elimination
Example: The boys all got round beads and the girls played with them; Therefore, the boys all got round beads.

Schema 3. Disjunction Elimination
Example: Every boy either found a few metal beads or got some wooden beads; therefore, the boys who did not find any metal beads got some wooden beads.

Schema 4. Negated Conjunction
Example: There are no red square beads; there are some square beads; therefore, the square beads are not red.

Schema 5. Single-term Disjunctive Transition
Example: All the girls played with either John or Tom; each of the girls who played with Tom got wooden beads; each of the girls who played with John got wooden beads; therefore, every girl got wooden beads.

Schema 6. Two-term Disjunctive Transition
Example: All the beads are green or blue; the green beads are plastic; the blue beads are metal; therefore, all the beads are plastic or metal.

Schema 7. Modus Ponens
Example: The boys found no square beads in their bags; therefore, the boys found no square metal beads in their bags (or, the boys who like red square beads found no square beads in their bags).

Schema 8. Existential Introduction
Example: All the boys played with girls who got red beads; therefore, all the boys played with some children who got red beads.

Schema 9. Simple Contradiction
Example: All the beads are round. Some of the beads are not round. The premises are incompatible.

Schema 10. D. Morgen Contradiction
Example: All the children got either wooden beads or metal beads. Some of the children got neither wooden beads nor metal beads. The premises are incompatible.

Table 2: Schema weights generated from Chinese data sets and English data sets.

	Schema									
Data Set	1	2	3	4	5	6	7	8	9	10
English	Weight									
Overall	0.54	0.61	0.90	1.46	1.47	1.50	0.67	0.62	0.54	1.02
Monadic	0.47	0.65	0.66	1.48	1.34	1.56	0.75	0.60	0.49	0.95
Dyadic	0.60	0.56	1.16	1.44	1.61	1.42	0.60	0.64	0.61	1.09
Chinese										
Overall	0.97	0.80	1.34	1.78	2.09	1.98	0.76	0.84	0.99	1.51
Monadic	0.97	0.81	1.26	1.75	2.00	2.05	0.83	0.81	0.98	1.48
Dyadic	0.97	0.79	1.43	1.81	2.18	1.91	0.70	0.88	0.99	1.55

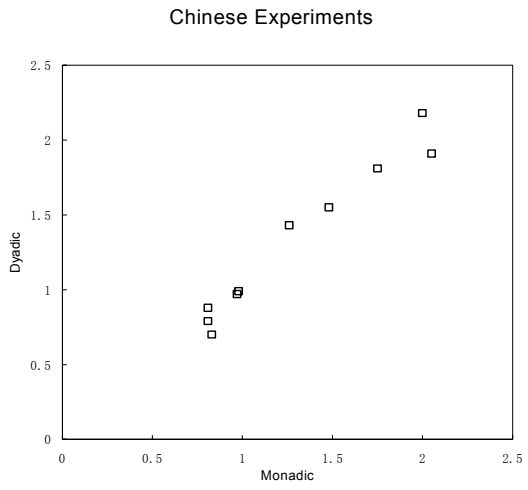

Figure 1. Cross tabulations of schema weights.

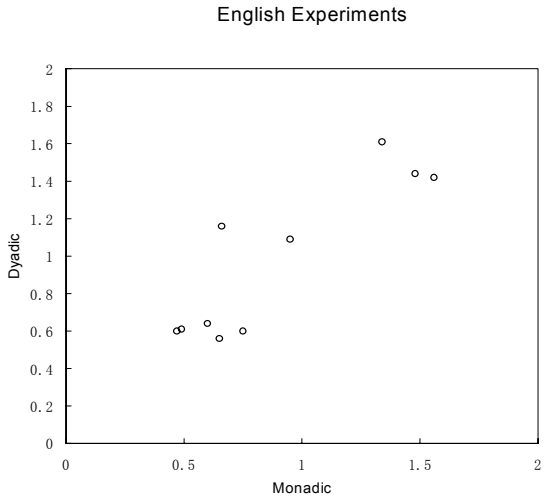

Figure 2. Cross tabulations of schema weights

By mental model theory, this table represents all possibilities. The principle of truth has a two-level constraint. At the first level, it says reasoners normally do not represent falsities (or false possibilities). Thus, the second row should be eliminated from the truth table. At the second level, reasoners do not feel comfortable reasoning with a false antecedent, and so do not represent such a possibility explicitly; instead, they make some mental footnotes as implicit models and only flesh them out when really necessary. Thus, the mental models for a conditional statement can be represented as this:

P Q

...

It includes one explicit model that reflects the first row in the truth table, and an implicit model denoted by three dots that footnote the two possibilities with false antecedents. By mental model theory, a statement is possibly true if it is true according to at least one model, and it is necessarily true if it is true in all mental models, given the premises.

English Study

The Principle of True has lead to the discovery a robust phenomenon in human reasoning: illusory inferences. For example, suppose that the subject is given two premises, and a preface says that only one of them is true. The logical solution has to consider two cases: the first premise is true and the second premise is false, and vice versa. Yang and Johnson-Laird (2000) showed that individuals succumb to illusions in inferences about what is possible, and what is impossible, when they are given quantified assertions. The phenomenon was predicted by model theory's Principle of

Truth, according to which reasoners take into account what is true, but not what is false. For example, given the following problem,

> Only one of the following statements is true:
> At least some of the metal beads are not blue; or
> At least some of the blue beads are not metal.
> Is it possible that none of the beads are blue?

Three quarters of the participants responded "Yes", even though the correct response is "No". Yang et al. (2000) examined 20 problems of the above kind. These problems are given in Table 3 in symbolic forms. Half of the problems are predicted as illusory inference (Yes/No, No/Yes), and another half are control problems (Yes/Yes, No/No). Each problem has two versions corresponding to whether monadic predicates or dyadic predicates are employed. Two experiments corroborated the occurrence of such illusions. Experiment 1 showed that participants erroneously inferred that impossible situations were possible, and that possible situations were impossible, but they performed well with control problems (i.e., the falsity does not effect a correct response) based on the same premises. Experiment 2 corroborated these findings in inferences from assertions based on dyadic relations, such as, "all the boys played with girls". The results from accuracy data are given in Table 3. This study was conducted in English at Princeton University.

Table 3: The percentage of correct responses

		Percentages of correct answers			
		Experiment 1		Experiment 2	
Problems	Status of Question	Chinese	English	Chinese	English
Only one is true:					
Some A are not B.					
No A are B.					
1. Possible that no B are A?	Yes/No	45	20	45	50
2. Possible that some B are A?	Yes/Yes	80	80	85	95
3. Possible that all B are A?	No /Yes	35	70	35	67
4. Possible that all A are B?	No / No	90	95	90	95
Only one is true:					
Some A are B.					
All A are B.					
5. Possible that all A are B?	Yes/No	50	25	60	14
6. Possible that some B are A?	Yes/Yes	95	100	95	100
7. Possible that all B are A?	No /Yes	50	70	45	90
8. Possible that no A are B?	No / No	90	100	85	95
Only one is true:					
Some B are not A					
Some A are B					
9. Possible that all B are A?	Yes/Yes	55	60	54	81
10. Possible that some A are not B?	Yes/Yes	85	100	80	100
11. Possible that all A are B?	No /Yes	70	80	50	71
12. Possible that no A are B?	No /Yes	35	55	50	67
Only one is true:					
Some A are not B.					
Some B are not A.					
13. Possible that no A are B?	Yes/ No	60	25	60	19
14. Possible that some A are B?	Yes/Yes	65	95	70	95
15. Possible that all A are B?	No /Yes	50	55	45	62
16. Possible that all B are A?	No /Yes	50	60	40	33
Only one is true:					
All A are B					
All B are A					
17. Possible that all A are B?	Yes/Yes	80	90	80	90
18. Possible that some A are not B?	No /Yes	75	80	60	76
19. Possible that no A are B?	No / No	75	95	70	95
20. Possible that no B are A?	No / No	85	85	90	86

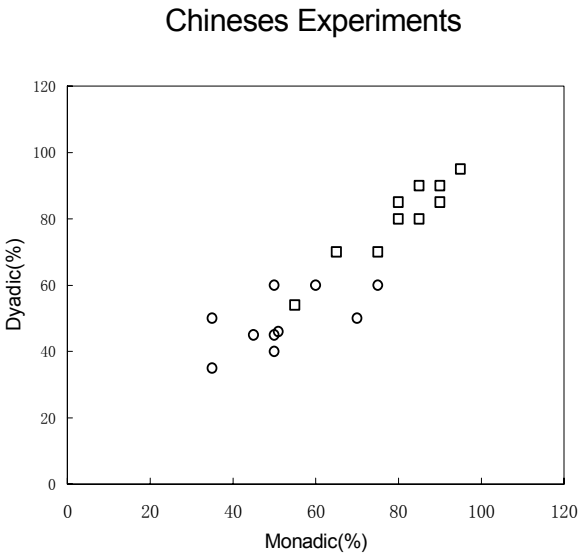

Figure 3. A scatter plot of Chinese data

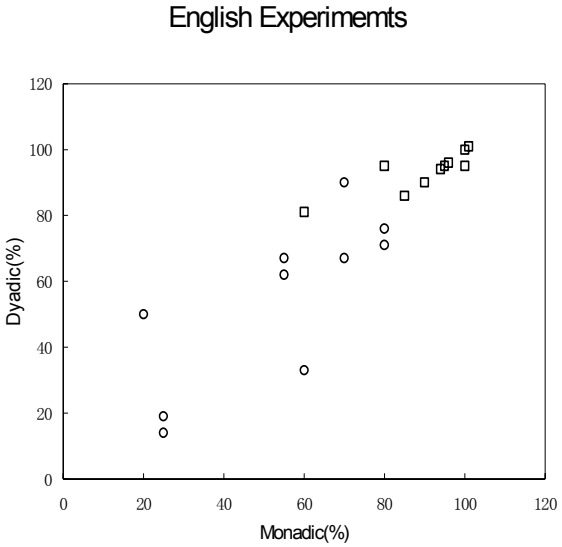

Figure 4. A scatter plot of English data.

Chinese Study

Two experiments were conducted in Chinese at Zhongshan University (China), parallel to the two experiments reported in Yang and Johnson-Laird (2000). The Chinese experiments used strict Chinese translations of the English materials, the same instructions, and strictly followed the same procedures. The results show the significant correlation between Chinese data and English data (Pearson's r = .73 for Experiment 1, r =.59 for Experiment 2, and r = .66 overall, p<.01). English results and Chinese results are given in Table 3, and Figures 3 and 4 show scatter plots of the percentages of correct responses for each problem form in Chinese and in English, respectively.

General Discussion

The comparison between English experiments and Chinese experiments corroborated the prediction by both mental logic and mental model theories that the mental representations and mechanisms in human deductive reasoning, either using mental logic or mental models, are likely to be available across languages.

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