Final author draft only. The copyedited article may differ slightly from this manuscript version. The details of the published article are as follows:

Running Head: BELIEF-LOGIC CONFLICT RESOLUTION

Belief-Logic Conflict Resolution in Syllogistic Reasoning: Inspection-Time Evidence

for a Parallel-Process Model

Edward J. N. Stupple

University of Derby, UK

Linden J. Ball*

Lancaster University, UK

_____

*Corresponding author:

Department of Psychology, Lancaster University

Lancaster, LA1 4YF, UK.

Email: L.Ball@lancaster.ac.uk

Tel: +44 (0)1524 593470

Fax: +44 (0)1524 593744

Abstract

An experiment is reported examining dual-process models of belief bias in syllogistic reasoning using a problem complexity manipulation and an inspection-time method to monitor processing latencies for premises and conclusions. Endorsement rates indicated increased belief-bias on complex problems, a finding that runs counter to the "belief-first" selective scrutiny model, but which is consistent with other theories, including "reasoning first" and "parallel-process" models. Inspection-time data revealed a number of effects that, again, arbitrated against the selective scrutiny model. The most striking inspection-time result was an interaction between logic and belief on premise processing times, whereby belief-logic conflict problems promoted increased latencies relative to non-conflict problems. This finding challenges belief-first and reasoning-first models, but is directly predicted by parallel-process models, which assume that the outputs of simultaneous heuristic and analytic processing streams lead to an awareness of belief-logic conflicts than then require time-consuming resolution.

Belief-Logic Conflict Resolution in Syllogistic Reasoning: Inspection-Time Evidence

for a Parallel-Process Model

Belief bias in reasoning is a non-logical tendency to accept conclusions that

are compatible with beliefs more frequently than conclusions that contradict beliefs.

The bias is more pronounced on invalid than valid problems, giving rise to a logic by

belief interaction in conclusion-endorsement rates that has been studied extensively

since it was established by Evans, Barston, and Pollard (1983). Contemporary

theories of belief bias are couched within a dual-process framework (e.g., Evans,

2006; Stanovich, 2004) which characterises the phenomenon as arising from the

interplay between belief-based "heuristic" processes that are rapid, associative and

implicit, and logic-based "analytic" processes that are slow, sequential, explicit, and

constrained by working memory limitations. The belief-bias effect suggests that

heuristic processes may often dominate over analytic processes in cueing responses.

Dual-process theories of belief bias have gained support from a wide range of

sources, including: neuroimaging studies demonstrating the neurological

differentiation of logic-based and belief-based responding (Goel & Dolan, 2003);

research indicating how resolving belief-logic conflicts in favour of logic declines

with age (Gilinsky & Judd, 1994); and studies demonstrating how people high in

general intelligence are better able to resist belief bias (Stanovich & West, 1997).

Despite the support for a general dual-process view of belief bias, however, little

consensus exists as to which specific dual-process theory of belief bias is best able to

capture the full range of available data. Indeed, all current theories gain some support,

yet differ markedly in their assumptions about the sequencing of heuristic and

analytic operations.

The primary goal of the present research was to realise a syllogism-

complexity manipulation so as to examine predictions deriving from three distinct classes of belief-bias theory that we refer to as "belief-first", "reasoning-first" and "parallel-process" models (we are grateful to Jonathan Evans, personal communication, for this characterisation of theories). Our research was also motivated by a secondary goal, which was to employ an inspection-time measure of processing to clarify how heuristic and analytic processes compete to determine responding. To this end, we developed a computer-based, mouse-contingent display technique to monitor problem inspection-times for syllogism components (cf. Roberts & Newton, 2001; Schroyens, Schaeken, Fias, & d'Ydewalle, 2000)[1].

We know of two previous belief-bias studies that involved response-time measures (i.e., Ball, Phillips, Wade, & Quayle, 2006; Thompson, Striemer, Reikoff, Gunter, & Campbell's, 2003). These studies revealed some inconsistencies in observed effects, although they converged in showing that people spend more time processing syllogisms with believable conclusions. Both studies, however, had limitations that the present research aimed to overcome. In Ball et al.'s (2006) experiment conclusion validity was confounded with premise configuration such that valid conclusions were always presented with "Some A are B; No B are C" premises, whilst invalid conclusions were always presented with "No A are B, Some B are C" premises. Thompson et al.'s experiment involved a latency measure that simply recorded the overall time to evaluate conclusions. This rather coarse measure may have obscured more subtle chronometric evidence that might emerge from a finer-grained examination of the locus of processing effort on premise and conclusion components. Moreover, Thompson et al. failed to examine latency data for violations of normality, yet such violations are common in chronometric data and can impact severely on test validity (Ball, Lucas, Miles, & Gale, 2003).

Belief-First Models

Belief-first theories come in two distinct flavours, referred to by Evans (in press) as *pre-emptive conflict resolution* and *default-interventionist* models. An example of the former is the selective scrutiny model (Evans et al., 1983). This assumes that believable conclusions are responded to heuristically (and simply accepted), whereas unbelievable conclusions motivate more rigorous analytic processing directed at testing conclusion validity. Evans and Pollard (1990) found support for the selective scrutiny model by demonstrating how a complexity manipulation affected discrimination of true from false conclusions, but not the magnitude of the belief-bias effect. This makes sense under the selective scrutiny model (Evans, Newstead, & Byrne, 1993), since belief is processed first, followed by an attempt at logical analysis; if analytic processing fails (more likely with complex problems) then random errors will ensue.

Evans and Pollard's (1990) apparent failure to find increased belief bias with complex problems has, however, been questioned by Klauer, Musch, and Naumer (2000), who note that the decreased variance observed in responses to such problems actually suggests that "the *relative* impact of belief was *larger* in the groups with complex problems" (Klauer et al., 2000, p. 856, emphasis added). This proposal underlines the need for further research exploring how complexity influences belief bias. It is also important to consider what the selective scrutiny model might predict concerning inspection times. Presumably, the premises of unbelievable conclusions should be inspected for longer, since reasoners are more likely to engage in analytic processing for these than believable ones (Evans, 2007). Such increased processing of unbelievable syllogisms should arise irrespective of problem complexity.

Default-interventionist models also assume an early influence of beliefs,

viewing heuristically-cued "default" responses as being either supported or inhibited by subsequent analytic processing. For example, the selective processing model (Evans, 2000, 2007; Evans, Handley, & Harper, 2001), proposes that the default heuristic response is to accept believable and reject unbelievable conclusions, which explains why belief-bias arises on both valid and invalid problems. If analytic processes intervene, however, then it is assumed that such processes will try to construct only a single mental model of the premises. But this analytic component of reasoning is itself biased by conclusion believability, such that a search is initiated for a *confirming* model when the conclusion is believable and for a *falsifying* model when the conclusion is unbelievable (cf. Klauer et al., 2000). These assumptions readily explain the increased belief-bias seen on invalid syllogisms since both confirming and falsifying models exist.

The selective processing model also explains the increased belief bias and decreased logical performance that was predicted and observed under speeded-response instructions by Evans and Curtis-Holmes (2005), since these effects would be a natural consequence of elevations in default, heuristic responding. Presumably, too, any effect of problem complexity on the magnitude of belief bias would likewise arise through increased recourse to default responding and diminished analytic intervention (i.e., there should be an increase in belief-bias and a decrease in logic-based responding). As for inspection-time predictions, the selective-processing model differs from the selective scrutiny model and does *not* predict that people will take longer to process unbelievable conclusions, since analytic intervention is just as likely for believable as unbelievable conclusions (Evans, 2007).

<div align="center">Reasoning-First Models</div>

Reasoning-first models of belief bias propose that people strive to reason

analytically, only falling back on heuristic responding when analytic processing fails. Such accounts have been referred to as *computational escape hatch model*s (Ball & Quayle, 2000; Stanovich & West, 2000). A recent example is Quayle and Ball's (2000) metacognitive uncertainty theory, which is closely allied to the misinterpreted necessity model proposed by Evans et al. (1983). Both accounts emphasise uncertainty as a determinant of belief-bias, with people producing a belief-based response when a conclusion is *possible* but not necessitated by the premises (i.e., when conclusions are *indeterminate*). The difference between the metacognitive uncertainty theory and the misinterpreted necessity model resides primarily in the weight that the former places on limited working-memory capacity as a cause of uncertainty.

In terms of conclusion-acceptance rates, these reasoning-first theories predict that problem complexity should increase belief-bias (e.g., by further increasing uncertainty) and decrease logical responding. As for inspection times, reasoning-first models would predict more rapid responding with valid conclusions irrespective of problem complexity, since reasoners should generally be more confident with valid than invalid syllogisms.

<center>Parallel-Process Models</center>

A third way in which heuristic and analytic reasoning processes may operate is as *parallel* processing streams. The best example of such a model is arguably Sloman's (1996, 2002) theory, which posits parallel "associative" (heuristic) and "rule-based" (analytic) systems. Sloman proposes that both systems will usually try to generate a response, and that the rule-based system has some capacity to suppress the associative system, although the associative system always "has its opinion heard" and can defuse a rule-based response. This model would lead to response conflicts

whenever belief-based (associative) and logical (rule-based) processes cue different outputs. These conflicts, moreover, would need to be resolved, perhaps according to some mechanism favouring logic with a certain probability (see Evans, in press, for a mathematical instantiation of such a mechanism that captures standard belief-bias effects). Within a parallel-process model, problem complexity would presumably shift the balance of responding toward beliefs and away from logic since the analytic processing stream would have difficulty in delivering an output.

Inspection-time predictions for parallel-process models of belief bias are unique, since people should be "aware" of the conflict between belief-based and logic-based responses cued by the two systems (we are grateful to Jonathan Evans, personal communication, for alerting us to this). Such conflict awareness would arise for valid-unbelievable and invalid-believable syllogisms, and the need for conflict resolution should lead to increased processing times for these problems relative to those where belief and logic deliver equivalent responses (valid-believable and invalid-unbelievable syllogisms).

<div align="center">Method</div>

Participants

Forty-eight undergraduates aged between 18 and 55 from the University of Derby received course credit for participation. None had received prior instruction concerning the psychology of reasoning. All were tested individually.

Design

A 2 x 2 x 2 x 2 repeated-measures design was used that manipulated figural complexity (AB-BC vs. BA-CB), mood (IEO vs. EIO), logic (valid vs. invalid conclusions) and belief (believable vs. unbelievable conclusions). To control for biases linked to preferred conclusion orders (A-C or C-A), problems were collapsed

across mood in all analyses. The use of the BA-CB figure to produce complex

problems was based on evidence that people find this figure harder to process because

demanding mental operations are required to ensure that middle terms of premises are

represented contiguously (Espino, Santamaría, & Garcìa-Madruga, 2000, Johnson-

Laird & Bara, 1984; Stupple & Ball, 2005, 2007). Dependent measures were

conclusion-acceptance rates and inspection times for premises and conclusions.

Materials and Procedure

Participants received 16 target syllogisms (eight AB-BC; eight BA-CB) in

IEO and EIO moods, preceded by four practice syllogisms in AEA, III, IAI and AEE

moods. Belief-oriented contents drew on those employed by Quayle and Ball (2000).

Unbelievable conclusions were definitionally false (e.g., *Some cats are not animals*),

and believable conclusions were definitionally true (e.g., *Some animals are not cats).*

Invalid conclusions were indeterminate (consistent with premises but not necessitated

by them). For each figure there were equal numbers of valid and invalid problems and

believable and unbelievable conclusions. Presentation order of target syllogisms was

counterbalanced using a balanced Latin square design, with thematic contents

systematically rotated through the 16 problems.

Authorware 5.1 on a PC was used to present problems and standard

instructions (cf. Ball et al., 2006) and to record responses and inspection times for

problem regions. Participants were informed that for each problem there would be

masked statements labelled "Premise 1", "Premise 2" and "Conclusion", and that a

single click of the mouse on masked areas would reveal the underlying statement until

the mouse was moved from that area. Participants could revisit masked areas as often

as they wished before registering a "yes" or "no" decision as to the conclusion's

necessity.

Results and Discussion

Conclusion Acceptance Rates

Conclusion acceptance data (Table 1) were subjected to a three-way analysis of variance (ANOVA).

Main Effects. The analysis revealed standard effects of logic, $F(1, 47) = 47.32$, $MSE = 0.14$, $p < .001$, with more valid conclusions accepted than invalid, and belief $F(1, 47) = 34.42$, $MSE = 0.19$, $p < .001$, with more believable conclusions accepted than unbelievable. The effect of figure was unreliable, $F(1, 47) = 2.88$, $MSE = 0.10$, $p = .096$, though in the direction of more conclusion acceptances in the easier AB-BC figure.

(Table 1 about here)

Two-Way Interactions. A typical logic by belief interaction was evident, $F(1, 47) = 9.15$, $MSE = 0.10$, $p = .004$. In addition, belief bias increased in the BA-CB figure, as revealed by a significant belief by figure interaction, $F(1, 47) = 6.17$, $MSE = 0.06$, $p = .017$. Post-hoc Bonferroni tests pinpointed the source of this interaction to a difference in acceptance rates for unbelievable conclusions across the figures ($p = .002$). This increased belief bias in the harder figure corresponds to the predictions of most theories, which assume that complexity will amplify cognitive load, thereby inducing more heuristic responding. The one theory that does not make this prediction is the selective scrutiny model.

The selective scrutiny model also predicts a decrease in the effect of logic for the harder figure - as do the other theories described earlier - yet no logic by figure interaction was observed, $F(1, 47) = 2.86$, $MSE = .08$, $p = .10$. This failed prediction of extant theories may call into question the efficacy of our complexity manipulation, and we concur that a degree of caution is needed in interpreting our acceptance data. Still,

the increase in belief bias for the BA-CB figure seems readily interpretable as a complexity effect, and we wonder if the lack of a logic effect is an artefact of the generally reduced tendency to endorse conclusions in the BA-CB figure (except in the believable-valid condition).

Higher-Order Interactions. In terms of higher-order effects, a significant three-way interaction between logic, belief and figure was observed, $F(1, 47) = 5.40$, $MSE = .06$, $p = .025$. As can be seen from Table 1, the typical logic by belief interaction that is evident for the AB-BC figure is eliminated for the BA-CB figure. People evidently respond in a belief-biased manner to both valid and invalid conclusions in the harder figure, whereas belief bias only dominates responses to invalid problems in the easier figure, as is traditionally observed. Post-hoc Bonferroni tests confirmed this interpretation by revealing that: (1) more valid-unbelievable conclusions were rejected with the BA-CB than the AB-BC figure ($p = .013$); (2) more invalid-unbelievable conclusions were rejected with BA-CB than AB-BC ($p = .049$); and (3) more valid-believable conclusions were accepted with BA-CB than the AB-BC ($p = .033$).

Total Premise Inspection Times

Total premise inspection times were subjected to a three-way ANOVA. Since data were positively skewed a logarithmic transformation was conducted to normalise the scores. Figure 1 shows premise inspection times for each condition in the form of transformed data converted back into natural units (seconds).

(Figure 1 about here)

The analysis revealed no influence of figure on premise inspection times, either as a main effect, $F(1, 47) = 0.06$, $MSE = 0.04$, $p = .81$, or in interaction with other factors. Existing belief-bias theories do not lend themselves to clear-cut predictions concerning the effect of figure on premise inspection times. Indeed, whilst

figural complexity might be expected to increase the processing of premises, such an effect might well be mitigated by increased belief-based responding, which could curtail processing time. On balance, then, one might expect little direct impact of figural complexity on premise processing times, as was observed.

The analysis indicated no main effect of belief on premise inspection times, $F(1, 47) = 0.38$, $MSE = 0.04$, $p = .54$. This lack of a belief effect goes against the predictions of the belief-first selective scrutiny model, which assumes more premise processing for unbelievable than believable conclusions, since only unbelievable conclusions will receive analytic examination. Our failure to find a main effect of belief also runs counter to Thompson et al.'s (2003) study, where latency data indicated that people were actually spending more time processing syllogisms with believable conclusions than unbelievable ones (i.e., the opposite of what would be expected according to the selective scrutiny model). We recognise, however, that the *absence* of any form of belief effect in our analysis cannot be taken as strong evidence against extant theories because of possible concerns with statistical test power. For the same reason, we are cautious about interpreting this null effect as evidence *supporting* models that do not predict an influence of belief on premise inspection times.

The ANOVA, however, did reveal a reliable effect of logic, $F(1, 47) = 5.90$, $MSE = 0.04$, $p = .02$, with increased premise inspection times for invalid problems over valid ones. Only the reasoning-first theories predict this effect. Crucially, however, the main effect of logic was qualified by the presence of a reliable logic by belief interaction, $F(1, 47) = 9.74$, $MSE = 0.03$, $p = .003$, with the premises of conflict problems (valid-unbelievable and invalid-unbelievable ones) being inspected substantially longer than the premises of non-conflict problems. Post-hoc Bonferroni tests indicated that: valid-unbelievable premises were inspected longer than valid-

believable premises (p = .027); invalid-believable premises were inspected longer than invalid-unbelievable premises, although this difference was not reliable (p = .12); and invalid-believable premises were inspected longer than valid-believable premises (p = .001). Only one belief-bias theory places a strong emphasis on the critical role of such conflict problems: Sloman's (e.g., 2002) parallel-process model.

Conclusion Inspection Analysis

We also conducted a three-way ANOVA to examine inspection-time effects arising during conclusion processing. Data were skewed, and distribution problems were again normalized using a logarithmic transformation. The analysis revealed a reliable effect of figural complexity, with BA-CB conclusions scrutinised for longer than the AB-BC ones, $F(1, 47)$ = 4.53, MSE = .02, p = .039. This effect provides another strong hint that our complexity manipulation was successful in increasing the cognitive load associated with processing BA-CB problems. There was also a reliable effect of logic, $F(1, 47)$ = 12.70, MSE = .02, p = .001, with invalid conclusions being scrutinised for longer than valid ones. There was no belief effect, $F(1, 47)$ = 0.24, MSE = 0.06, p = .878, and no interaction effects approached significance.

The main effect of logic across both figures seems to be most readily explicable in terms of reasoning-first theories, since people are predicted to engage in increased processing for invalid problems. We note, however, that if the parallel-process account was augmented with an assumption that invalid problems are more difficult to reason through than valid ones, then it could accommodate the observation of a logic effect on both conclusion processing and premise processing, whilst also dealing with the striking effect of increased processing times on the premises of conflict problems.

(Figure 2 about here)

General Discussion

Contemporary belief-bias accounts are framed as dual-process theories, whereby conclusion-endorsement decisions arise from the interplay between pre-attentive heuristic processes and conscious analytic processes (Evans, 2006, Stanovich, 2004). Given this dual-process characterisation of belief bias, our research had two objectives. First, we wanted to use a figural complexity manipulation to examine the predictions of three classes of dual-process theory that we have referred to as belief-first, reasoning-first, and parallel-process models. Second, we wished to monitor inspection-times for syllogism components to clarify how heuristic and analytic processes drive responding. We note that there have been recent calls for the enrichment of belief-bias data through the addition of process-tracing and chronometric measures (e.g., Klauer et al., 2000), yet little research has taken up this challenge. Moreover, the two published studies that have monitored latencies in a belief-bias paradigm (Ball et al., 2005; Thompson et al., 2003) have limitations that render their findings inconclusive. Our experiment attempted to improve on previous research, for example, by employing carefully controlled syllogisms and fine-grained process monitoring.

Turning to our findings, conclusion-endorsement data revealed significantly increased belief bias on the harder figure as well as reduced logic by belief interaction. There was, however, no evidence for decreased logical responding on this harder figure. This pattern of findings runs counter to the selective scrutiny model – a belief-first model – since problem complexity should result in additional *random error* rather than recourse to belief-based responding (Evans & Pollard, 1990). This model would, therefore, predict decreased logical decisions with complex problems but no increased belief-bias (in direct opposition to our actual findings).

The pattern of data is, however, broadly consistent with most other models of

belief bias, which concur in predicting an increase in belief-based responding for more demanding problems given that task complexity should undermine the effectiveness of analytic processing, thereby allowing belief-based decisions to take precedence. The attenuation in the logic by belief interaction with the harder problems also makes perfect sense for these models, since the influence of belief on both valid and invalid problems would be at its greatest with the demanding figure. The support for these models from endorsement data, however, is not incontrovertible, since they also predict decreased logical responding in the harder figure, which was not apparent. We have suggested that the lack of a logic effect is an artefact of the generally reduced tendency to endorse conclusions in the BA-CB figure; this may itself reflect a lack of confidence in responding that could be a by-product of problem difficulty (Quayle & Ball, 2000).

In the case of inspection-time findings, there was no evidence for figural influences on inspection times for premises, although a reliable effect emerged in relation to conclusions. This latter result provides some support for the efficacy of our figural manipulation in inducing increased processing difficulties, although it is unclear why such an effect should be localised to conclusions rather than distributed across both premise and conclusion components. One possibility is that increased uncertainty induced by problem complexity leads to greater recourse to conclusion-centred reasoning (cf. Stupple & Ball, 2007).

We found little effect of conclusion believability on premise or conclusion inspection-times. Although this finding concurs with reasoning-first and parallel-process models – and contradicts belief-first models – we are cautious about over-interpreting a null effect as evidence for or against extant theories of belief bias. More impressive evidence, however, comes from our observation of reliable increases in the inspection times for the premises and the conclusions of invalid problems relative to

valid ones, as per the reasoning-first theories, which assume greater levels of uncertainty with invalid problems given that conclusions are possible but not necessitated (Quayle & Ball, 2000; Thompson et al., 2003). This logic effect on processing time is contrary to the belief-first models and seems difficult to reconcile with them given their emphasis on conclusion believability as driving analytic processing. The logic effect, however, whilst also not predicted by the parallel-process model, is readily reconcilable with this theory if it is assumed that invalid problems require more analytic processing than valid ones (see Quayle & Ball, 2000, for supporting evidence). We also note that the parallel-process model assumes that the decision system that reconciles the outputs from the heuristic and analytic processing streams effectively *waits* for the results of both processing streams before producing a response (see Evans, in press, for a relevant discussion). Without this assumption the heuristic system would typically win out because of its processing speed, which would produce exclusively biased performance.

Arguably our most striking inspection-time finding is the reliable interaction between logic and belief on premise processing, which indicates that conflict problems where logic and belief collide lead to increased processing latencies relative to non-conflict problems, a result that replicates the trend identified by Ball et al. (2006). The one theory that places a central emphasis on the reconciliation of heuristic-analytic conflicts in reasoning is Sloman's (e.g., 2002) parallel-process model. Given the compatibility of this model with the majority of our findings we feel that it may well be the strongest contender for a comprehensive account of our data. An additional strength of the model is its apparent parsimony. Other models require a considerable number of assumptions to accommodate conclusion-endorsement findings, yet such accounts still appear to struggle to interpret latency-based data. As a general dual-process theory of

reasoning, the parallel-process model certainly deserves further in-depth analysis across a range of reasoning paradigms to assess its generality.

Perhaps the most important upshot of our study is the indication that whilst many dual-process theories are able to provide plausible accounts of acceptance-rate data (as they were in the present case), these theories seem to falter when it comes to accounting for chronometric evidence. As such, we suggest that our study underscores the value of going beyond conclusion-acceptance measures as a way to progress the advancement of dual-process theories in the reasoning domain.

References

Ball, L. J., Lucas, E. J., Miles, J. N. V., & Gale, A. G. (2003). Inspection times and the selection task: What do eye-movements reveal about relevance effects? *Quarterly Journal of Experimental Psychology, 56A,* 1053-1077.

Ball, L. J., Phillips, P., Wade, C. N., & Quayle, J. D. (2006). Effects of belief and logic on syllogistic reasoning: Eye-movement evidence for selective processing models. *Experimental Psychology, 53,* 77-86.

Ball, L. J., & Quayle, J. D. (2000). Alternative task construals, computational escape hatches, and dual-system theories of reasoning. *Behavioral & Brain Sciences, 23,* 667.

Espino, O., Santamaría, C., & Garcìa-Madruga, J. A. (2000b). Figure and difficulty in syllogistic reasoning *Current Psychology of Cognition 19,* 417-428.

Evans, J. St. B. T. (1996). Deciding before you think: Relevance and reasoning in the selection task. *British Journal of Psychology*, 87, 223-240.

Evans, J. St. B. T. (1998). Inspection times, relevance and reasoning: A reply to Roberts. *Quarterly Journal of Experimental Psychology, 51A*, 811-814.

Evans, J. St. B. T. (2000). Thinking and believing. In J. Garcìa-Madruga, N. Carriedo, & M. J. González-Labra (Eds.), *Mental models in reasoning* (pp.41-56). Madrid: UNED.

Evans, J. St. B. T. (2006). The heuristic-analytic theory of reasoning: Extension and evaluation. *Psychonomic Bulletin & Review, 13,* 378-395.

Evans, J. St. B. T. (2007). *Hypothetical thinking: Dual processes in reasoning and judgement.* Hove, UK: Psychology Press.

Evans, J. St. B. T. (in press). On the resolution of conflict in dual process theories of reasoning. *Thinking & Reasoning.*

Evans, J. St. B. T., Barston, J. L., & Pollard, P. (1983). On the conflict between logic and belief in syllogistic reasoning. *Memory & Cognition, 11,* 295-306.

Evans, J. St. B. T., & Curtis-Holmes, J. (2005). Rapid responding increases belief bias: Evidence for the dual-process theory of reasoning. *Thinking & Reasoning, 11,* 382-389.

Evans, J. St. B. T., Handley, S. J., & Harper, C. (2001). Necessity, possibility and belief: A study of syllogistic reasoning. *Quarterly Journal of Experimental Psychology, 54A,* 935-958.

Evans, J. St. B. T., Newstead, S. E., & Byrne, R. M. J. (1993). *Human reasoning: The psychology of deduction*. Hove, UK: Erlbaum.

Evans, J. St. B. T., & Pollard, P. (1990). Belief bias and problem complexity in deductive reasoning. In J.-P. Caverni, J.-M. Fabre, & M. Gonzalez (Eds.), *Cognitive biases* (pp.131-154)*. Elsevier: North Holland.

Goel, V., & Dolan, R. J. (2003). Explaining modulation of reasoning by belief. *Cognition, 87,* B11-B22.

Gilinsky, A. S., & Judd, B. B. (1994). Working memory and bias in reasoning across the life span. *Psychology & Aging, 9,* 356-371.

Johnson-Laird, P. N., & Bara, B. G. (1984). Syllogistic inference. *Cognition 16,* 1-61.

Klauer, K. C., Musch, J., & Naumer, B. (2000). On belief bias in syllogistic reasoning. *Psychological Review, 107, 852*-884.

Quayle, J. D., & Ball, L. J. (2000). Working memory, metacognitive uncertainty, and belief bias in syllogistic reasoning. *Quarterly Journal of Experimental Psychology, 53A,* 1202-1223.

Roberts, M. J. (1998). Inspection times and the selection task: Are they relevant?

Quarterly Journal of Experimental Psychology, 51A, 781-810.

Roberts, M. J., & Newton, E. J. (2001). Inspection times, the change task, and the rapid response selection task. *Quarterly Journal of Experimental Psychology, 54A,* 1031-1048.

Schroyens, W., Schaeken, W., Fias, W., & d'Ydewalle, G. (2000). Heuristic and analytic processes in propositional reasoning with negatives. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1713-1734.

Sloman, S. A. (1996). The empirical case for two systems of reasoning. *Psychological Bulletin, 119,* 3-22.

Sloman, S. A. (2002). Two systems of reasoning. In T. Gilovich, D. Griffin, & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment* (pp. 379-398). Cambridge, UK: Cambridge University Press.

Stanovich, K. E. (2004). *The robot's rebellion: Finding meaning in the age of Darwin*. Chicago: University of Chicago Press.

Stanovich, K. E. & West, R. F. (1997). Reasoning independently of prior belief and individual differences in actively open-minded thinking. *Journal of Educational Psychology, 89,* 342-357.

Stanovich, K. E. & West, R. F. (2000). Individual differences in reasoning: Implications for the rationality debate. *Behavioral & Brain Sciences, 23,* 645-726.

Stupple, E. J. N., & Ball, L. J. (2005). An inspection-time analysis of figural effects and processing direction in syllogistic reasoning. In B. G. Bara, L. Barsalou, & M. Bucciarelli (Eds.), *Proceedings of the Twenty-Seventh Annual Conference of the Cognitive Science Society* (pp. 2092-2097). Alpha, NJ: Sheridan Printing.

Stupple, E. J. N., & Ball, L. J. (2007). Figural effects in a syllogistic evaluation paradigm: An inspection-time analysis. *Experimental Psychology, 54,* 120-127.

Thompson, V. A., Striemer, C. L., Reikoff, R., Gunter, R. W., & Campbell, J. D.

(2003). Syllogistic reasoning time: Disconfirmation disconfirmed. *Psychonomic*

Bulletin & Review, 10, 184-189.

Author Note

Footnotes

[1]There has been some debate in the literature over the efficacy of mouse tracking methodologies for studying reasoning processes on the Wason Selection Task (see Evans, 1996; Roberts, 1998; Evans 1998, for contrasting perspectives). We note, however, that our use of a mouse-contingent display technique circumvents many of the concerns identified by Roberts (1998), and reflects a method that he himself appears to favour (Roberts & Newton, 2001).

Table 1

Percentage of conclusion acceptances as a function of figural complexity, logic and

belief

Conclusion validity	Figure AB-BC			Figure BA-CB		
	Believable	Unbelievable	*Mean*	Believable	Unbelievable	*Mean*
Valid	76	72	74	88	60	74
Invalid	71	36	53	61	25	43
Mean	74	54	64	74	42	58

Figure 1

Mean inspection times for premises as a function of figural complexity, logic and belief. Transformed data have been converted back into original measurement units (seconds) for ease of interpretation, although this renders it impossible to display standard errors. We note, however, that, standard errors for the logarithmic scores ranged from .035 to .042.
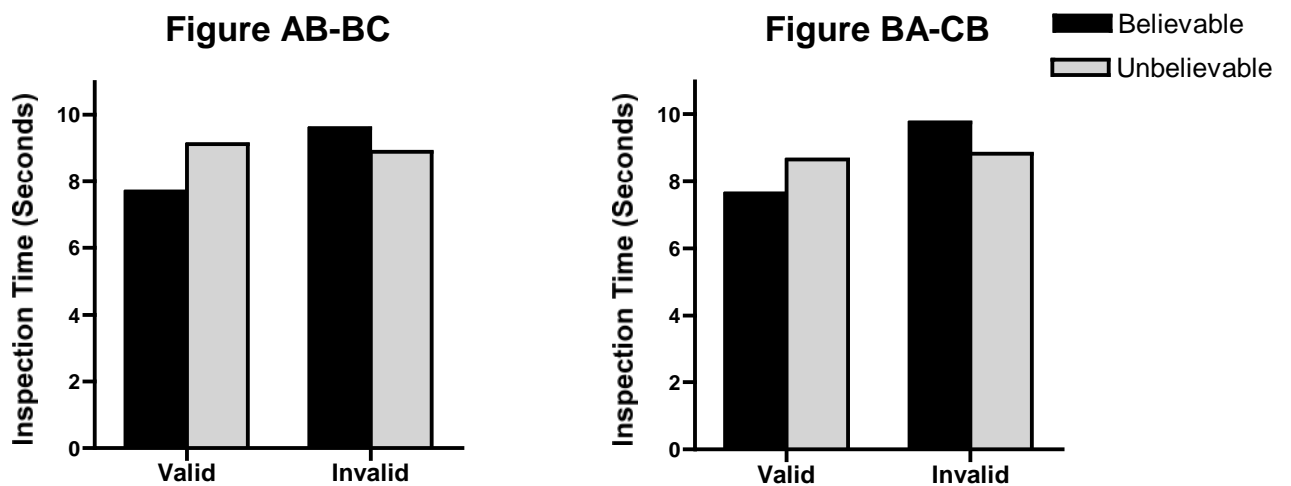
Figure 2

Mean inspection times for conclusions as a function of figural complexity, logic and

belief. Transformed data have been converted back into original measurement units

(seconds) for ease of interpretation. Standard errors for the logarithmic scores ranged

from .026 to .038.