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Inhibitory mechanism of the matching heuristic in syllogistic reasoning ☆

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ABSTRACT

A number of heuristic-based hypotheses have been proposed to explain how people solve syllogisms with automatic processes. In particular, the matching heuristic employs the congruency of the quantifiers in a syllogism — by matching the quantifier of the conclusion with those of the two premises. When the heuristic leads to an invalid conclusion, successful solving of these conflict problems requires the inhibition of automatic heuristic processing. Accordingly, if the automatic processing were based on processing the set of quantifiers, no semantic contents would be inhibited. The mental model theory, however, suggests that people reason using mental models, which always involves semantic processing. Therefore, whatever inhibition occurs in the processing implies the inhibition of the semantic contents.

We manipulated the validity of the syllogism and the congruency of the quantifier of its conclusion with those of the two premises according to the matching heuristic. A subsequent lexical decision task (LDT) with related words in the conclusion was used to test any inhibition of the semantic contents after each syllogistic evaluation trial. In the LDT, the facilitation effect of semantic priming diminished after correctly solved conflict syllogisms (match-invalid or mismatch-valid), but was intact after no-conflict syllogisms. The results suggest the involvement of an inhibitory mechanism of semantic contents in syllogistic reasoning when there is a conflict between the output of the syntactic heuristic and actual validity. Our results do not support a uniquely syntactic process of syllogistic reasoning but fit with the predictions based on mental model theory.

1. Introduction

Syllogisms are logical arguments comprising two premises and a conclusion. For example,

Abstract	Concrete
Premise 1: All A are B.	All dogs are mammals.
Premise 2 : No B are C.	No mammals are reptiles.
Conclusion: No A are C.	No dogs are reptiles.

There are 4 possible quantifiers per premise and conclusion:

Abbreviation	Quantifier	Example
A	Universal affirmative	All A are B.
E	Universal negative	No A are B.
I	Particular affirmative	Some A are B.
O	Particular negative	Some A are not B.

The conclusion is composed of two terms which we refer as “A” and “C”, and they appear in the first and second premises respectively. In both premises, there is a connecting term which we refer as “B”. The “B” term does not appear in the conclusion. The term ‘mood’ refers to the different combinations of quantifiers within the premises and conclusion. Therefore, the syllogism above has the mood AE–E. The 64 possible combinations of the mood together with the four possible figures (see Appendix A) yield a total of 256 syllogisms. However, among these 256 possible syllogisms, only 27 are valid (10.5%).

Syllogistic reasoning encapsulates many aspects of day-to-day reasoning, which involves the manipulation and transformation of our

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stored knowledge and information to make inferences about the world. In the above example, the knowledge concerned is our assumptions about category membership. However, even though this kind of reasoning is very common in day-to-day thinking, the average accuracy of syllogistic problems is only around 50% and the accuracy can be as low as 5–30% for the most difficult problems. Many studies have found evidence supporting the hypothesis that people do not often reason logically but rather they use some heuristic strategies, for example, the atmosphere (e.g. Begg & Denny, 1969; Woodworth & Sells, 1935) and the matching hypotheses (García-Madruga, 1983; Wetherick, 1989).

The atmosphere heuristic (Begg & Denny, 1969) leads to a conclusion that can be logical or not. There are two main assumptions in the atmosphere hypothesis:

1. Principle of quality: if there is at least one negative premise ('No' or 'Some…are not'), a negative conclusion is favoured; otherwise, a positive conclusion is preferred ('All' or 'Some').
2. Principle of quantity: if there is at least one particular premise ('Some' or 'Some…are not'), a particular conclusion is favoured; otherwise, a universal conclusion is preferred ('All' or 'No').

The matching hypothesis is a modified version of the atmosphere hypothesis which suggests that people choose the conclusion which matches the quantifier of the more 'conservative' premise, the premise with a lower number of entities. The suggested conclusion has the same quantifier (matches) as at least one of the premises, favouring the particular over the universal and negative rather than affirmative, i.e. E > O = I >> A (e.g. García-Madruga, 1983; Wetherick, 1989; Wetherick & Gilhooly, 1995). In the above AE-premises example, according to the surface structure of the premises, participants would tend to produce or accept E-conclusions. The atmosphere and matching hypotheses predict the same conclusions except for IE and EI-premises in which participants tend to produce/accept O-conclusions as suggested by the atmosphere hypothesis but E-conclusions by the matching hypothesis.[1] Wetherick and Gilhooly (1995) have found that 25 of their 71 participants apparently used matching to solve a syllogistic construction task of 40 problems. Only 16 participants used logical means to solve the problems. Stupple and Waterhouse (2009) have found evidence of the matching effect in conclusion evaluation tasks.

This heuristic strategy is purely syntactic in nature, in which the processing involves bind manipulation or "matching" of the quantifiers of the two premises and conclusion. Presumably, the semantic contents of the syllogism are not involved in such processing. However, these hypotheses are difficult to falsify as most of the valid conclusions do agree with the hypotheses, with the exception of five of the 27 valid syllogisms (AA–I4, AE–O2, AE–O4, EA–O1 and EA–O4, see Appendix B). The effect may be just an "unfortunate coincidence" of this fact (Johnson-Laird, 2006). We will explore this claim on the basis of mental model theory in this article.

2. Dual-process theories of reasoning

Since the article of Wason and Evans (1975), an increasing number of authors have proposed that there are 2 types of processing (systems) when people reason (Evans, 1984, 2003, 2007, 2009, 2011; Evans & Over, 1996; Evans & Stanovich, 2013a, 2013b; García-Madruga, 1983, 1989; Gigerenzer & Goldstein, 1996; Sloman, 1996; Stanovich, 2004; Stanovich & West, 2000). Type 1 processing (also known as System 1) refers to the unconscious, associative, intuitive and rapid processes which give outputs that may be prone to the bias of common sense, beliefs and previous experience. It is relatively undemanding of cognitive resources and independent of fluid intelligence. Responses from Type 1 processes are quick but errors are, sometimes, inevitable. The matching heuristic process is one of the Type 1 processes. Type 2 processes (also known as System 2) are thought to be conscious, analytical, rule-based, slow and more demanding of cognitive resources. They operate with effort and control and develop over time in humans. To solve complicated problems successfully, reasoners have to go beyond the superficial Type 1 output, discard it and engage in Type 2 processing[2] (through cognitive decoupling and mental stimulation).

Traditionally, Type 1 processing is thought to be context-based, while Type 2 processing is abstract and context-free. Several researchers have proposed a control system or mechanism for the shift from Type 1 to Type 2 processing (Evans, 2009; Stanovich, West, & Toplak, 2011) in possible conflict resolution. They have mainly proposed a tripartite structure, a System 3, which deactivates Type 1 processing (System 1). However, the mechanism of this shift is still under debate (see the "feeling of rightness" hypothesis of Thompson, 2009, 2010). In everyday life, people tend to accept the output of Type 1 processing and only activate Type 2 processing in some special situations, such as being explicitly instructed to reason logically, (Evans, 2006; Verschueren, Schaeken, & d'Ydewalle, 2005a). Due to the limitations of cognitive resources and other factors, Type 2 processing sometimes still gives wrong responses (see Evans & Stanovich, 2013b).

Evans and Stanovich (2013a, 2013b) have pointed out that the degree of involvement of working memory (WM) is one of the main distinctions between Type 1 and 2 processing. A significant (higher) correlation of WM measures can be regarded as an *indirect* proof of the use of analytical processes. Individual differences in WM capacities have been shown to be associated with syllogistic reasoning performance (e.g. Gilhooly, Logie, Wetherick, & Wynn, 1993). For example, studies employing a dual-task paradigm have consistently reported a role for the central executive and verbal WM in syllogistic reasoning (e.g. Gilhooly, Logie, & Wynn, 1999, 2002; Capon, Handley, & Dennis, 2003). We will elaborate on this point later.

One illustration of the interaction between Type 1 and Type 2 processing in everyday reasoning can be observed in the belief bias effect. This happens when common belief and logic are in conflict. More specifically, for syllogisms with concrete terms, in addition to the validity of the syllogism, both premises and the conclusion can agree or contradict with common beliefs. For example, "All apples are red" is "unbelievable" because there are green apples but "All apples are fruits" is "believable" because apple is a typical example of a fruit. In most of the belief bias studies, researchers manipulated the believability and the validity of the conclusion: a believable conclusion is not necessarily valid and vice versa.

As reasoning by automatic heuristic processes is more effective by demanding less cognitive resources (Evans, 2003, 2008; Sloman, 1996), it is natural that oftentimes people use common sense over logical reasoning as the preferred way of heuristics. As a result, they tend to commit the mistake of accepting invalid believable conclusions but rejecting valid unbelievable ones.

In the dual-processing theory framework, we may attribute the "superficial" response of participants to the automatic activation of the common belief (knowledge) by Type 1 processing. However, when Type 2 processing is activated, the problem is decoupled from its contents in the WM and the abstract/decontextualized representations are manipulated independently. Therefore, the output is free from belief bias effect. However, to produce the correct analytic response (with Type 2 processing), the inhibition/deactivation of the Type 1 output is essential, and the effect is more pronounced for invalid (but believable) than valid (but unbelievable) problems. The notion that inhibition plays an important role in analytical response is supported by some studies (e.g. Moutier, Plagne-Cayeux, Melot, & Houdé, 2006). De Neys and

[1] As the matching and the atmosphere hypotheses have the same prediction for our stimuli, we will just use "matching" in the rest of the article. We will just use "matching" in the rest of the article.

[2] We adopted the default-interventionist structure (Evans, 2007) in this article, though there are other proposals of how the two systems/types of processing work together, such as the parallel-competitive architecture (Sloman, 1996; Smith & De Coster, 2000).