THINKING & REASONING, 2006, 12 (3), 309–328

Psychology Press
Taylor & Francis Group

How reaction time measures elucidate the matching bias and the way negations are processed

Jérôme Prado and Ira A. Noveck
Institut des Sciences Cognitives, CNRS, France

Matching bias refers to the non-normative performance that occurs when elements mentioned in a rule do not correspond with those in a test item (e.g., consider the double mismatch between the rule *If there is a not a T on the card then there is not a 4* and a card showing *H6*). One aim of the present work is to capture matching bias via reaction times as participants carry out truth-table evaluation tasks. Experiment 1 requires participants to verify conditional rules, and Experiment 2 to falsify them as the paradigm (a) employs four types of conditional sentences that systematically rotate negatives in the antecedent and consequent; and (b) presents predominantly cases having true antecedents. These experiments reveal that mismatching is linked to higher rates of incorrect responses and slower evaluation times. A second aim is to investigate the way *not* is processed. We compare a *narrow* view of negations, which argues that negation only denies information (e.g., *not-T* only says there is no T), to a *search for alternatives* view, which says that negations function to prime appropriate alternatives (e.g., *not-T* primes a search for other letters). Findings from both experiments support a narrow reading view.

One of the better-known reasoning phenomena, especially with respect to conditional reasoning, is the *matching bias* (for a history, see Evans, 1998). While the word *matching* refers to the correspondence between the features mentioned in a given rule and those in a test case (e.g., consider a scenario having a conditional rule such as *If there is a H on the card then there is a 6* and the pair H6 on a card), effects of matching are actually best known for

Correspondence should be addressed to Jérôme Prado, Institut des Sciences Cognitives, 67, Boulevard Pinel, 69675 Bron cedex, France. Email: jprado@isc.cnrs.fr

We are grateful to Jonathan Evans, Ken Manktelow, Mike Oaksford, and one other, anonymous, reviewer for some incisive comments on an earlier version of the manuscript, as well as to Jean-Baptiste Van der Henst and Carine Ciceron for their comments and helpful suggestions on all phases of the work. We also wish to thank Thomas Castelain for his assistance in collecting the data. This work was supported by *Emergence*, a Rhône-Alpes Developmental grant, awarded to both authors.

http://www.psypress.com/tar DOI: 10.1080/13546780500371241

describing cases where normative performance is influenced negatively when features *mismatch*. For example, in truth-table tasks, participants have difficulty detecting that the pair P4 falsifies the conditional rule *If there is not an H then there is a 6* because the two elements in the pair are not specifically mentioned in the rule. According to Evans, the effect arises because mismatching cases are seen as irrelevant to the rule; this prevents participants from carrying out the logical demands of a given task (Evans, 1996). Once items match and are made to seem relevant, straightforward classifications (of true and false) become available. To return to the first example above, the letter–number pair H6 readily verifies the rule *If there is an H on the card then there is a 6* (Evans, Clibbens, & Rood, 1996), presumably because the match in features between the rule and the card prompts participants to see their relevance.

Effects of *matching* have revealed themselves in a variety of tasks. It was originally discovered on a truth-table construction task (Evans, 1972) in which participants are asked to *choose* cards from a deck that would verify (or falsify) a rule. It has also been a prominent explanation for the choice of cards on the well-known Wason Selection Task (Evans & Lynch, 1973). As Evans and others have noted, however, it has been studied most systematically and extensively with the truth-table evaluation paradigm (Evans, 1998). In this sort of task—variations of which we will present in the Experiments that follow—participants are required to judge whether an exemplar (e.g., the pair H6) conforms to, is contradictory to, or is irrelevant to a conditional rule (*If there is an H then there is a 6*). Since negations are systematically varied with the items in this sort of task (e.g., a version with two negatives is *If there is not an H then there is not a 6*), this paradigm is often referred to as the *negatives paradigm*.

Evans, who is the originator of nearly all the work regarding this phenomenon, explains matching effects more specifically through heuristics, two to be precise, that make up a first stage in processing. One heuristic is the *if*-heuristic. Its function is to pick out the features that are mentioned in the antecedent of a conditional. If the heuristic is engaged then the conditional goes through; if it is not engaged, the conditional appears irrelevant and is essentially ignored. In other words, the *if-heuristic* reflects the participant's tendency to consider as relevant only conditional rules with a true antecedent.

The second is called the *matching-heuristic* (Evans, 1998).[1] Given that the force of heuristics in general is that "logically related information may be selected out, or logically irrelevant information selected in" (Evans, 1998,

[1]This name is potentially confusing because it represents only a part of the matching phenomenon (writ large) and it was also linked to what Oaksford and Stenning once dubbed a "not" heuristic. Part of our aim here is to clarify the distinctions between all three of these notions (the matching bias, the matching heuristic and the not-heuristic).

p. 54), the idea here is that the features mentioned in a rule are going to be critical to further processing. If a rule mentions specific elements, they are going to appeal to the matching heuristic, and if the test item does not share elements with those mentioned in the rule, they risk being ignored.

Arguably, *matching* has not received the kind of collective attention lavished on other sorts of well-known effects or tasks in the literature. We believe that this inattention arises for two main reasons. One is that there is room for confusion in the theoretical explanations related to the effect. It is hard to wrap one's arms around detailed explanations of the *matching effect* because terms overlap or have been modified (see footnote 1) and theoretical explanations end up seeming distant from its very intuitiveness. This leads ultimately to some muted theoretical debates (Evans, 1998; Oaksford, 2002; Oaksford & Stenning, 1992). The other is that discussions related to matching quickly dovetail into debates concerning the processing of negation and it is not clear to what extent the two issues are related. Negation processing is obviously an important topic in itself. However, negations are linked to *matching* phenomena mostly because experimental techniques call for them. In principle, one ought to be able to accept Evans' account of matching and disagree with his account of negations (or vice versa). However, the two factors—matching and negation—remain inextricably linked and act as a conjunction in theoretical discussions.

Just how does negation processing figure in *matching*? If only the terms (the Hs and 6s etc. in the above rules) count, then it would imply that negations are immaterial. However, we know that negations have to play *some* role in sentences containing them. For example, when a rule such as *If there is not an H then there is not a 6* is presented, participants might be seduced by cards showing Hs and 6s, but at least some of them recognise that a card showing a P and a 4 would verify the rule (see Evans et al., 1996, Experiment 1). It seems safe to assume, then, that the negation of some mentioned component (e.g., to say that *there is not a square*) naturally leads to a search for alternatives (Oaksford, 2002; Oaksford & Stenning, 1992). To what extent, then, are negations processed? Is their unique role to search for alternatives?

One school of thought is that *not* narrowly focuses on what is denied *and goes no further*. As described by Evans and colleagues (Evans et al., 1996; see also Evans & Over, 2004, p. 77, for a more recent description), the negation's function is "to deny propositions rather than assert information" (Evans et al., 1996, p. 394):

> If someone tells you that they did not watch the football game last night the topic of their discourse is clearly the [game]... They are not asking you to think about any of the many things they may have done instead (Evans et al., 1996, p. 394).

The football game in the Evans et al. quote is exemplary in highlighting how the listener is not supposed to go beyond the object mentioned in the sentence. We will call this the *narrow-scope* view.

The other school of thought is that negation processing can also be viewed more widely, as a guide to making a negated object the basis for a search among cases that can instantiate the negated-object, i.e., "the many things" that the denied proposition can be. According to this reading, participants detect that, e.g., the not-H and the not-6 in *If there is not an H then there is not a 6* are the basis of further processing that will lead a reasoner to find non-Hs and eventually non-6s. According to this account, participants' failures (errors in mismatching cases, say) are presumably due to computational errors linked to the processing of negations. Oaksford and Stenning (1992) made this argument by drawing on Wason (1965) and saying that a negation leads a listener to construct a *constrast class* and that this is done "with greater or lesser success" (p. 849). We will call this the *search-for-alternatives* view of negation.

The extent to which either of these accounts is linked to the *matching heuristic* remains unclear (Evans, 1998). When writing about Oaksford and Stenning's proposal, Evans (1998, p. 58) wrote: "I am not clear . . . that this proposal is really very different from the matching-heuristic." This quote seems hard to reconcile with the two diametrically opposing views of negation that are typically included as part of discussions on matching. Our reading of this quote is that the matching-heuristic picks out information to be processed or ignored, but that a second stage allows for negation processing proper. In the event such analytic processing occurs, Evans can be read as saying that it takes on a narrow reading while Oaksford and Stenning argue that it takes on a search-for-alternatives reading. Whether or not our interpretation of Evans is correct,[2] we want to take advantage of not only of accuracy scores but also reaction times, in order to see how negations are processed in a task as fundamental as the truth-table evaluation task.

THE EXPERIMENTS

Matching bias effects

Reaction time measures provide great insight into cognitive processes and, surprisingly, there are few reasoning studies that exploit this technique. As far as we know, only two studies have used on-line measures to directly investigate the matching bias. One paper focused on the well-known

[2]Evans seems to be aware of, and takes some responsibility for, the potential for confusion (see Evans & Over, 2004, p. 77).

Wason selection task (Evans, 1996) and the other on the conditional inference task (Schroyens, Schaeken, Verschueren, & d'Ydewalle, 1999). It is important to note that the recorded measurements in these two papers focus primarily on comprehension times (i.e., reading times) rather than reaction times strictly speaking. Only one paper (Evans & Newstead, 1977) introduced response latencies in the truth-table evaluation task, and there the authors were more concerned with testing another hypothesis; they did not focus on the matching bias's direct influence on response times. One of the main empirical goals in the present study is to better characterise the influence of the matching bias on a basic reasoning task while using reaction times. Specifically, if one considers *matching* a robust and influential perceptual bias, manipulating it in a reasoning task should show direct effects on response times.

Here, it pays to introduce our paradigm and materials in greater detail. As is typical for this paradigm, there are four cases for investigating negations in conditionals:

- Affirmative antecedent, Affirmative consequent (AA): *If p then q.*
- Affirmative antecedent, Negative consequent (AN): *If p then not q.*
- Negative antecedent, Affirmative consequent (NA): *If not p then q.*
- Negative antecedent, Negative consequent (NN): *If not p then not q.*

The materials in the current study present a letter *in* a shape so that a test item consisted of a picture showing, e.g., an *H-in-a-square*. This allows the test item to represent a single image that minimises saccades. Now, consider an AA conditional sentence that could precede it: *If there is an H then there is a square* when in a verification task. This ought to provide a *Hit* (a "yes, this is correct" response). One can also present items (such as an *H-in-a-circle* to the above AA rule) that ought to prompt *Correct Rejections*. Each sort of response ought to interact with the matching bias. A *Hit* with full matching ought to produce greater accuracy and faster reaction times than a *Hit* with none (imagine an NN rule of the sort *If there is not an H then there is not a square* and the test item *P-in-a-circle*). Likewise, the item *H-in-a-square* ought to be correctly rejected more often and more quickly with respect to the AN rule *If H then not square* (total match) than the item *P-in-a-circle* with respect to the NA rule *If not H then square* (double mismatch). See Table 1 below for other examples.

In order to gather solid data, we carry out the truth-table evaluation task with conditionals that involve largely those cases in which the antecedent is true (with respect to the rule). This way we neutralise the *if-heuristic* and can concentrate on the *matching*-heuristic. We cite three reasons for this focus. First, the *if*-heuristic is specifically geared towards conditionals and, although we will be investigating conditional reasoning, the matching phenomenon is, in principle, generalisable to other connectives (Evans, Legrenzi, & Girotto, 1999). Second, the *matching-heuristic*, as its name suggests, is more intimately related to matching bias phenomena. Finally, the present study aims to understand the word *not* in reasoning scenarios and, historically speaking, negations have been more closely linked with the matching-heuristic. This led to our main innovation to the *negatives paradigm*, which is that we present true antecedents in the large majority (over 85%) of cases. In other words, only 2 trials out of 15 for each condition include the potentially confusing cases that have a false antecedent (consider *H-in-a-square* for an AA rule such as *If there is a T then there is a square*). We include two cases in order to keep participants attentive. Experiment 1 investigates the effects of matching with a truth-table evaluation task that requires verification and Experiment 2 investigates the effects of matching with a truth-table evaluation task that requires falsification. Having both a verification and falsification version of the negatives paradigm with reaction times allows one to take two different snapshots of the matching bias in action.

Negation processing

In order to investigate negation processing, we focus on the case AN (e.g., *If there is an H then there is not a square*) where the role of negation in this task can be limited to the consequent and where the effort required to process the antecedent remains minimal. According to a narrow reading of *not*, the conditional puts the focus (squarely!) on *square* and (initially, at least) goes no further; the participant ought to be prepared for the square and little else. If that is the case, the appearance of an *H-in-a-square* in the verification task, for example, ought to be correctly rejected with relative ease when compared to a *Hit* (*H-in-a-circle*). This should translate into higher rates of correct responses or faster reaction times for the *Correct Rejection* of AN cases when compared to the *Hit*. On the other hand, according to the search-for-alternatives of negation, one should be prompted to search for an *H* in a non-square (e.g., an *H-in-a-circle* or an *H-in-a-triangle*). If that is the case, the appearance of an *H-in-a-square* in a verification task (of an AN case) ought to be surprising. It follows, then, that a *Correct Rejection* of this item (e.g., an *H-in-a-square*) ought to trigger more errors and take more time than an item such as *H-in-a-circle* (a *Hit*).

Predictions are similar for the falsification version of the truth-table evaluation task (Experiment 2). According to a narrow reading of *not*, the *not a square* in *If there is an H then there is not a square* puts the focus on *square* and actually facilitates the search for the counterexample needed to falsify this AN case. If that is the case, a Hit (saying that an *H-in-a-square* indeed falsifies the conditional) ought to lead to fewer errors and to faster reaction times than a Correct Rejection (e.g., saying that *H-in-a circle* does not reject the conditional). If, on the other hand, the primary role of *not* in a sentence such as *If there is an H then there is not a square* is to search for alternatives that satisfy *non-square* (e.g., circle), then it should be relatively difficult to double back and arrive at *H-in-a-square* as exemplary of falsification. This should translate into fewer errors and faster reaction times for Correct Rejections (e.g., rejecting *H-in-a-circle* as exemplary of non-falsification) than Hits (accepting *H-in-a-square* as a case of falsification).

To summarise, our experiments have two basic concerns. One is to better characterise the matching bias with reaction time measures. We aim to see whether matching in a task as fundamental as the negations paradigm is directly linked with rates of correct responses and reaction times. We also aim to see how negations are processed: Is there evidence for a narrow reading of negations or rather for a search-for-alternatives treatment?

EXPERIMENT 1

As we stated earlier, our version of the truth-table evaluation task focuses largely on cases that prompt definitive outcomes and thus includes only a token number of test items with a false antecedent. We did this to neutralise the *if-heuristic* (participants' tendency to consider false antecedent cases as irrelevant). Experimentally, these cases are known to produce large variations in the frequency of correct responding and we would expect their reaction times to become very difficult to interpret as well.

Method

Subjects. A total of 21 right-handed native speakers of French from the Université Catholique de Lyon participated voluntarily. Participants were recruited from an Introductory Psychology class in an undergraduate programme that has no obligatory subject pool requirement, but does encourage its students to become acquainted with experimentation. Two subjects were below 30% accuracy and were excluded from further analyses. The remaining 19 subjects (one male) were aged between 17 and 23 (mean age: 19 years).

Stimuli. A total of 36 target items were prepared based on letter-in-shape combinations. There were six letters (H, I, J, P, Q, and R) presented as capitals in bold in 30-point font and six shapes (square, circle, star, diamond, rectangle, and triangle) that were standardised to be roughly 4 centimetres high and 4 centimetres across. A single session ultimately included 120 trials, so the 36 target items were used up to four times each across the experiment.

Four different *if-then* statements were prepared. These are based on the presence or absence of a negation in the antecedent and the presence or absence of a negation in the consequent. As shown below, Condition I was affirmative throughout, Condition II presented a negation in the consequent of the rule, Condition III presented a negation in the antecedent of the rule, and Condition IV presented a negation in both the antecedent and consequent of the rule:

- Condition I: If there is an H then there is a square.
- Condition II: If there is an H then there is not a circle.
- Condition III: If there is not a J then there is a square.
- Condition IV: If there is not a J then there is not a circle.

Upon seeing the letter–shape combination that followed a rule, the participant was asked to determine whether or not the rule was verified. Each of the above rules can readily yield a verifying case and a non-verifying case. An *H in a square* would verify each of the above rules; an *H in a circle* would lead to a negative response for each of the above.

We were almost exclusively concerned with those cases that yield determinative responses, i.e., cases that can yield an unambiguous response. Thus, 26 out of 30 stimuli per condition contained items that had a true antecedent and the remaining four stimuli per condition presented a letter that was irrelevant to the antecedent (e.g., a *P* for the examples in Conditions I or II above). These four were included in order to avoid predictability in the task. Of the 26 target items per condition, 13 were presented as confirming cases (potential Hits) and 13 as disconfirming cases (potential Correct Rejections).

Task and procedure. The task was presented with a standard PC monitor and the software *Presentation* (Neurobehavioral Systems). Each trial started with the presentation of a fixation mark (a dot) in the centre of the screen for 500 ms (see Figure 1). The two parts of the rule then appeared one line at a time, with the first part (e.g., "If there is an H") appearing at 500 ms and the second part ("then there is a square") at 1500 ms. The entire rule then remained on the screen for a further 3000 ms, at which point the rule disappeared and the central dot reappeared for 500 ms. This was immediately followed by the target item. Each trial ended when the participant provided a response. A new trial began immediately afterwards.

The experiment began with five training trials, which included four relevant (two confirming cases and two disconfirming cases) and one non-relevant case taken from condition I (the simplest condition without negations). The participants responded by pressing one of two corresponding response keys with the index finger of their left or right hand upon the

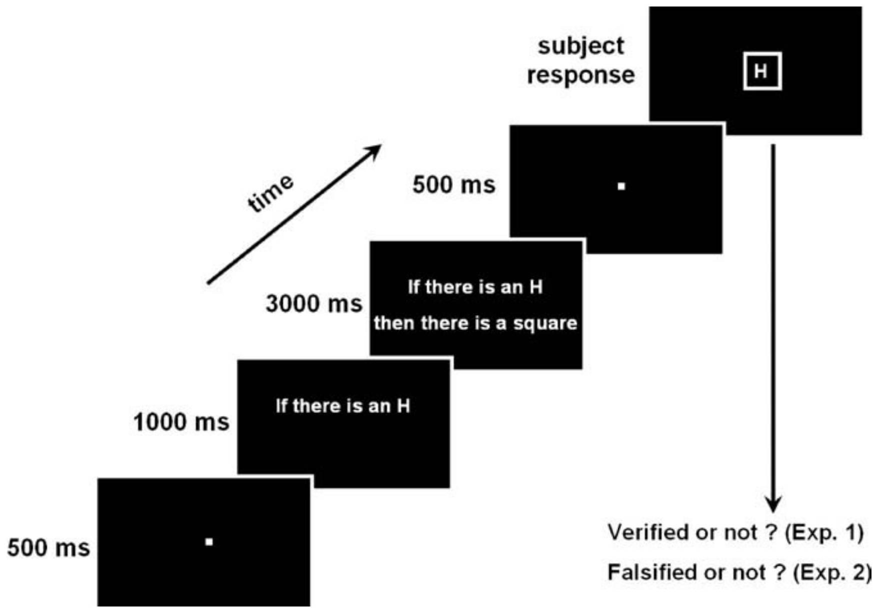

Figure 1. A representation of the experimental procedure during the verification version of the truth-table evaluation task (Experiment 1) and the falsification version of the task (Experiment 2).

appearance of the target item. If the item confirmed the rule, participants were required to press the "yes" key (i.e., "yes, the rule is verified"); if the rule was not confirmed by the item, they were required to press the "no" key (i.e., "no, the rule is not verified"). Subjects were instructed to respond as quickly and as accurately as possible. The assignment of response keys (the Z and P on an AZERTY keyboard) was counterbalanced across participants. There were 120 trials, which were presented in a random order and were part of a single block. Although the task was rather long, there was little indication that participants found it difficult.

Results

We analysed the experiment using both accuracy and reaction times. In all the analyses concerning accuracy, arcsine transformations were carried out before analysis to improve the conformity of the data to the standard assumptions of ANOVA (e.g., Howell, 1997). Likewise, a log transformation was applied to the reaction time data. Following Clark (1973) we also carried out an analysis using both participants and stimuli items as random effects in our model. By convention, we refer to *F*-values obtained with participants as the random factor as F_1, and F-values obtained with items as the random factor as F_2. We also included the min F' statistic (Clark, 1973), which treats subject and items as random effects in a single ANOVA and is an even more conservative measure that can give further insight into the strength of an effect. All p-values assume a two-tailed test unless otherwise stated.

Data treatment. The experiment was analysed with primary interest for both accuracy (i.e., percent of correct responses) and reaction times (RTs) of the determinate responses. For each participant and condition, RTs of more than three standard deviations from the mean were excluded from the analyses. This resulted in 1% of the trials being removed from the data set. In addition, when analysing the response time data of determinative trials, we removed all error trials (i.e., non-normative responses). This meant that a further 12% of the responses were removed for the reaction time analysis.

In order to study the influence of matching bias generally, we assigned a "matching level" index to each trial (see Table 1). For example, a matching level 2 (total match) describes the trial *If there is an H then there is a square* followed by the target item *H-in-a-square*. In the same way, a matching level 0 (total mismatch) was applied to the trial *If there is not an H then there is not a square* followed by the item *P-in-a-circle*. Matching level 1 was finally applied to trials with just one matching element between the rule and the target (*If H then not square* followed by *H-in-a-circle*). This leads to three levels of matching (0, 1 and 2 matches). All results are summarised in Table 1.

TABLE 1
Experiment 1

Rule	*Item*	*Correct response*	*Matching level*	*Percentage correct*	*RT**
If H then square (AA)	*H-in-square*	Yes (Hit)	2	97	1027
If H then square (AA)	*H-in-circle*	No (CR)	1	90	1392
If H then not square (AN)	*H-in-square*	No (CR)	2	96	1613
If H then not square (AN)	*H-in-circle*	Yes (Hit)	1	88	1696
If not H then square (NA)	*P-in-square*	Yes (Hit)	1	87	1748
If not H then square (NA)	*P-in-circle*	No (CR)	0	85	1722
If not H then not square (NN)	*P-in-square*	No (CR)	1	81	2246
If not H then not square (NN)	*P-in-circle*	Yes (Hit)	0	78	2278

Rates of correct responses and reaction times to correct and incorrect responses in Experiment 1 (verification task) when the pictorial item matches or mismatches with the letter and shape mentioned in the rule. This table is based on a model case *If there is an H then there is a square*, but of course letters and shapes were varied.
*These are reaction times to correct responses only.

Does the matching bias affect the frequency of correct responses? We carried out a repeated measures ANOVA with the factors Matching Level (0, 1, 2) and Response Type (Hits vs Correct Rejections) on accuracy and found a main effect of matching level, $F_1(1, 18) = 7.19$, $p < .01$, $F_2(1, 35) = 36.51$, $p < .001$, min F' $(1, 25) = 6.01$, $p < .05$. Subjects' rates of accuracy for matching level 2 (total match), level 1, and level 0 (total mismatch) were 96%, 86%, and 82%, respectively. No interaction was found between the two factors, $F_1(1, 18) = 0.12$, *ns*, $F_2(1, 35) = 1.69$, *ns*, min $F'(1, 21) = 0.11$, *ns*.

Does the matching bias affect reaction time? A repeated measures ANOVA with the factors Matching Level (0, 1, 2), and Response Type (Hits vs Correct Rejections) on reaction times shows a main effect of matching level, $F_1(1, 18) = 13.22$, $p < .001$, $F_2(1, 35) = 36.53$, $p < .001$, min F' $(1, 31) = 9.71$, $p < .01$. Responses were fast when the pictorial item completely matched with the letter and shape mentioned in the rule (1288 ms; matching level 2), slower when there was not a complete match (1753 ms; matching level 1), and even slower when there was a complete mismatch (1981 ms, matching level 0). There was also a significant interaction between matching level and response type, $F_1(1, 18) = 4.37$, $p < .05$, $F_2(1, 35) = 7.62$, $p < .01$, min $F'(1, 38) = 2.78$, $p < .10$. Responses are faster when participants had to confirm (i.e., make Hits of) an item that completely matched the rule (1027 ms) as opposed to when they had to disconfirm (i.e., make CRs of) the same item: 1613 ms; $F_1(1, 18) = 21.4$, $p < .001$, $F_2(1, 35) = 36.3$, $p < .001$, min $F'(1, 39) = 13.46$, $p < .001$. When the item completely mismatched the rule, confirming (i.e., making Hits of) it was slower (2278 ms) than disconfirming (i.e., making CRs of) it: 1722 ms; $F_1(1, 18) = 5.29$, $p < .05$, $F_2(1, 35) = 7.37$, $p < .05$, min $F'(1, 42) = 3.08$, $p < .10$. Finally, if there was one matching element (matching level 1), no difference was observed, $F_1(1, 18) = 2$, *ns*, $F_2(1, 35) = 0.08$, *ns*, min $F'(1, 38) = 0.08$, *ns*, between Hits (1713 ms) and Correct Rejections (1793 ms).

Narrow vs search for alternatives views of negation: The AN case. Rates of correct responses to the AN case were higher for correct rejections (96%), i.e., when items disconfirmed a rule (to say that an *H-in-a-square* does not verify *If there is an H then there is not a square*), than they were for Hits (88%), i.e., when items confirmed the rule (to say that an *H-in-a-circle* verifies *If there is an H then there is not a square*). This effect was significant for both participants and items analyses, $F_1(1, 18) = 4.70$, $p < .05$, $F_2(1, 9) = 13.9$, $p < .01$, min F' $(1, 26) = 3.51$, $p < .10$. However, the difference in terms of reaction times (1696 ms for Hits vs 1613 ms for Correct rejections) did not reach significance, $F_1(1, 18) = 0.57$, *ns*, $F_2(1, 9) = 2.31$, *ns*, min F' $(1, 27) = 0.46$, *ns*.

Another comparison worth making is between Hits for the AN rule and Correct Rejections for the AA rule. Both involve the mismatch on shape but only the former has a negation in the rule. If a search-for-alternatives priming has precedence over a narrow reading, Hits for AN should prompt more accurate responses and faster reaction times than Correct Rejections for AA. An analysis of this comparison actually reveals the opposite. Whereas Hits for the AN rule prompt slightly more inaccurate responses than Correct Rejections for the AA rule (the difference is not significant) they are actually significantly slower: 1696 ms vs 1392 ms; $F_1(1, 18) = 10.73$, $p < .01$, $F_2(1, 9) = 14.56$, $p < .01$, min $F'(1, 26) = 6.18$, $p < .05$. This further shows the extent to which a narrow reading of negation is primary on this fundamental reasoning task.

Discussion

In this experiment, we carried out a basic truth-table evaluation task while recording reaction times. We focused largely on cases that prompt definitive outcomes and do not risk being considered irrelevant (with a false antecedent). The first relevant result is that we found a clear matching effect. Our data indicate that as the number of matching elements (i.e., between the rule and the target item) decreases (i) rates of correct responses decline, and (ii) reaction times slow down. This finding is very consistent with the literature on the matching bias for the truth-table evaluation task (Evans et al., 1996; Evans & Newstead, 1977; Ormerod, Manktelow, & Jones, 1993). As should be clear, more mismatching implies a greater risk of error.

The novel result here is (ii), that the matching effect is visible with respect to response times. In other words, participants are faster at evaluating items with elements that were mentioned in the rule and slower when the elements were not mentioned. It appears that reasoning is easier when the elements contained in a rule overlap with those in the test item. This last result is in line with the idea that the matching bias is a way to consider as relevant only items that are mentioned in the rule. This is so despite the fact that there were only six letters and six shapes and the universe of possibilities is quite limited.

To explore more carefully the two hypotheses concerning negation (*narrow-scope* versus *search for alternatives* view), we focused on the AN case (when there is a negation only in the consequent). We found that participants were more accurate in disconfirming the rule (i.e., making Correct Rejections) than they were in confirming the rule (i.e., Hits). This suggests that participants are perceptually prepared for the element mentioned in the negated component of the rule. We take this to be consistent with the narrow-scope view of negation because it indicates that participants' initial reaction to a negation (e.g., *there is not a circle*) is to consider the object mentioned (circle) rather than use the negative as a springboard to look for other non-circular shapes (such as squares and stars etc.). Moreover, we found that reaction times to Hits for the AN case were significantly slower than those to Correct Rejections for the AA case. The presence of a negation in the consequent of the AN case (which ought to prime a search for alternatives according to Oaksford's account) does not facilitate the Hit response in any way. This is again consistent with the *narrow reading* view of negation.

In sum, our results clearly show a matching bias effect on a truth-table verification task with respect to both accuracy and response latencies. The narrow scope treatment of *not* appears more dominant in this task while participants' performance indicates that a search for alternatives is particularly difficult. In the General Discussion we will consider how to integrate this set of results with those gathered in Experiment 2.

EXPERIMENT 2

Before drawing conclusions about matching and negation processing, it would be relevant to know if the same conclusions hold when the task becomes more difficult. That is, will we find the same sort of results when we use a falsification version of the truth-table evaluation task? Experiment 2 is designed to answer that question.

Method

Subjects. A total of 23 participants (two males, aged 19 – 22 years, mean: 20 years) were recruited from the Catholic University of Lyon in France. All subjects (one left-handed) were native French speaking and only one of them was below 30% accuracy and so excluded from analyses of this experiment.

Stimuli and experimental design. The materials and experimental design were the same as in Experiment 1. The only difference was with respect to the participant's task.

Task. Experiment 2 differed from Experiment 1 in that participants had to (not verify but) falsify the rule. In other words, they had to determine whether the rule was falsified or not falsified by the target item (by pressing the same yes/no response keys as in Experiment 1). Here, a Hit occurs when the participant appropriately determines that a test item falsifies a rule, and a Correct Rejection occurs when the participant appropriately determines that the test item does not falsify the rule.

Data analyses. Mean percent of correct responses and response times were computed for each condition. Due to data trimming, 15% of the data was removed in the relevant trials.

We looked at both accuracy rates and reaction times. Arcsine transformations were carried out on rates of correct responses and a log transformation was applied to the reaction time data to conform the data to the standard assumptions of ANOVA. As with the analyses of Experiment 1, we will refer to F-values obtained with participants as the random factor as F_1, and F-values obtained with items as the random factor as F_2. We also include the min F' statistic. All p-values assume a two-tailed test unless otherwise stated.

Results

Matching indexes (0, 1, and 2) were applied to all trials to characterise the matching bias influence (see Experiment 1). All results are shown in Table 2.

Does the matching bias affect the frequency of correct responses? We carried out a repeated measures ANOVA with the factors Matching Level (0, 1, 2) and Response Type (Hits vs Correct Rejections) with respect to accuracy. We found a main effect of matching level only with stimulus items as random effects, $F_1(1, 21) = 0.01$, *ns*, $F_2(1, 35) = 4.47$, $p < .05$, min $F'(1, 21) = 0.01$, $p < .10$. Subjects were accurate for matching level 2 (91%; complete match), less accurate for matching level 1 (87%; matching level 1),

TABLE 2
Experiment 2

Rule	*Item*	*Correct response*	*Matching level*	*% Correct*	*RT**
If H then square (AA)	*H-in-square*	No (CR)	2	94	1704
If H then square (AA)	*H-in-circle*	Yes (Hit)	1	93	1951
If H then not square (AN)	*H-in-square*	Yes (Hit)	2	87	1937
If H then not square (AN)	*H-in-circle*	No (CR)	1	88	2192
If not H then square (NA)	*P-in-square*	No (CR)	1	89	2166
If not H then square (NA)	*P-in-circle*	Yes (Hit)	0	65	2570
If not H then not square (NN)	*P-in-square*	Yes (Hit)	1	78	2511
If not H then not square (NN)	*P-in-circle*	No (CR)	0	81	2646

Reaction times in Experiment 2 (falsification task) to correct and incorrect responses when the pictorial item matches or mismatches with the letter and shape mentioned in the rule. This table is based on a model case *If there is an H then there is a square*, but of course letters and shapes were varied.
*These are reaction times to correct responses only.

and even less accurate for matching level 0 (74%; matching level 0). No interaction was found between the two factors, $F_1(1, 21) = 1.88$, *ns*, $F_2(1, 35) = 0.04$, *ns*, min $F'(1, 36) = 0.04$, *ns*. Notably, participants evaluated the Hits of AN cases at a rate of 87% correct, which in this case is a complete match (matching level 2), and they correctly evaluated the Hits of the NA cases at a rate of 65%, which represents a complete mismatch (matching level 0). This difference was significant, $F_1(1, 21) = 21$, $p < .001$, $F_2(1, 11) = 22.18$, $p < .001$, min $F'(1, 29) = 10.78$, $p < .01$. It is worthwhile pointing out here that the one case that the literature has shown to be problematic for participants—to disconfirm an NA rule (i.e., to get a Hit) when there is zero matching (to say that a *P-in-a-circle* properly disconfirms *If not H then square*)—is indeed the hardest case across both experiments (e.g., see Houde et al., 2000). The rate of correct responses on this particular problem is 65%, which is far lower than the rates of correct performance when compared to any other condition in our two experiments.

Does matching bias affect reaction times. We performed a within-subject ANOVA with the factors Matching Level (0, 1, 2) and Response Type (Hits vs Correct Rejections) with reaction times serving as the dependent variable. This analysis revealed a main effect of Matching Level but only with respect to stimulus items as random effects, $F_1(1, 21) = 0.27$, *ns*, $F_2(1, 35) = 55.49$, $p < .001$, min $F'(1, 21) = 0.268$, *ns*, showing relatively fast responses for matching level 2 (2012 ms), slower responses for matching level 1 (2456 ms), and even slower responses for matching level 0 (2887 ms). No interaction reached significance, $F_1(1, 21) = 0.30$, *ns*, $F_2(1, 35) = 0.88$, *ns*, min $F'(1, 35) = 0.22$, *ns*, due to the fact that a difference between Hits and Correct Rejections was only seen with complete matching (i.e., level 2) cases, $F_1(1, 21) = 12.69$, $p < .001$, $F_2(1, 35) = 13.86$, $p < .001$, min $F'(1, 51) = 6.62$, $p < .05$, with faster reaction times for Correct Rejections cases as opposed to Hits of the rule (1704 ms vs 1937 ms).

Narrow vs search for alternatives views of negation: The AN case. Much as in Experiment 1, we compared Hits (which in this case are disconfirming cases) and Correct Rejections (which in this case are non-disconfirming cases) for the AN case. The Hit rate (to say that a *P-in-a-square* properly disconfirms *If P then not square*) was 87% and the Correct Rejection rate (to say that a *P-in-a-square* does not disconfirm *If P then not circle*) was 88%. Unlike in Experiment 1, we found no difference for accuracy, $F_1(1, 21) = 0.01$, *ns*, $F_2(1, 10) = 2.03$, *ns*, min $F'(1, 21) = 0.01$, $p < .10$. However, we did find a significant difference for reaction times based on analyses of both participants and items, $F_1(1, 21) = 6.35$, $p < .05$, $F_2(1, 10) = 18.15$, $p < .001$, min $F'(1, 30) = 4.70$, $p < .05$, showing faster response for Hits (1937 ms) than for Correct Rejections (2192 ms).

Moreover, as in Experiment 1—where we compared correct rejections for the AA rule with Hits for the AN rule—to uncover potential support for the search for alternatives view, we compared Hits for the AA rule with Correct Rejections for the AN rule here. Both involve the mismatch on shape but only the latter has a negation in the rule and so should provide an advantage for contrast class members. So, if a search-for-alternatives treatment of negation has precedence, Correct Rejections for AN should show an advantage over Hits for AA. This comparison actually reveals the opposite: Correct Rejections to the AN rule are produced at lower rates than Hits of the AA rule (although the difference is not significant) and Correct Rejections to the AN are actually significantly slower (2192 ms vs 1951 ms); $F_1(1, 21) = 5.35$, $p < .05$, $F_2(1, 9) = 5.76$, $p < .05$, min $F'(1, 26) = 6.18$, $p < .10$. The mention of *not* (as in *there is not a square*) does not automatically prompt a search for alternatives (i.e., to find a non-square such as circle) as a first step. These results appear to support Evans et al. (1996) who argue that the negation serves to deny a proposition rather than assert information.

Discussion

As did the verification task of Experiment 1, the falsification version of the truth-table judgement task in Experiment 2 provides evidence that the matching bias effect can be captured with the present paradigm. Although effects on accuracy and reaction times related to matching are less pronounced here than they are in the verification version of the task, key pieces of evidence emerge in support of the matching bias. For example, the matching effect was exemplified by those instances where complete matching cases yielded significantly higher Hit rates than complete mismatching cases (87% vs 65%). That the general predictions of matching effects should be supported with fewer significant effects with respect to the results of Experiment 1 (especially with respect to reaction times) is not surprising, since the falsification version of the truth-table task is prima facie more difficult than the verification task and thus introduces more variability.

Also, an examination of negation processing in the AN case reveals faster responses to disconfirming cases (Hits in this instance) than confirming cases (Correct Rejections). This echoes the effect seen in Experiment 1. Although based on reaction times rather than accuracy scores, the findings from Experiment 2, like those in Experiment 1, indicate that a reasoner's initial reaction to a negation is narrow; that is, the elements mentioned in the rule have prominence as the participant aims to disconfirm the rule. The negation does not serve to automatically prime a search for alternatives.

GENERAL DISCUSSION

This work had two general goals. One was to generalise effects of the matching bias by using reliable reaction time measures. In order to get stable measures, an overwhelming majority of test items concerned cases that had definitive responses. The other was more theoretical: to determine how negations are processed in this sort of task. Evans and colleagues (Evans et al., 1996; Evans & Over, 2004) make the claim that negations serve primarily to deny propositions, while Oaksford and colleagues (Oaksford, 2002; Oaksford & Stenning, 1992), claim that the role of negation is to prompt a search for alternatives. In what follows, we review the findings from the experiments, explain how Evans' account appears to be supported, and propose how the *narrow* and *search-for-alternatives* views of negation can be integrated into a single account.

As far as effects of matching bias go, the data are largely straightforward. Matching influences both accuracy scores and response times. Rates of correct responses are lower when elements in a rule do *not* overlap with those in the test item; this is the very basis of the matching bias. Although the matching effect has been reported in earlier studies using the construction task (Evans, 1972; Oaksford & Stenning, 1992), the truth-table evaluation task (Evans et al., 1996; Evans & Newstead, 1977; Ormerod et al., 1993), or the Wason selection task (Evans & Lynch, 1973; Manktelow & Evans, 1979; Yama, 2001), the present study is the first to show a clear matching effect via reaction times with the verification, as well as with the falsification, versions of the truth-table evaluation task. The reaction time findings give direct evidence that matching influences the reasoning process: Most notably, mismatching cases tend (a) to prompt higher error rates and (b) be slower, with respect to matching cases.

We also found that higher accuracy scores and faster reaction times linked with greater matching are weaker with the falsification task in Experiment 2 than they are in the verification task in Experiment 1; nevertheless, key findings are largely reproduced. As indicated earlier, this difference can be explained by the high level of variability introduced by falsification in Experiment 2. This observation only underlines the necessity to simplify task designs in order to reduce variability (and facilitate interpretation) when investigating reaction times. The reduced variability actually justifies our strategy of putting the focus on rules with a true antecedent and to bypass effects that are potentially linked to the *if-heuristic*.

The investigation of the AN cases indicates that the processing of *not* involves a narrow focus on the negated item. Experiment 1 showed higher rates of *Correct Rejections* than *Hits* for AN cases and Experiment 2 showed faster reaction times when providing *Hit* responses as opposed to *Correct Rejections*. Both of these results were predicted by the narrow view of negations. Although it would be ideal to have both higher rates of correct responses *and* faster reaction times in support of a narrow reading in *both* experiments, it is important to point out that we do not find support for a search-for-alternatives view reading in these cases. Furthermore, we did not find evidence for a search-for-alternatives view with respect to comparisons of AA and AN cases in Experiment 1, nor in Experiment 2. That is, we did not find advantages for the AN case over its nearest comparable cohort among the AA rules (i.e., a search-for-alternative view predicts that the main function of negation is to prime a search among the contrast class, which only the AN case can do in this comparison). In short, the present results largely corroborate Evans' claim that a negation heuristic denies and does not assert.

That a narrow reading of negations is primary is attractive because it conforms with the intuition that denials readily entail other denied propositions. For example, the linguistic literature has pointed out how Negative Polarity items work.[3] When a speaker says, e.g., *I did not eat ice cream*, it automatically entails that he did not eat chocolate ice cream either (see Noveck, Chierchia, Chevaux, Guelminger, & Sylvestre, 2002). If the primary role of negation were to point to things he ate instead, then it would be hard to see how negations could so readily license further inferences like these.

Unmitigated support for the narrow reading of *not* can appear surprising in light of some recent papers reporting evidence in favour of the search-for-alternatives view (Oaksford, 2002; Yama, 2001). However, we point out that much of this evidence is based on Wason's selection task, a reasoning problem that is, despite appearances, relatively complex (Noveck & O'Brien, 1996; Sperber, Cara, & Girotto, 1995), making it an unreliable source for uncovering immediate reactions to negations and the like. Moreover, as noted by Oaksford (2002), the explicit negations effect in the selection task observed in Evans et al. (1996) cannot really be explained by a search for alternatives account.

It could be argued that our findings—which show that participants' performance is quite accurate even though an increase in negations leads to lower rates of correct performance and slower reaction times—could be taken as global support of Oaksford and Stenning's (1992) claim that negations primarily add processing load via a search for contrast classes. This could be so. How does one then reconcile data showing support for a narrow reading of *not* with the overall data from our experiments which show that the inclusion of negations evidently prompts successful searches for alternatives while also prompting higher error rates?

[3]Words like *any* or *ever* only work in what are generally referred to as negative contexts. For example, one can say that *John does not have any money*, but one cannot say that *John has any money*.

We propose that the two accounts are compatible and here we describe how. In order to know what the speaker has in mind by saying *not-p*, one indeed needs to *first* know something about the object being negated: *p*. The initial reading of a negation will be narrow and in some scenarios this might be enough. For example, if a participant is required to evaluate *If there is an H then there is not a square* while looking for a falsifying instance of that rule, the square in the *H-in-a-square* item is as far as one need look. However, the interlocutor (a participant) can further process the negation, leading to an analysis of alternatives. If the above rule *If there is an H then there is not a square* were presented as part of a verification task, the participant would be justified in not only considering what the negated object is (the square), but to consider what cases would lead to verification (e.g., a circle or a star). A search for alternatives arises, but as part of a secondary effort to interpret the negation in the proposition.

Support for our two-step analysis of negation comes from the fact that it is known that contrast classes can be facilitated by manipulations that increase relevance, e.g., when using realistic materials (Oaksford & Stenning, 1992). It would make sense that more engagement in a task on the part of the participant leads to further efforts (e.g., searching for alternatives upon encountering a negation). We contend, however, that this sort of search arrives subsequent to an immediate denial of the proposition (as represented by the negation). It is hard to imagine how a listener would undertake a search for alternatives before knowing something about what is denied.

In summary, we began this endeavour by aiming to investigate two of Evans' well-known claims. The first concerns the matching *bias* and the effect it has on a basic conditional reasoning task. Our contribution has been to provide definitive data based on non-obfuscating cases, which show that matching strongly overlaps with higher rates of correct responses and faster reaction times. Our study supports the view that matching in reasoning is a perceptual phenomenon that highlights the relevance of cases when they match the rule. The obvious corollary is that *mismatching* implies that the cases not mentioned risk being deemed irrelevant. The second concerns Evans' claim that negation is (at least initially) viewed narrowly. This is less intuitive and less obvious and we found strong evidence in support of this claim as well. Thirty or so years after the first studies on the matching bias, the negations paradigm continues to provide innovation as well as data to corroborate Evans' claims.

Manuscript received 28 April 2005
Revised manuscript received 23 September 2005
First published online 1 May 2006

REFERENCES

Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. *Journal of Verbal Learning and Verbal Behavior*, *12*, 335–359.

Evans, J. S. B. T. (1972). Interpretation and matching bias in a reasoning task. *British Journal of Psychology*, *24*, 193–199.

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

Evans, J. S. B. T. (1998). Matching bias in conditional reasoning: Do we understand it after 25 years? *Thinking and Reasoning*, *4*, 45–110.

Evans, J. S. B. T., Clibbens, J., & Rood, B. (1996). The role of implicit and explicit negation in conditional reasoning bias. *Journal of Memory and Language*, *35*, 392–409.

Evans, J. S. B. T., Legrenzi, P., & Girotto, V. (1999). The influence of linguistic form on reasoning: The case of matching bias. *Quarterly Journal of Experimental Psychology*, *52*A, 185–216.

Evans, J. S. B. T., & Lynch, J. S. (1973). Matching bias in the selection task. *British Journal of Psychology*, *64*, 391–397.

Evans, J. S. B. T., & Newstead, S. E. (1977). Language and reasoning: A study of temporal factors. *Cognition*, *5*, 265–283.

Evans, J. S. B. T., & Over, D. E. (2004). *If*. Oxford: Oxford University Press.

Houde, O., Zago, L., Mellet, E., Moutier, S., Pineau, A., Mazoyer, B. et al. (2000). Shifting from the perceptual brain to the logical brain: The neural impact of cognitive inhibition training. *Journal of Cognitive Neuroscience*, *12*, 721–728.

Howell, D. C. (1997). *Statistical method for psychology*. Belmont, CA: Wadsworth.

Manktelow, R. I., & Evans, J. S. B. T. (1979). Facilitation of reasoning by realism: Effect or non-effect? *British Journal of Psychology*, *70*, 477–488.

Noveck, I. A., Chierchia, G., Chevaux, F., Guelminger, R., & Sylvestre, E. (2002). Linguistic-pragmatic factors in interpreting disjunctions. *Thinking and Reasoning*, *8*, 297–326.

Noveck, I. A., & O'Brien, D. P. (1996). To what extent do pragmatic reasoning schemas affect performance on Wason's selection task? *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *2*, 463–489.

Oaksford, M. R. (2002). Contrast classes and matching bias as explanations of the effects of negation on conditional reasoning. *Thinking and Reasoning*, *8*, 135–151.

Oaksford, M. R., & Stenning, K. (1992). Reasoning with conditionals containing negated constituents. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *18*, 835–851.

Ormerod, T. C., Manktelow, K. I., & Jones, G. V. (1993). Reasoning with three conditionals: Biases and mental models. *Quarterly Journal of Experimental Psychology*, *46*, 653–678.

Schroyens, W., Schaeken, W., Verschueren, N., & d'Ydewalle, G. (1999). Conditional reasoning with negations: Matching bias and implicit versus explicit affirmation or denial. *Psychologica Belgica*, *39*, 235–258.

Sperber, D., Cara, F., & Girotto, V. (1995). Relevance theory explains the selection task. *Cognition*, *57*, 31–95.

Wason, P. C. (1965). The contexts of plausible denials. *Journal of Verbal Learning and Verbal Behavior*, *4*, 7–11.

Yama, H. (2001). Matching versus optimal data selection in the Wason selection task. *Thinking and Reasoning*, *7*, 295–311.