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Published online: 28 Sep 2017.

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Inferences from disclosures about the truth and falsity of expert testimony

Sergio Moreno-Ríos [ID][a] and Ruth M. J. Byrne [ID][b]

[a]Departamento de Psicología Evolutiva y de la Educación, Facultad de Psicología, University of Granada, Granada, Spain; [b]School of Psychology and Institute of Neuroscience, Trinity College Dublin, University of Dublin, Dublin, Ireland

ABSTRACT
Participants acting as mock jurors made inferences about whether a person was a suspect in a murder based on an expert's testimony about the presence of objects at the crime scene and the disclosure that the testimony was true or false. Experiment 1 showed that participants made more correct inferences, and made inferences more quickly, when the truth or falsity of the expert's testimony was disclosed immediately after the testimony rather than when the disclosure was delayed. Experiment 2 showed no advantage for prior disclosure over immediate disclosure. Experiment 3 showed that the pattern of inferences when there was no disclosure mirrored the pattern when it was disclosed that the expert's testimony was true rather than false. Participants made more correct inferences from true conjunctions than disjunctions, and from false disjunctions than conjunctions. We discuss the implications for theories of the mental representations and cognitive processes that underlie human reasoning.

In the OJ Simpson 'trial of the century' in Los Angeles in 1994, a crucial piece of evidence was the presence of a blood-stained glove at the scene of the murder of Nicole Simpson and Ron Goldman, matching a glove found near OJ Simpson's home that same evening. Equally crucial to the case was the truth or falsity of the testimony provided by one of the Los Angeles detectives about finding the glove at the scene. At the start of the trial, the prosecutors believed they had watertight evidence to convict Simpson, but by the end, the jury acquitted him, following a complex and controversial trial during which the defence team argued that the detective's testimony was false and that the glove had not been found where he said. The District Attorney concluded at the press conference that 'apparently their decision was based on emotion, that overcame their reason' (Garcetti, 1995). But how accurately can

a jury reason about such matters, and in particular, about the inferential consequences of discredited expert testimony? Can people make correct inferences about the presence or absence of objects at the scene of a crime, and accordingly, about whether a person is or is not a suspect, based on a disclosure that an expert's testimony is false? We report three experiments that aim to answer these questions.

Jurors appear to try to construct a story from the evidence (e.g., Hastie, 1993; Pennington & Hastie, 1992) and they try to resolve inconsistencies by combining different strands of evidence into a coherent model (e.g., Holyoak & Simon, 1999). Their judgements are informed not only by what happened but also by thoughts about what could have happened differently (e.g., Branscombe, Owen, Garstka, & Coleman, 1996; Macrae, 1992). People make inferences with greater certainty when the information is based on assertions by experts (e.g., Stevenson & Over, 2001), but when they are told that a speaker is not telling the truth, they find it very difficult to reason accurately about the specific implications of their utterances (e.g., Byrne & Handley, 1997; Byrne, Handley, & Johnson-Laird, 1995). For example, their judgements that a suspect is guilty are reduced when eye-witness testimony is discredited, e.g., that the suspect was seen acting suspiciously outside a burgled house, even when there is other evidence that indicates the suspect's guilt, such as forensic evidence (Lagnado & Harvey, 2008; see also Kennedy & Haygood, 1992). Instructions to disregard some previous information do not eliminate its influence, which is affected by whether there is a reason for discarding it and what the reason is, and whether the warning is given before or after the information itself (e.g., Chambers & Zaragoza, 2001; Ecker, Lewandowsky, & Tang, 2010; Jou & Foreman, 2007; Kassin & Sommers, 1997; Schul, 1993). Little is known about how the discredited information is interpreted and what inferences are made from it.

In the three experiments we report, we asked participants to suppose that they were members of a jury, we gave them information about an expert's testimony about the presence of objects at the scene of the crime, such as that the expert testified that at the crime scene there was a glove and a stone, and we then informed them that the expert's testimony was true, or false. The participants were given a rule concerning the implications of the presence of an object at the scene, such as if, and only if, there was a glove, the person was a suspect. The expert's testimony referred to either a conjunction or a disjunction, it was described subsequently as either true or false, and the rule about declaring the person a suspect was expressed as a bi-conditional. Participants made inferences about the presence of objects at the scene, such as whether there was a glove, and inferences about the person as a suspect, such as whether the person was a suspect. Accordingly, the experiments examined four forms of inference, as Table 1 shows.

Table 1. Examples of the sorts of inferences examined in the three experiments.

	Conjunction		Disjunction	
Premises				
Expert's testimony	At the crime scene there is a glove and a stone *A and B*		At the crime scene there is a glove or a stone or both *A or B or both*	
Truth of testimony	The expert's testimony is true	The expert's testimony is false	The expert's testimony is true	The expert's testimony is false
	It is true that *A and B*	It is false that *A and B*	It is true that *A or B or both*	It is false that *A or B or both*
Rule	If and only if there is a glove, the person will be declared a suspect *If and only if A then C*			
Inferences				
According to this information, was there a glove? (A?) (1) yes, (2) no, (3) we cannot conclude .	Yes	We cannot conclude	We cannot conclude	No
	A (by conjunction elimination)	*Not-A or not-B (by DeMorgan's law)*	*A or B or both*	*Not-A and not-B (by DeMorgan's law)*
		No valid conclusion about A	*No valid conclusion about A*	*Therefore Not-A (by conjunction elimination)*
We can conclude the person (C) (1) is a suspect, (2) is not a suspect, (3) we cannot conclude.	Is a suspect	We cannot conclude	We cannot conclude	Is not a suspect
	Therefore C	*No valid conclusion about C*	*No valid conclusion about C*	*Therefore not-C*
	(by modus ponens)			*(by denial of the antecedent)*

The experiments we report examine participants' reasoning about complex pieces of information, such as compound assertions about the presence of objects, and conditional assertions about the consequences of evidence for judgements about a person. They are designed to isolate these inferences in an abridged situation, somewhat akin to a snapshot of the intermediate building blocks that might occur during a trial. In acknowledgment of the richness and complexity of information that is required to make an overall judgement of a person's guilt or innocence, the inferences instead focus on simpler judgements about the presence of objects, and about a person's status as a suspect. The goal is primarily to help to distinguish between alternative explanations about how people make inferences, although some of the results may also contribute to understanding reasoning in the applied domain of jurors' deliberation, notwithstanding the significant limitations to ecological validity that our experimentally controlled methods introduce.

Our primary aim in the three experiments is to examine the effects on inferences of disclosing the information that the expert's testimony is false at different junctures in an argument, for example, immediately after the

expert's assertion compared to delayed to some time after the expert's assertion (e.g., Lagnado & Harvey, 2008). The inferences require participants to reason about the truth and falsity of compound assertions, that is, to make inferences based on the negation of conjunctions and disjunctions. We first consider how people make inferences about the truth and falsity of conjunctions and disjunctions, and then we consider how disclosure of truth and falsity at different junctures in an argument may influence the process.

Reasoning about the truth and falsity of conjunctions and disjunctions

Reasoning about the falsity of an assertion depends on understanding negation. One of the main uses of negation is to deny, for example, to correct an erroneous belief, and so a speaker who utters, say, 'a pen is not a weapon' presupposes that the listener believes, 'a pen is a weapon' (e.g., Wason, 1965). Negation reverses the truth value of a sentence, for example, when 'there is a pen on the table' is true, its negation, 'there is not a pen on the table' is false (e.g., Khemlani, Orenes, & Johnson-Laird, 2012). Hence, negation can be considered equivalent to an assertion of falsity in many situations, for example, 'there is not a pen on the table' is equivalent to the assertion 'it is false that "there is a pen on the table"' (e.g., Khemlani et al., 2012). People have difficulty understanding negation. They find it easier to verify an affirmative assertion, e.g., 'The circle is above the triangle' compared to a negative one, e.g., 'The circle is not above the triangle'. They find true affirmatives (in which a picture corresponds to the assertion) easier to verify than false ones (in which the picture does not correspond to the assertion); but they find false negatives easier to verify than true ones (e.g., Wason & Jones, 1963; see also Kaup, Yaxley, Madden, Zwaan, & Ludtke, 2007). People appear to try to mentally simulate the situation depicted by a negative assertion, such as 'the figure is not red' (e.g., Orenes, Beltrán, & Santamaría, 2014). Their mental simulation may rely on alternates, such as a green figure, but experimental results indicate that it can contain symbols, such as 'not'. As a result, when they are told 'the figure is not red' in the context of red or green figures, they look at the green figure, but when they are told 'the figure is not red' in the context of red or green or blue or yellow figures, they look at the red figure (e.g., Orenes et al., 2014).

Negation of conjunctions and disjunctions

A conjunction, such as 'there is a glove and a stone', is consistent with a single situation in which the two elements co-occur – there is a glove and a stone. Its falsity is consistent with the complement set, that is, the assertion 'it is false that there is a glove and a stone' is consistent with the three situations in which one or other of the two elements occurs – there is a glove and no

Table 2. The set of situations consistent with true and false conjunctions and inclusive disjunctions.

	Conjunction: A and B	Disjunction: A or B or both
True	A and B	A and B A and not-B Not-A and B
False	Not-A and not-B A and not-B Not-A and B	Not-A and not-B

stone, or there is no glove but there is a stone – or neither occurs – there is no glove and no stone (e.g., Jeffrey, 1981), as Table 2 shows. An inclusive disjunction of two elements, e.g., 'there is a pen or a book or both', is consistent with three situations, in which one or other of the two elements occurs – there is a pen and no book, or there is no pen but there is a book – or both occur – there is a pen and a book. Its falsity, i.e., 'it is false that there is a pen or a book or both' is consistent with a single situation in which neither element occurs – there is no pen and no book (see Table 2).

People have considerable difficulty in making inferences from negated conjunctions and negated disjunctions. When they are given a negated disjunction such as 'It is false that there is a postcard or there is a drawing on the noticeboard or both' and they are asked to say what follows, they make the correct inference 'there is no postcard and no drawing' on only 43% of trials (e.g., Byrne & Handley, 1992). And they have even greater difficulty when they are given a negated conjunction such as 'It is false that there is a postcard and there is a drawing on the noticeboard' (only 25% correct inferences, Byrne & Handley, 1992). Their difficulty appears to arise from misinterpreting the scope of the negation, interpreting it to have a small scope applicable to each element, rather than a wide scope applicable to the utterance as a whole (e.g., Johnson-Laird & Byrne, 1991). Hence, they mistakenly infer that 'it is false that there is a postcard and a drawing' means that 'there is no postcard and there is no drawing'. They conjoin the negation of the mentioned elements in a process of 'enumerative negation' (e.g., Khemlani et al., 2012; see also Macbeth, Razumiejczyk, Crivello, Fioramonti, & Girardi, 2013). The difficulties people experience in understanding the negation of conjunctions and disjunctions occur also for the negation of other compound assertions such as the negation of conditionals (e.g., Barres & Johnson-Laird, 2003; Espino & Byrne, 2012; Handley, Evans, & Thompson, 2006). More generally, people experience difficulties in working out the relations between different compound assertions, such as the relation between conditionals and disjunctions (e.g., Espino & Byrne, 2013; Oberauer, Geiger, & Fischer, 2011).

One putative explanation of their difficulties is that people understand and reason about the truth and falsity of conjunctions and disjunctions by

envisaging alternative possibilities (e.g., Johnson-Laird & Byrne 2002). A conjunction such as 'A and B' requires people to think about a single possibility:

<div align="center">

A   B

</div>

whereas an inclusive disjunction, 'A or B or both' requires them to think about multiple possibilities:

<div align="center">

A   Not-B
Not-A   B
A   B

</div>

where each line in the diagram corresponds to a different possibility (e.g., Johnson-Laird & Byrne, 1991; Johnson-Laird, Lotstein, & Byrne, 2012). The possibilities may be represented in an initial set of mental models that makes some information explicit, corresponding to the elements mentioned in the assertion, but leaves other information implicit, e.g.,

<div align="center">

A   B
A   B

</div>

Because conjunctions require people to envisage a single possibility and disjunctions require them to envisage multiple possibilities, it is easier to reason about true conjunctions than disjunctions (e.g., García-Madruga, Moreno, Carriedo, Gutierrez, & Johnson-Laird, 2001; Johnson-Laird, Byrne, & Schaeken, 1992). In contrast, the negation of a conjunction 'it is false that A and B' requires people to envisage multiple possibilities by constructing the complement set,

<div align="center">

Not-A   Not-B
A   Not-B
Not-A   B

</div>

whereas the negation of a disjunction 'it is false that A or B or both' requires them to envisage a single possibility,

<div align="center">

Not-A   Not-B

</div>

as shown in Table 3. Hence, it is easier to reason about false disjunctions than false conjunctions (e.g., Byrne & Handley, 1992).

There are surprisingly few alternative theories of how people reason about the negation of conjunctions and disjunctions. Probabilistic accounts of how

Table 3. Initial and explicit mental models for true and false conjunctions and disjunctions (after Johnson-Laird & Byrne, 2002).

Connective	A and B		A or B or both	
Truth	True	False	True	False
Initial models	A B	Not-A Not-B	A B A B	Not-A Not-B
Explicit models	A B	Not-A Not-B A not-B Not-A B	A not-B Not-A B A B	Not-A Not-B

people reason about the negation of compound assertions have focused on the negation of conditionals (e.g., Handley et al., 2006; Pfeifer, 2012); such accounts have not been applied to the negation of disjunctions or conjunctions. One of the few accounts of reasoning about the negation of conjunctions and disjunctions is the formal rules of inference view, according to which people have a mental repertoire of inference rules that they access to construct derivations or proofs of conclusions (e.g., Rips, 1994; see also Braine & O'Brien, 1998). The mental logic contains rules for reasoning from negated conjunctions and negated disjunctions, for example, elementary rules corresponding to the propositional calculus's 'De Morgan's laws' (e.g., Jeffrey, 1981). According to these logical laws, the negation of a conjunction of two elements,

not (p and q)

is equivalent to the disjunction of the negation of each element,

not (p and q) = (not p) or (not q).

Similarly, the negation of a disjunction of two elements,

not (p or q)

is equivalent to the conjunction of the negation of each of them,

not (p or q) = (not p) and (not q).

Such views of the cognitive processes that underlie reasoning about the negation of assertions lead to different predictions. One account that incorporates such rules predicts that people can readily make accurate inferences from a negated conjunction or a negated disjunction because their mental logic contains elementary rules that correspond to these inferences, and accordingly their mental derivation consists of just one or two steps (e.g., Rips, 1994). The experimental evidence that people make more accurate inferences from a negated disjunction compared to a negated conjunction pose difficulties for such accounts (e.g., Khemlani et al., 2012).

Truth and falsity of expert's testimony

What sorts of alternative possibilities might people consider when they think about the truth or falsity of an expert's testimony that conveys a conjunction or a disjunction? The initial and fully explicit models for each of the four problems that we examine in the experiments are outlined in Table 4, as well as the errors predicted on the view that people make inferences by envisaging possibilities. We illustrate the processes for the two inferences based on conjunctions. For the first inference,

Table 4. The initial and explicit models for the four sorts of inferences examined in the three experiments and the predicted responses.

Expert testimony	Truth of testimony	Rule	Inference about person	Inference about object
A and B	True: A and B	If and only if A C	C?	A?
Initial models A B	Initial models A B	Initial models A B C	Initial Yes by MP	Initial Yes
		Explicit models A B C Not-A Not-C	Explicit Yes	Explicit Yes
A and B	False: A and B	If and only if A C	C?	A?
Initial models A B	Initial models Not-A Not-B	Initial models Not-A Not-B Not-C	Initial No by DA	Initial No
	Explicit models Not-A Not-B Not-A B A Not-B	Explicit models Not-A Not-B Not-C Not-A B Not-C A Not-B C	Explicit NVC	Explicit NVC
A or B or both	True: A or B or both	If and only if A C	C?	A?

Initial models
A   B
A
        B
	Initial models
	A B
	A
	        B
		Initial models
		A B C
		A C
		        B
			Initial
			Yes by MP
				Initial
				Yes

Explicit models A B A Not-B Not-A B	Explicit models A B A Not-B Not-A B	Explicit models A B C A not-B C Not-A B not-C	Explicit NVC	Explicit NVC
A or B or both	False: A or B or both	If and only if A C	C?	A?
Initial models A B A B	Initial models Not-A not-B	Initial models Not-A Not-B Not-C	Initial No by DA	Initial No
Explicit models A B A Not-B Not-A B			Explicit No	Explicit No

Expert's testimony: 'At the crime scene there is a glove and a stone'.	*(A and B).*
The expert's testimony is true.	*(It is true that A and B).*
Rule: If and only if there is a glove, the person will be declared a suspect.	*(If and only if A then C).*

the correct conclusion is 'the person will be declared a suspect' (C), as outlined earlier in Table 1. Participants will envisage a possibility for the conjunction,

A	B

and they will add the information from the bi-conditional to it,

A	B	C

They can draw the conclusion 'C' from this possibility, and the inference is the simplest one, as Table 4 illustrates. For the second inference,

Expert's testimony: 'At the crime scene there is a glove and a stone'.	(A and B).
The expert's testimony is false.	(It is false that A and B).
Rule: If and only if there is a glove, the person will be declared a suspect.	(If and only if A then C).

the correct conclusion is that no inference can be made about whether or not the person will be declared a suspect, as shown in Table 1. The inference is based on the falsity of the conjunction. Participants will envisage a possibility for the conjunction,

A	B

The information that the testimony is false will lead them to attempt to negate the conjunction. They may initially think about only a single possibility, corresponding to an enumerative negation strategy of negating each element (e.g., Khemlani et al., 2012),

Not-A	Not-B

If so, they will add the information from the bi-conditional to this possibility,

Not-A	Not-B	Not-C

and make the error of concluding 'the person is not declared a suspect' (not-C). Alternatively, when they attempt to negate the conjunction, they may construct the fully explicit models:

Not-A	Not-B
A	Not-B
Not-A	B

If so, they will add the information from the bi-conditional to these possibilities,

Not-A	Not-B	Not-C
A	Not-B	C
Not-A	B	Not-C

and they will reach the correct conclusion that no valid conclusion about C can be made, since in some models 'not-C' is the case, and in some 'C' is the case.

Accordingly, if people make inferences by thinking about possibilities, they will find it easier to make inferences from expert testimony that is true when it contains a conjunction rather than a disjunction, because the true conjunction requires them to think about fewer possibilities than the true disjunction, whereas they will find it easier to make inferences from expert testimony that is false when it contains a disjunction rather than a conjunction, because the false disjunction requires them to think about fewer possibilities than the false conjunction. Moreover, they will make specific errors, such as mistakenly concluding that 'the person is not declared a suspect' when it is disclosed that an expert's testimony of a conjunction is false, and mistakenly concluding that 'the person is declared a suspect' when it is disclosed that an expert's testimony of a disjunction is true, as Table 4 outlines. In contrast, the explanation of reasoning based on formal rules of inference outlined earlier predicts no differences in the accuracy of inferences from a negated conjunction or a negated disjunction.

Disclosure of information about truth and falsity

In a trial, an expert who presents testimony may subsequently be challenged and revealed to have made false assertions. We address three key questions. First, what is the effect of delaying the provision of a disclosure that an expert's testimony is false? Second, is there any advantage to prior disclosure that an expert's testimony is false before the expert presents their testimony? Third, do participants tend to assume at the outset that an expert's testimony is true, or do they tend to assume it is false, compared to matched situations in which there is no information about its truth or falsity?

In the first experiment, we examined an 'immediate' disclosure, i.e.,

Expert's testimony: 'At the crime scene there is a glove and a stone'.
The expert's testimony is false.
Rule: If and only if there is a glove, the person will be declared a suspect.

And compared it to a 'delayed' one:

Expert's testimony: 'At the crime scene there is a glove and a stone'.
Rule: If and only if there is a glove, the person will be declared a suspect.
The expert's testimony is false.

Participants' judgements that a suspect is guilty are reduced when eye-witness testimony is discredited after other evidence such as forensic evidence has been introduced, but not when it is discredited immediately after the testimony is described (Lagnado & Harvey, 2008). The order effect may arise because participants combine the eye-witness testimony and forensic evidence in a coherent model in the former case, whereas in the latter, the early discrediting information disrupts the combination of information

(e.g., Lagnado & Harvey, 2008; see also Holyoak & Simon, 1999). Our interest is in how the provision of information that an expert's testimony is false either immediately after the expert's testimony, or delayed until after the rule about declaring the person a suspect, affects the inferences they make. In the immediate disclosure situation, when a participant is provided with the expert's testimony,

Expert's testimony: 'At the crime scene there is a glove and a stone'. *(A and B).*

their first step will be to envisage the possibility corresponding to it,

A   B

When they are provided with the immediate disclosure that the expert's testimony is false,

The expert's testimony is false.   *(It is false that A and B).*

their second step will be to try to negate the conjunction, perhaps by thinking initially about a single possibility,

Not-A   Not-B

They may take the additional step of interrogating their understanding of the falsity of the expert's testimony further to consider alternative possibilities that are consistent with it,

Not-A   Not-B
A   Not-B
Not-A   B

If so, when they are provided with the rule,

Rule: If and only if there is a glove, the person will
be declared a suspect.
                                         *(If and only if A
                                            then C).*

they will combine the information from the bi-conditional rule in fully explicit models:

Not-A   Not-B   Not-C
A   Not-B   C
Not-A   B   Not-C

When the information that the expert's testimony is false is provided immediately after the testimony, participants may be able to take the additional step of considering alternative possibilities consistent with the negation of the expert's statement, and thus they may be able to make an accurate inference,

that no valid conclusion can be reached about whether the person is declared a suspect. In contrast, in delayed disclosure situations, when a participant is provided with the expert's testimony,

Expert's testimony: 'At the crime scene there is a glove and a stone'. *(A and B)*.

their first step will be to envisage the possibility corresponding to it,

A   B

They are then provided with the rule,

Rule: If and only if there is a glove, the person will   *(If and only if A*
be declared a suspect.   *then C)*.

and their second step will be to add the information from the bi-conditional rule to their representation,

A   B   C

When they are then provided with the delayed disclosure that the expert's testimony is false,

The expert's testimony is false.   *(It is false that A and B)*.

they need to retrace their steps. The cognitive effort of attempting to do so may result in them thinking only about a single possibility in their attempts to negate the earlier information,

Not-A   Not-B   Not-C

and hence they will be more inclined to make errors, and to conclude that the person is not declared a suspect. Accordingly, if participants envisage possibilities, they will make fewer accurate inferences and take longer to make inferences when disclosures are delayed rather than immediate.

The second question we address is, is there any advantage to prior disclosure that an expert's testimony is false? Warnings about misinformation are more effective when they are presented before rather than after participants have heard the misinformation, even if it takes them longer to process (e.g., Chambers & Zaragoza, 2001; Ecker et al., 2010; Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012; Schul, 1993). In the second experiment, we compared the immediate disclosure version described earlier, to a prior disclosure one:

The expert's testimony is false.
Expert's testimony: 'At the crime scene there is a glove and a stone'.
Rule: If and only if there is a glove, the person will be declared a suspect.

In some trials, jurors may be primed to believe that what an expert will say is false. Does prior disclosure confer an advantage for inferential accuracy and speed? We expect, not, if people envisage possibilities. When the disclosure is made close to the testimony, whether immediately after it or immediately before it, an accurate inference can be made from the testimony, for example, based on negating the conjunction or disjunction, and that conclusion can be used as a basis for the subsequent inference after incorporating the information from the bi-conditional rule. We speculate that an alternative prediction may follow from the view of reasoning that people rely on their prior beliefs to compute the probabilities of various suppositions (e.g., Evans & Over, 2004; Oaksford & Chater, 2007). This Bayesian account has not been extended to explain the sorts of deductions we examine here based on information about the falsity of a conjunction or disjunction and the inferences that can be made from such assertions in relation to a bi-conditional rule. However, we conjecture that a potential implication of this view is that the provision of prior information that the expert's testimony is true or false may confer some advantage, since it facilitates a calculation of prior probabilities and degrees of belief in the statements from the outset. Hence, a tentative suggestion is that it may enable more accurate or faster inferences compared to subsequent disclosures.

The third question we address is whether participants tend to assume at the outset that an expert's testimony is true, or whether they tend to assume it is false, compared to matched situations in which there is no disclosure about its truth or falsity. Given the general linguistic conventions that govern communication, such as assumptions of truth and relevance (e.g., Grice, 1975; Sperber & Wilson, 1986), and the principle of truth incorporated in the model theory (e.g., Johnson-Laird & Byrne, 2002), we expect the former. Hence, we predict that the pattern of inferences that people make when they are given no disclosure about the truth or falsity of the expert's testimony will mirror the pattern of inferences they make when they are told that the expert's testimony is true, rather than the pattern of inferences they make when they are told that it is false. In sum, our aim is to examine whether disclosing the information that the expert's testimony is true or false at different junctures in a series of premises has an effect on the accuracy and latency of the inferences that participants make.

Experiment 1: immediate and delayed disclosure

The aim of the experiment was to examine the accuracy and latency of inferences when it is immediately disclosed that an expert's testimony is true or false, compared to when the disclosure of truth or falsity is delayed. Participants were given 'immediate' information, e.g.,

Expert's testimony: 'At the crime scene there is a glove and a stone'.
The expert's testimony is false.
Rule: If and only if there is a glove, the person will be declared a suspect.
We can conclude that the person:
(1) is a suspect (2) is not a suspect (3) we cannot conclude.

Or else they were given 'delayed' information, e.g.,

Expert's testimony: 'At the crime scene there is a glove and a stone'.
Rule: If and only if there is a glove, the person will be declared a suspect.
The expert's testimony is false.
We can conclude that the person:
(1) is a suspect (2) is not a suspect (3) we cannot conclude.

We expect that they will make the inference more accurately and more quickly for the immediate than the delayed disclosure.

Method

Participants

The participants were 60 volunteers from Granada University, Spain. There were 49 women and 11 men aged between 19 and 27 years, with an average age of 19 years. The participants were students in second year developmental psychology who had no training in logic.

Materials and design

Each problem consisted of three premises. The first premise was an assertion by an expert witness about the presence of two objects at the crime scene, in the form of a conjunction (A and B), or an inclusive disjunction (A or B or both), e.g., 'at the crime scene there is a pencil or a bag or both'. The second premise (in the immediate condition) was about the truth or falsity of the expert's assertion, e.g., 'The expert's testimony is true'. The third premise was a rule about the consequence of the presence or absence of the object for judging a person to be a suspect, in the form of a bi-conditional (if and only if A then C), e.g., 'if and only if there is a pencil, the person will be declared a suspect'. The task was to make an inference about whether a conclusion could be drawn about C, e.g., 'we can conclude that the person (1) is a suspect, (2) is not a suspect, (3) we cannot conclude'.[1]

We constructed eight distinct forms of problems by varying whether the expert's statement contained a conjunction or disjunction, whether the expert's statement was said to be true or false, and whether the disclosure of

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[1]We included an inference about the object at the end after participants had completed the inference about the person, in both versions; however, due to an administrative error, the wording of the inference was ambiguous and it did not contain the response option 'we cannot conclude'. We eliminated it prior to any data analysis and we return to inferences about the object in the next experiments.

information about the truth of the expert's statement was immediate, just after the expert's statement (i.e., as premise 2), or delayed to after the bi-conditional rule (i.e., as premise 3). The design was thus a 2 (disclosure: immediate vs. delayed disclosure of truth information) × 2 (testimony: conjunction vs. disjunction) × 2 (truth of testimony: true or false) within-participant design. As a control to ensure a systematic distribution of yes and no responses, we ensured that half of the problems contained a bi-conditional with an affirmative antecedent, e.g., 'if and only if there is a pencil the person will be declared a suspect' and the other half contained a bi-conditional with a negative antecedent, e.g., 'if and only if there is not a pencil the person will be declared a suspect'. Also, for half of the trials, the object mentioned in the bi-conditional corresponded to the first mentioned object in the conjunction or disjunction, and for the other half it corresponded to the second mentioned object. Participants completed four instances of each of the eight problems. We assigned 32 pairs of common objects at random to the 8 problems to create 32 different contents (see the Appendix for the list of 32 pairs of objects).

Procedure

The materials were presented using E-Prime v2.0 (Psychology Software Tools, Inc.) running on a PC. Participants were given instructions about the task with two practice trials. Each participant was instructed to imagine that he or she was a member of a jury evaluating a report from a scene in which a crime (a murder) had been committed. Their task was to decide whether or not a person is a suspect for the crime; they were told they did not have to decide whether or not the person is guilty. They were asked to consider an expert's testimony and they were given an example that referred to a single object, 'there is a glove at the crime scene'. They were told that they must apply a rule, e.g., 'if and only if there is a glove at the crime scene, the person will be declared a suspect'. They were also told that they would be informed about whether the expert's testimony is true or false, and that in cases when they were told the expert's testimony is false, what happened was exactly the opposite of what the expert said and so even in such cases, they would be able to obtain information from the testimony. As an example, they were told that when the expert says 'there is a calendar' and the expert's testimony is false, that means 'there is not a calendar', and hence, following the rule, 'if and only if there is a calendar at the crime scene, the person will be declared a suspect', it can be concluded that the person is not a suspect.

The premises and inferential tasks in the experiment were presented on a computer screen and they appeared one sentence at a time when the participant pressed the space bar, and each new sentence replaced the previous sentence. Participants responded to the inference about whether the person was judged to be a suspect by pressing one of three response keys (1, 2 and

3 respectively) corresponding to the conclusion (1) is a suspect, (2) is not a suspect and (3) we cannot conclude. The sentences were shown in the centre of the screen, in black font on a white background. The testimony given by the expert and the assertion of its truth or falsity were displayed against a red background. Participants were informed that the accuracy of their inferences and the time it took for them to make their inferences would be recorded.

Results and discussion

The data are available at https://reasoningandimagination.wordpress.com/data-archive/ for all three experiments.

Inferences about the person

A 2 (disclosure: immediate vs. delayed) $\times$ 2 (connective: conjunction vs. disjunction) $\times$ 2 (truth of testimony: true vs. false) repeated measures ANOVA on the correct conclusions about the person showed that participants made more correct inferences following the immediate disclosure of truth or falsity compared to delayed disclosure, $F(1,59) = 14.75, p < .001, \eta p^2 = .20$, disclosure did not interact with connective, or truth, $F < 1$ in both cases, and the three variables did not interact, $F(1,59) = 1, p > .30$.

Participants made more correct inferences when the assertions were true than when they were false, $F(1,59) = 27.92, p < .001, \eta p^2 = .32$, they made as many correct inferences from conjunctions and disjunctions overall, $F(1,59) = 1.78, p > .10$, but the two variables interacted, $F(1,59) = 164.42, p < .001, \eta p^2 = .74$. Contrasts to decompose the interaction showed that participants made more correct inferences from conjunctions than disjunctions for true assertions, $F(1,59) = 109.52, p < .001, \eta p^2 = .65$, whereas they made more correct inferences from disjunctions than conjunctions for false assertions, $F(1,59) = 169.44, p < .001, \eta p^2 = .74$, as Figure 1 shows.

The most frequent response for the true conjunctions was the predicted correct response of 'C' (89% immediate, 81% delayed), and the most frequent response for the true disjunctions was the predicted error of C (60% immediate and delayed), as Table 5 shows. The most frequent response for the false conjunctions was the predicted error of not-C (85% immediate and 83% delayed), and the most frequent response for the false disjunction was the predicted correct response of not-C (72% immediate and 67% delayed). We note that even though participants made more correct inferences following the immediate disclosure of truth or falsity compared to delayed disclosure, the pattern of their most frequent errors is similar in both conditions.

An alternative explanation for the results is that they arise not from reasoning difficulties but from memory difficulties. For example, when the disclosure is delayed, participants may have forgotten the precise testimony and so they adopt a cautious strategy of responding 'we cannot conclude'. We can rule
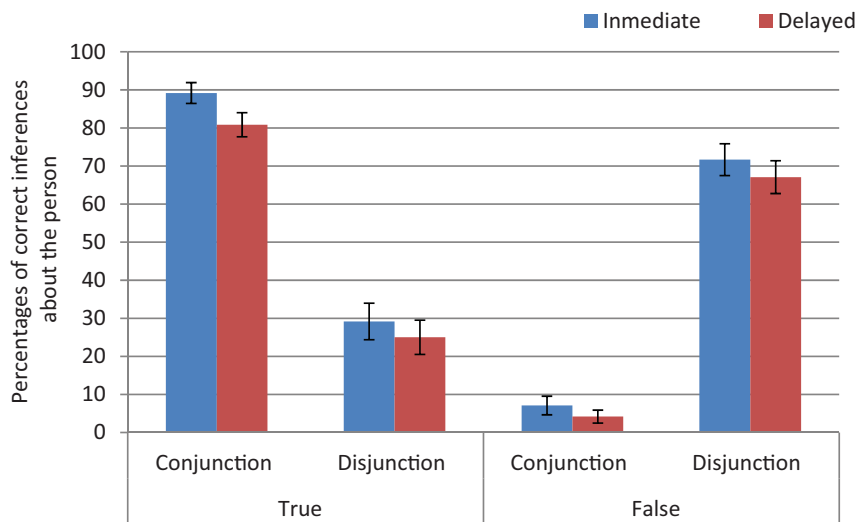
Figure 1. The percentages of correct inferences about the person in Experiment 1. Error bars are standard error of the mean.

out the idea that the effect is merely a memory one because there is no significant change in the 'we cannot conclude' response from immediate to delayed disclosure, 12.5% vs. 12% overall, $F < 1$, as Table 5 shows. We also note that although the differences between immediate and delayed disclosure in Figure 1 appear to occur for the easiest inferences rather than the

Table 5. The percentage of different inferences made about the person as a suspect in Experiments 1, 2 and 3. Correct inferences are in bold (standard deviations are in parentheses).

Inference		Yes	No	Cannot conclude	Yes	No	Cannot conclude
Experiment 1			**Immediate**			**Delayed**	
True	Conjunction	**89**(21)	8(16)	0(0)	**81**(25)	13(19)	0(0)
	Disjunction	60(37)	11(19)	**29**(37)	60(35)	15(19)	**25**(35)
False	Conjunction	8(16)	**85**(26)	7(19)	13(21)	**83**(24)	4(13)
	Disjunction	15(22)	**72**(32)	14(25)	15(24)	**67**(33)	18(31)
Experiment 2			**Immediate**			**Prior**	
True	Conjunction	**78**(25)	14(17)	8(17)	**77**(25)	15(21)	8(15)
	Disjunction	40(41)	9(17)	**51**(42)	43(39)	9(16)	**48**(41)
False	Conjunction	11(17)	**79**(29)	10(23)	15(21)	**73**(28)	12(22)
	Disjunction	10(16)	**64**(34)	27(35)	10(16)	**65**(34)	24(31)
Experiment 3			**Immediate (before-object)**			**Immediate (after-object)**	
True	Conjunction	**84**(24)	7(13)	9(21)	**79**(26)	10(19)	10(23)
	Disjunction	40(38)	8(17)	**52**(42)	42(39)	5(10)	**53**(42)
False	Conjunction	14(18)	**79**(24)	7(17)	15(17)	**78**(26)	7(19)
	Disjunction	11(18)	**61**(32)	28(34)	8(16)	**64**(35)	27(32)

more difficult inferences, there is no interaction between disclosure and connective, or between disclosure, connective and truth.

Latencies for inferences about the person

An ANOVA of the same design on the logarithmically transformed latencies to respond to the inference about the person showed that participants responded more quickly in the immediate disclosure condition than the delayed one, 1908 ms vs. 2150 ms, $F(1,59) = 11.29$, $p < .001$, $\eta p^2 = .16$, disclosure did not interact with either connective or truth, $F < 1$ in both cases, and the three variables did not interact, $F(1,59) = 2.03$, $p > .10$. There were no differences in time to respond to the inference question for conjunctions and disjunctions, or true or false assertions, $F < 1$ in both cases, and the two variables did not interact reliably, $F(1,59) = 3.25$, $p = .08$, as Figure 2 shows.

The analysis of latencies combines correct and incorrect responses because the high number of errors in some conditions results in insufficient data points to warrant an analysis of the latencies for the correct responses only. However, since latencies for correct and incorrect responses may reflect different inferential processes, we carried out a second analysis on the correct responses only, restricted to those conditions in which there were more than 60% correct responses: the true conjunction and false disjunction conditions. Although such an analysis must be viewed with caution because it is based on few data points, we note that the 2 (disclosure: immediate vs. delayed) ×
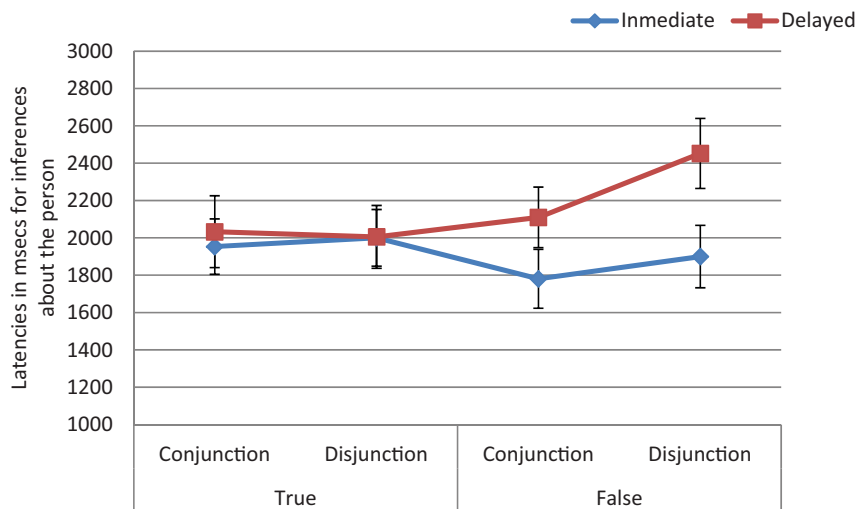
Figure 2. Latencies in milliseconds to respond to the inference question about the person in Experiment 1. Error bars are standard error of the mean.

2 (connective: true conjunction vs. false disjunction) ANOVA on the latencies to the correct responses showed the same results as the overall latencies analysis. Participants responded more quickly in the immediate disclosure condition than the delayed one, 1134 ms vs. 2008 ms, $F(1,52) = 4.45$, $p < .05$, $\eta p^2 = .08$; there was no effect of connective, and no interaction, $F < 1$. We note that the latency results are consistent with the accuracy ones in showing that people find it easier to reason following an immediate disclosure rather than a delayed disclosure, and their coherence suggests that there is no trade-off between accuracy and latency.

The results show that participants made more correct inferences, and they made the inferences more quickly, when the truth or falsity of the expert's testimony was disclosed immediately rather than delayed. The results are consistent with the suggestion that participants envisage alternative possibilities, in an attempt to construct a consistent and parsimonious model (see also Holyoak & Simon, 1999). The results are also consistent with the finding that judgements of guilt are more accurate when eye-witness testimony is discredited immediately rather than after it has been combined with other evidence such as forensic evidence (Lagnado & Harvey, 2008). The results also show that participants made more correct inferences from true conjunctions than disjunctions but more correct inferences from false disjunctions than conjunctions, consistent with previous research (e.g., Byrne & Handley, 1992; Khemlani et al., 2012). They made the predicted errors for true disjunctions and false conjunctions and these patterns occurred in both the immediate and delayed conditions. The results are consistent with the idea that participants attempt to envisage alternative possibilities when they make inferences from the truth or falsity of an expert's testimony that contains a conjunction or disjunction. Their errors may reflect difficulties in establishing the scope of the negation, and in particular in the pragmatic context of information about false testimony, they may interpret the information about the falsity of the expert's assertion to apply specifically to the critical conjunct under scrutiny, e.g., the glove, rather than to the conjunction as a whole. The results go against the idea that they have ready access to elementary inferential rules such as De Morgan's laws to guide inferences from negated conjunctions and negated disjunctions (cf Rips, 1994). The next experiment compares immediate disclosure to prior disclosure about the truth or falsity of the expert's testimony.

Experiment 2: immediate versus prior disclosure

The aim of the experiment was to examine the accuracy and latency of inferences when it is immediately disclosed that an expert's testimony is true or false compared to *prior* disclosure that the expert's testimony is true or false.

The immediate condition was the same as the previous experiment, in which the disclosure occurs immediately after the expert's assertion,

> Expert's testimony: 'At the crime scene there is a glove and a stone'.
> The expert's testimony is false.

It was compared to a disclosure provided prior to the expert's testimony, e.g.,

> The expert's testimony is false.
> Expert's testimony: 'At the crime scene there is a glove and a stone'.

We also included explicitly an intermediate inference about the presence of the object, after the expert's testimony about the presence of objects and the information about its truth or falsity, as an aid to participants, e.g.,

> Expert's testimony: 'At the crime scene there is a glove and a stone'.
> The expert's testimony is false.
> According to this information, was there a glove?
> *(a) yes, (b) no, (c) we cannot conclude.*
> Rule: If and only if there is a glove, the person will be declared a suspect.
> *We can conclude that the person:*
> *(1) is a suspect (2) is not a suspect (3) we cannot conclude.*

Method

Participants

The participants were a new set of 60 volunteers from Granada University, Spain who had not participated in the previous experiment. There were 47 women and 13 men aged between 18 and 43 years, with an average age of 20 years. The participants were students in second year developmental psychology who had no training in logic.

Materials, design and procedure

The materials were the same as the previous experiment except for two changes: the disclosure about the truth or falsity of the expert's testimony occurred immediately after the testimony as in the previous experiment in one condition, and in the other condition it occurred prior to the expert's testimony. We also included an explicit intermediate inference about the object, e.g., 'according to this information, was there a glove? (a) yes, (b) no, (c) we cannot conclude'. For half of the trials, the object was the first mentioned object in the conjunction or disjunction (A), and for the other half, it was the second mentioned object (B) and accordingly, the object mentioned in the bi-conditional was the first or second mentioned object. Participants completed 32 problems in a similar design to the previous experiment, a 2 (disclosure: immediate vs. prior) × 2 (testimony: conjunction vs. disjunction) × 2

(truth of testimony: true or false) within-participant design. The procedure was the same as the previous experiment.

Results and discussion

Inferences about the person

A 2 (disclosure: immediate vs. prior) × 2 (connective: conjunction vs. disjunction) × 2 (truth of testimony: true vs. false) repeated measures ANOVA on the correct conclusions about the person as a suspect showed that there was no difference in the frequency of correct inferences when the disclosure of the truth or falsity of the expert's testimony was immediate or prior, $F < 1$, disclosure did not interact with connective, $F < 1$, or truth, $F(1,59) = 1.15$, $p > .29$, and the three variables did not interact, $F < 1$.

Once again, participants made more correct inferences when the assertions were true than when they were false, $F(1,59) = 44.57$, $p < .001$, $\eta p^2 = .43$, they made more correct inferences from conjunctions than disjunctions, $F(1,59) = 26.17$, $p < .001$, $\eta p^2 = .31$, and the two variables interacted, $F(1,59) = 69.93$, $p < .001$, $\eta p^2 = .54$. Contrasts to decompose the interaction showed that participants made more correct inferences from conjunctions than disjunctions for true assertions, $F(1,59) = 24.16$, $p < .001$, $\eta p^2 = .29$; but more correct inferences from disjunctions than conjunctions for false assertions, $F(1,59) = 102.50$, $p < .001$, $\eta p^2 = .64$, replicating the results of the first experiment, as Figure 3 shows.
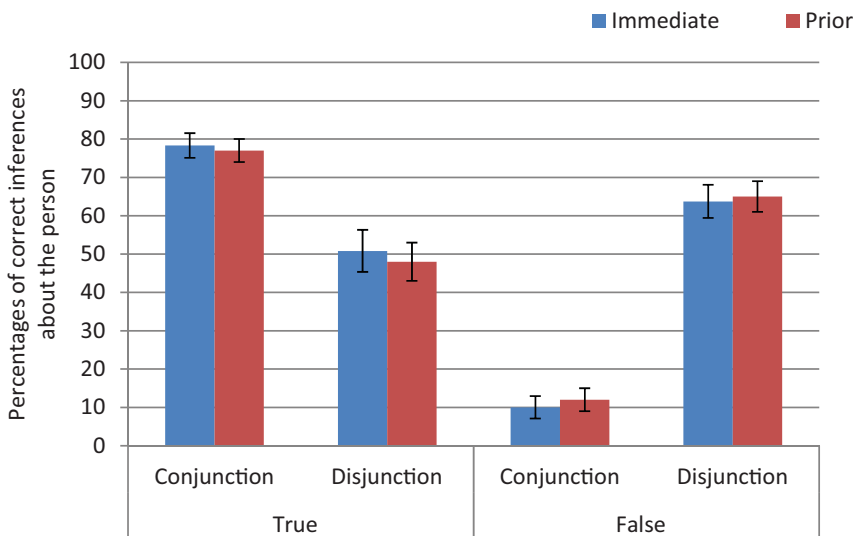
Figure 3. The percentages of correct inferences about the person in Experiment 2. Error bars are standard error of the mean.

The most frequent response for the inferences about the person for the true conjunctions was the predicted correct response of 'C' (78% immediate, 77% prior); the most frequent response for the true disjunctions was the correct response that we cannot conclude (51% immediate and 48% prior) and the next most frequent response was the predicted error of C (40% immediate and 43% prior). The most frequent response for the false conjunctions was the predicted error of not-C (79% immediate and 73% prior), and the most frequent response for the false disjunction was the predicted correct response of not-C (64% immediate and 65% prior).

Latencies for inferences about the person

An ANOVA of the same design on the logarithmically transformed latencies to respond to the inference showed there were no differences in the latencies to respond in the immediate and prior conditions, $F < 1$, and there were no differences overall for connective, $F(1,59) = 1.20, p > .20$. Participants responded faster on false trials than true ones in this experiment, 1544 ms vs. 1723 ms, $F(1,59) = 5.39, p < .05, \eta p^2 = .08$, and although inspection of Figure 3 suggests that the effect occurs primarily in the prior condition, order did not interact with truth, or connective, $F < 1$ in both cases, connective and truth did not interact, $F(1,59) = 1.88, p > .10$, and nor did the three variables $F < 1$, as Figure 4 shows.

An analysis of the latencies to make a correct response in those conditions with more than 60% correct responses (the true conjunction and false disjunction conditions) showed the same results. The 2 (disclosure: immediate vs. delayed) × 2 (connective: true conjunction vs. false disjunction) ANOVA
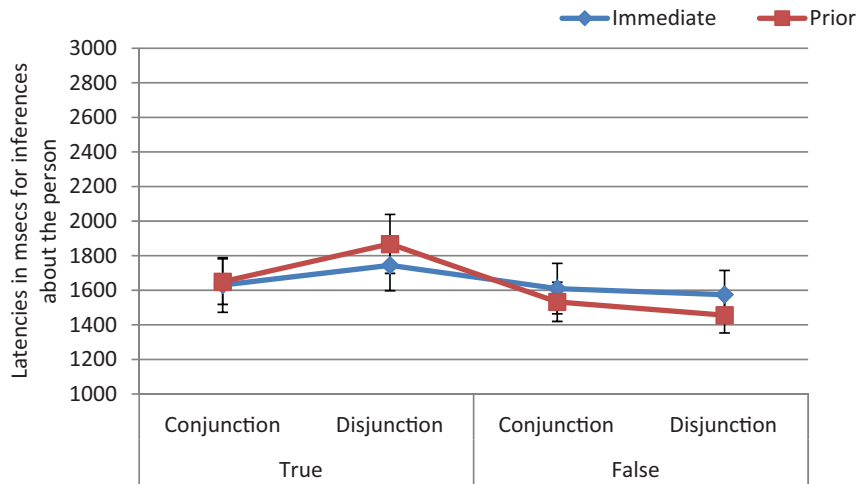

Figure 4. Latencies in milliseconds to respond to the inference question about the person in Experiment 2. Error bars are standard error of the mean.

showed no differences for disclosure or connective, and no interaction, $F < 1$ in each case.

Inferences about the object

Participants were also asked to make an inference in this experiment about the object, e.g., 'According to the expert's testimony, was there a glove?' An ANOVA of the same design carried out on the correct inferences about the object showed a slight *disadvantage* for prior disclosure compared to immediate, in that participants made more correct inferences about the object when the assertions about the truth or falsity of the testimony were immediate rather than prior, 58% vs. 54%, $F(1,59) = 7.96$, $p < .01$, $\eta p^2 = .12$ and disclosure interacted with connective, $F(1,59) = 4.15$, $p < .05$, $\eta p^2 = .07$. Contrasts showed that participants made more correct inferences about the object in the immediate than the prior condition for disjunctions $F(1,59) = 7.32$, $p < .01$, $\eta p^2 = .11$, but not for conjunctions $F < 1$. Disclosure did not interact with truth, $F(1,59) = 2.07$, $p > .10$, and the three variables did not interact, $F < 1$.

Participants made more correct inferences when the assertions were true than false, $F(1,59) = 68.07$, $p < .001$, $\eta p^2 = .54$; more correct inferences from conjunctions than disjunctions, $F(1,59) = 13.11$, $p < .01$, $\eta p^2 = .18$, and the two variables interacted, $F(1,59) = 141.36$, $p < .001$, $\eta p^2 = .71$. Contrasts showed that participants made more correct inferences from conjunctions than disjunctions for true assertions, $F(1,59) = 69.81$, $p < .001$, $\eta p^2 = .54$, but more correct inferences from disjunctions than conjunctions for false assertions, $F(1,59) = 169.32$, $p < .001$, $\eta p^2 = .74$, as Figure 5 shows.
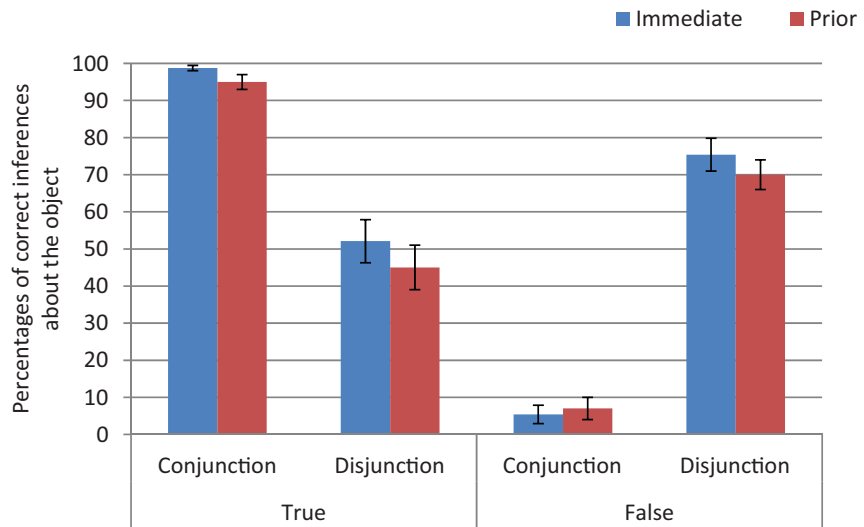

Figure 5. The percentages of correct inferences about the object in Experiment 2. Error bars are standard error of the mean.

Table 6. The percentages of different inferences about the object's location at the crime scene in Experiments 2 and 3. Correct inferences are in bold (standard deviation in parentheses).

Inference		Yes	No	Cannot conclude	Yes	No	Cannot conclude
Experiment 2			**Immediate**			**Prior**	
True	Conjunction	**99**(5)	0(3)	1(5)	**95**(12)	3(9)	(8)
	Disjunction	48(45)	0(3)	**52**(45)	48(44)	6(11)	**45**(44)
False	Conjunction	1(5)	**93**(19)	5(19)	13(21)	**80**(26)	7(20)
	Disjunction	2(8)	**75**(34)	23(34)	7(15)	**70**(34)	23(35)
Experiment 3							
True	Conjunction	**99**(5)	0(4)	0(4)			
	Disjunction	53(46)	0(4)	**47**(45)			
False	Conjunction	11(25)	**86**(28)	2(14)			
	Disjunction	7(20)	**68**(35)	25(32)			
No-disclosure	Conjunction	**78**(35)	1(4)	21(35)			
	Disjunction	39(43)	1(3)	**60**(43)			

The most frequent response for inferences about the object for the true conjunctions was the predicted correct response of, e.g., 'A' (99% immediate, 95% prior), the most frequent response for the true disjunctions was the correct response that we cannot conclude (52% immediate and 45% prior) and the next most frequent response was the predicted error of 'A' (48% in both conditions), as Table 6 shows. The most frequent response for the false conjunctions was the predicted error of not-A (93% immediate and 80% prior), and the most frequent response for the false disjunctions was the predicted correct response of not-A (75% immediate and 70% prior).

Latencies for object inferences

An ANOVA of the same design on the logarithmically transformed latencies to respond to the object inferences showed that participants responded more quickly for object inferences in the immediate condition than the prior one, 3115 ms vs. 3243 ms, $F(1,59) = 6.2, p < .05, \eta p^2 = .1$; for conjunctions than disjunctions, 2632 ms vs. 3725 ms, $F(1,59) = 40.8, p < .0001, \eta p^2 = .4$; and for true assertions rather than false ones, 3038 ms vs. 3320 ms, $F(1,59) = 9.4, p < .01, \eta p^2 = .1$. Disclosure interacted with truth, $F(1,59) = 5.2, p < .05, \eta p^2 = .1$, and contrasts showed that participants responded to the object inference question more quickly for immediate disclosures than prior ones (2904 ms vs. 3102 ms), when the assertion was true, $F(1,59) = 11.9, p < .01, \eta p^2 = .2$; there were no differences when it was false, $F < 1$. Truth also interacted with connective, $F(1,59) = 4.6, p < .05, \eta p^2 = .1$, and contrasts showed that participants responded more quickly to true conjunctions than false ones, 2455 ms vs. 2811 ms, $F(1,59) = 16.8, p < .001, \eta p^2 = .2$; there was no difference for disjunctions, $F < 1$. The three variables did not interact, $F < 1$, as Figure 6 shows.

We carried out the same sort of analysis as earlier on the latencies to make a correct response in those conditions with more than 60% correct responses
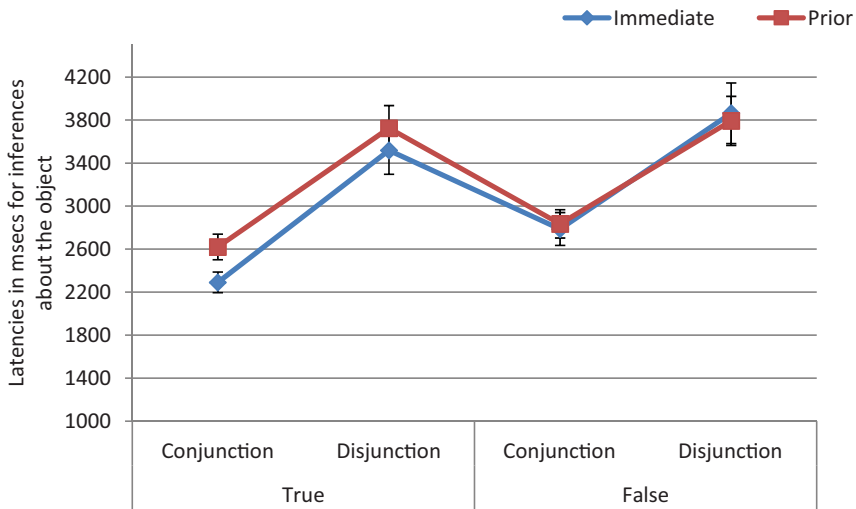
Figure 6. Latencies in milliseconds to the inference question about the object in Experiment 2. Error bars are standard error of the mean.

(true conjunction and false disjunction). The 2 (disclosure: immediate vs. delayed) × 2 (connective: true conjunction vs. false disjunction) ANOVA showed no main effect for disclosure, $F(1,33) = 1.24$, $p > .20$, but a main effect for connective $F(1,33) = 98$; $p < .001$, $\eta p^2 < .75$, as participants made correct inferences more quickly to true conjunctions than false disjunctions (2391 ms vs. 3608 ms), and the two factors did not interact, $F < 1$.

The experiment shows that there are no differences in correct inferences about the person, or in the latency of such inferences, for prior disclosure compared to immediate disclosure. The result indicates that there is no advantage conferred by prior disclosure of information about the truth or falsity of an expert's testimony compared to disclosure immediately after the testimony. For correct inferences about the object, and the latency of such inferences, there even appears to be a small *disadvantage* to prior disclosure. Once again the results are consistent with the suggestion that participants envisage alternative possibilities. We suggest that they may pose difficulties for the idea that people rely on computations of prior probabilities given our tentative conjecture that prior disclosure could facilitate a calculation of prior probabilities and degrees of belief in the statements.

Replicating the first experiment, the results also showed that participants made more correct inferences from true conjunctions than disjunctions but more correct inferences from false disjunctions than conjunctions, for both person inferences and object ones. They made the predicted errors for true disjunctions and false conjunctions and this pattern occurred in both the immediate and prior conditions. We note that participants made as many

correct inferences about the person overall in the immediate disclosure condition of the first experiment as they did in the immediate disclosure condition of the second experiment (49% vs. 51%). The comparison suggests that the requirement to make the inference about the object explicitly in the second experiment did not increase or decrease the difficulty of the inferences about the person. The next experiment compares immediate disclosure to no disclosure about the truth or falsity of the expert's testimony.

Experiment 3: immediate disclosure versus no disclosure

The aim of the experiment is to examine the accuracy and latency of inferences when there is no disclosure about the truth or falsity of the expert's testimony, compared to immediate disclosure. To do so, we compared the immediate disclosure condition from the previous experiment, e.g.,

Expert's testimony: 'At the crime scene there is a glove and a stone'.
The expert's testimony is false.
According to this information, was there a glove?
(a) yes, (b) no, (c) we cannot conclude.
Rule: If and only if there is a glove, the person will be declared a suspect.
We can conclude that the person:
(1) is a suspect (2) is not a suspect (3) we cannot conclude anything.

to a condition in which the disclosure was not made until after the object inference, which we will refer to as the 'no-disclosure before object inference' condition, e.g.:

Expert's testimony: 'At the crime scene there is a glove and a stone'.
According to this information, was there a glove?
(a) yes, (b) no, (c) we cannot conclude.
The expert's testimony is false.
Rule: If and only if there is a glove, the person will be declared a suspect.
We can conclude that the person:
(1) is a suspect (2) is not a suspect (3) we cannot conclude anything.

In both versions, the disclosure was provided before the rule about the person as a suspect, and hence both versions correspond to the immediate disclosure version used in the previous experiment. Hence, inferences about the person were not the measure of interest in this experiment, since in all of the problems, an immediate disclosure of the truth or falsity of the expert's testimony was provided with respect to the person inference. In other words, the disclosure in all conditions occurred immediately after the expert's testimony, either before the object inference or after the object inference but in both instances before the bi-conditional rule. The key difference is whether there is a disclosure about the expert's testimony before or after the object inference.

We expect that the pattern of inferences that people make about the object when they are given no information about the truth or falsity of the

expert's testimony will mirror the pattern of inferences they make when they are told that the expert's testimony is true, rather than the pattern of inferences they make when they are told that it is false. Hence, we are interested in three conditions: we compared the inferences about the object made in the no-disclosure before object inference condition to those made in the immediate disclosure that the testimony is true condition, and those made in the immediate disclosure that the testimony is false condition.

Method

Participants

The participants were a new set of 51 volunteers from Granada University, Spain who had not participated in the previous experiments. There were 35 women and 16 men aged between 19 and 33 years, with an average age of 20 years. The participants were students in second year developmental psychology who had no training in logic.

Materials, design and procedure

The materials were the same as the immediate disclosure version of the previous experiment in one condition, which we will call the no-disclosure before object inference condition, in which the disclosure of the truth or falsity of the expert's testimony did not occur until after the inference about the object; in the other two conditions, an immediate disclosure occurred before the object inference; in the true condition, the immediate disclosure was that the expert's testimony was true; and in the false condition, the immediate disclosure was that the expert's testimony was false. Participants completed 32 problems in a similar within-participant design to the previous experiment, 16 of the problems contained an immediate disclosure before the object inference, and half of these disclosures were that the testimony was true, and the other half were that it was false; the other 16 problems contained no disclosure until after the object inference. Once again, half of the expert testimonies contained a conjunction and the other half contained a disjunction. The design was thus a 3 (truth: no disclosure before object inference vs. disclosure that testimony is true vs. disclosure that it is false) × 2 (connective: conjunction vs. disjunction) within-participant design. The procedure was the same as the previous experiment.

Results and discussion

Inferences about the object

To test our hypotheses, we carried out a 3 (truth: no disclosure before object inference vs. disclosure that testimony is true vs. disclosure that it is false) × 2 (connective: conjunction vs. disjunction) repeated measures ANOVA on the

correct conclusions about the object. It showed that participants made more correct inferences in the no disclosure and true conditions compared to the false condition, $F(1,50) = 57.38$, $p < .001$, $\eta p^2 = .53$, there were no differences between conjunctions and disjunctions, $F(1,50) < .2$, $p > .7$, but the two variables interacted, $F(1,50) = 74.71$, $p < .001$, $\eta p^2 = .60$. Contrasts to decompose the interaction showed that participants made more correct inferences from conjunctions than disjunctions for true assertions, $F(1,50) = 68.23$, $p < .001$, $\eta p^2 = .58$, whereas they made more correct inferences from disjunctions than conjunctions for false assertions, $F(1,50) = 129.52$, $p < .001$, $\eta p^2 = .72$, replicating the previous experiments; importantly, they made more correct inferences from conjunctions than disjunctions when there was no disclosure about the truth or falsity of the expert's testimony, $F(1,50) = 3.99$, $p < .05$, $\eta p^2 = .07$, just as they do for true assertions. The contrasts also showed that for conjunctions, they made more correct inferences when they were told the testimony was true, $F(1,50) = 68.30$, $p < .001$, $\eta p^2 = .58$, or when they were given no information, $F(1,50) = 55.32$, $p < .001$, $\eta p^2 = .53$, compared to when they were told it was false; for disjunctions, they made more correct inferences when they were told the testimony was false than when they were told it was true, $F(1,50) = 5.62$, $p < .05$, $\eta p^2 = .10$, there was no difference when they were given no information, $F < 1$, as Figure 7 shows.

Participants given problems in the no-disclosure before object inference condition do not know whether the expert testimony is true or false which may increase their tendency to say 'we cannot conclude'. In the no-disclosure condition, participants tended to conclude 'we cannot conclude' more often
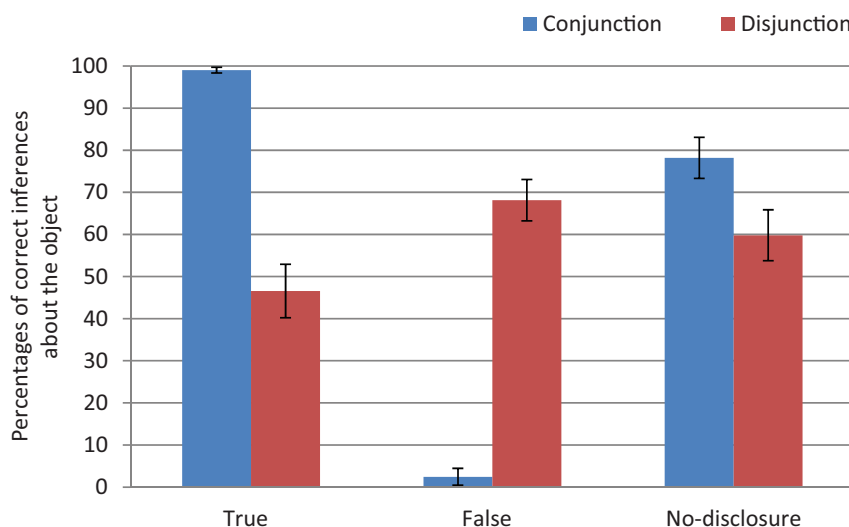

Figure 7. The percentages of correct inferences about the object in Experiment 3. Error bars are standard error of the mean.

than in the true condition, and this tendency occurs for conjunctions, 21% vs. 0%, $F(1,50) = 18$, $p < .001$, $\eta p^2 = .27$ and for disjunctions, 60% vs. 47%, $F(1,50) = 7.92$, $p < .01$, $\eta p^2 = .14$, as Table 6 shows. Hence, participants made more correct inferences to conjunctions in the true condition compared to the no-disclosure one, $F(1,50) = 18.77$, $p < .001$, $\eta p^2 = .27$, whereas they made more correct inferences to disjunctions in the no-disclosure condition than the true condition, $F(1,50) = 7.92$, $p < .01$, $\eta p^2 = .14$.

Latencies to inferences about the object

An ANOVA of the same design on the logarithmically transformed latencies to respond to the inference showed a main effect for truth, $F(1,50) = 30.53$, $p < .001$, $\eta p^2 = .56$, and connective, $F(1,50) = 22.18$, $p < .001$, $\eta p^2 = .31$, and the two variables interacted, $F(1,50) = 4.23$, $p < .05$, $\eta p^2 = .02$. Contrasts to decompose the interaction showed that participants responded more quickly to conjunctions than disjunctions in the true condition, 1949 ms vs. 2761 ms, $F(1,50) = 18.64$, $p < .001$, $\eta p^2 = .27$, and the false condition, 2623 ms vs. 3520 ms, $F(1,50) = 12.73$, $p < .01$, $\eta p^2 = .20$, but not in the no-disclosure condition, 2794 ms vs. 3029 ms, $F(1,50) = 2.24$, $p > .10$. They made inferences more quickly for conjunctions when they were told the testimony was true than when they were told it was false, 2355 ms vs. 3072 ms, $F(1,50) = 38.89$, $p < .001$, $\eta p^2 = .44$, or when they were given no disclosure, 2911 ms, $F(1,50) = 74.13$, $p < .001$, $\eta p^2 = .60$; similarly, they made inferences more quickly for disjunctions when they were told the testimony was true than when they were told it was false, 2761 ms vs. 3520 ms, $F(1,50) = 13.28$, $p < .001$, $\eta p^2 = .21$, or when they were given no disclosure, 3029 ms, $F(1,50) = 8.25$, $p < .01$, $\eta p^2 = .14$, as Figure 8 shows.
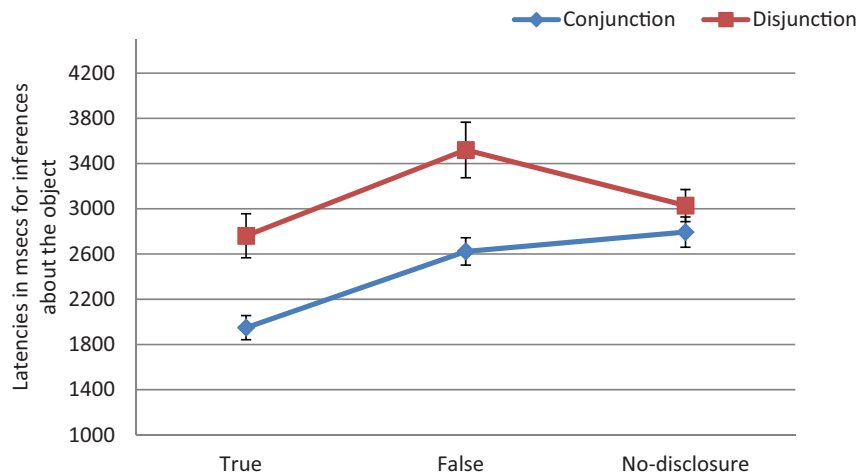

Figure 8. Latencies in milliseconds to respond to the inference question about the object in Experiment 3. Error bars are standard error of the mean.

We carried out an analysis of the latencies to make a correct response in those conditions with more than 60% correct responses (true conjunction, false disjunction, no-disclosure conjunction, and no-disclosure disjunction). A 2 (no disclosure before object inference vs. disclosure that testimony is true or false) × 2 (conjunction vs. disjunction) ANOVA showed that participants were faster to make correct inferences when they were given the disclosure that it was true or false vs. no disclosure, 2902 ms vs. 2609 ms, $F(1,26) = 9.27$, $p < .01$, $\eta p^2 = .26$. Participants made correct inferences more quickly for conjunctions than disjunctions, 2286 ms vs. 3225 ms, $F(1,26) = 22.38$, $p < .001$, $\eta p^2 = .46$, and the two factors interacted, $F(1,26) = 33.03$, $p < .001$, $\eta p^2 = .56$. Contrasts indicated that participants made correct inferences to conjunctions more quickly than disjunctions when the information was true or false, 1874 ms vs. 3343 ms, $F(1,26) = 44.98$, $p < .001$, $\eta p^2 = .63$, but there were no differences in the no-disclosure condition, 2697 ms vs. 3105 ms, $F(1,26) = 1.56$, $p > .20$.

Inferences about the person

Inferences about the person were not the target measure in this experiment because participants were always told about the truth of the expert testimony before the bi-conditional rule, that is, all conditions corresponded to the immediate disclosure condition of the previous experiments; the difference in this experiment was whether the disclosure occurred before or after they were asked about the presence of the object. Nonetheless, for comparison with the previous experiments, we also analysed the inferences about the person. Hence, we carried out a 2 (disclosure: disclosure before object inference vs. no disclosure before object inference) × 2 (connective: conjunction vs. disjunction) × 2 (truth of testimony: true vs. false) repeated measures ANOVA on the correct inferences about the person. It showed no effect on the person inference of whether the disclosure occurred before or after the object question, $F < 1$; disclosure did not interact with connective, $F < 1$, or truth, $F(1,50) = 1.95$, $p > .16$, and the three variables did not interact, $F < 1$, as Figure 9 shows. The results replicate the results for the immediate disclosure conditions in the previous experiments, as Table 5 shows.

Participants made more correct inferences when the assertions were true than when they were false, $F(1,50) = 46.562$, $p < .001$, $\eta p^2 = .48$, they made more correct inferences from disjunctions than conjunctions, $F(1,50) = 21.65$, $p < .001$, $\eta p^2 = .30$, and the two variables interacted, $F(1,50) = 70.52$, $p < 0.001$, $\eta p^2 = .59$. Contrasts to decompose the interaction showed that participants made more correct inferences from conjunctions than disjunctions for true assertions, $F(1,50) = 20.71$, $p < .001$, $\eta p^2 = .29$, and more correct inferences from disjunctions than conjunctions for false assertions $F(1,50) = 121.84$, $p < .001$, $\eta p^2 = .71$, replicating the results of the previous experiments.
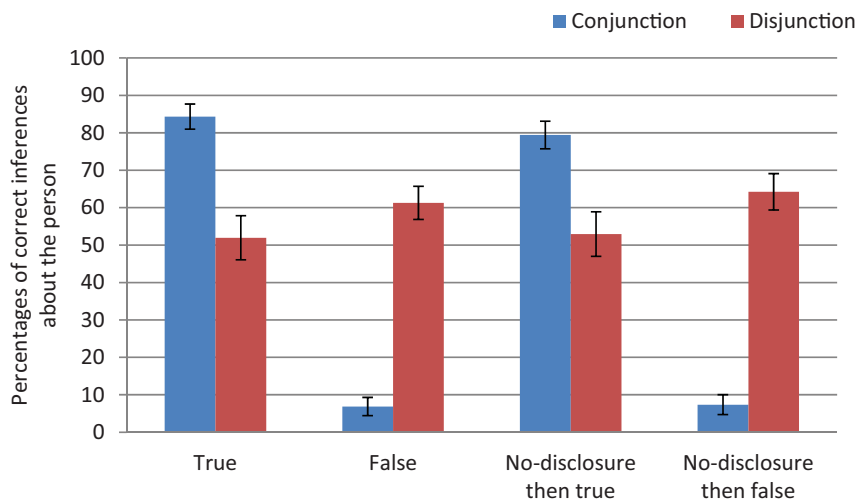
Figure 9. The percentages of correct inferences about the person in Experiment 3. Error bars are standard error of the mean.

Latencies for inferences about the person

An ANOVA of the same design on the logarithmically transformed latencies to respond to the inference showed there was no main effect of disclosure or connective, $F < 1$ in each case. Participants responded faster on false trials than true ones in this experiment, 1554 ms vs. 1609 ms, $F(1,50) = 10.88$, $p < .01$, $\eta p^2 = .18$. None of the interactions showed significant differences, $F < 1$ in each case, as Figure 10 shows.
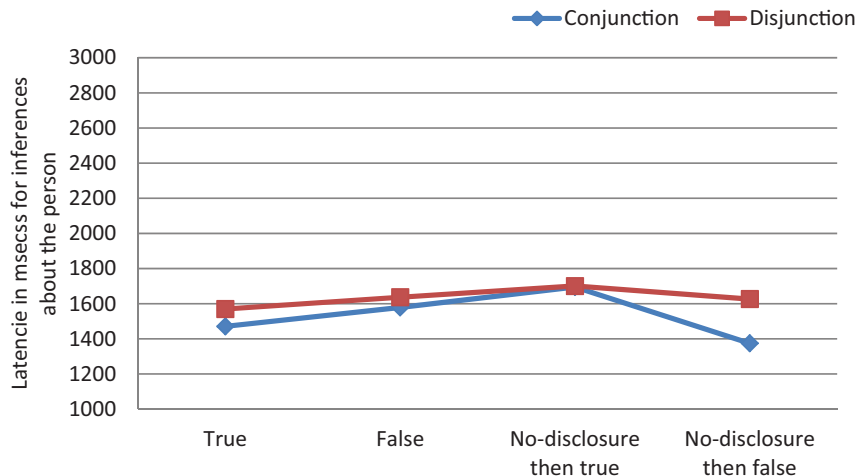

Figure 10. Latencies in milliseconds to the inference question about the person in Experiment 3. Error bars are standard error of the mean.

We carried out an analysis of the latencies to make a correct response to the person inference in those conditions with more than 60% correct responses (true conjunction and false disjunction). A 2 (disclosure: disclosure before object inference vs. no disclosure before object inference) × 2 (connective: true conjunction vs. false disjunction) ANOVA showed no main effect for disclosure, $F < 1$. Participants made correct inferences more quickly for true conjunctions than false disjunctions, 1367 ms vs. 1537 ms, $F(1,42) = 4.93$; $p < .05$, $\eta p^2 = .11$. The two factors did not interact, $F(1,42) = 1.14$, $p > .20$.

The pattern of inferences that people made about the object when they were given no information about the truth or falsity of the expert's testimony (because the disclosure was made after the object inference) mirrored the pattern of inferences they made when they were told that the expert's testimony is true – more correct inferences from true conjunctions than disjunctions, rather than the pattern of inferences they made when they were told that it is false – more correct inferences from false disjunctions than conjunctions, as Table 6 shows. The results replicate the results of the previous experiment for the inferences about the person as a suspect and extend them to inferences about the object. Participants made more correct inferences from true conjunctions than disjunctions but more correct inferences from false disjunctions than conjunctions. They also made the predicted errors for true disjunctions and false conjunctions, also consistent with the previous experiments.

General discussion

How accurately can a jury reason from disclosures of the truth or falsity of expert testimony, when the testimony contains compound assertions such as conjunctions and disjunctions? The results of the three experiments we report show that people experience considerable difficulty in making accurate inferences from the disclosure of the truth or falsity of an expert's testimony. Although they can reason very well from the disclosure that an expert's testimony is true when the expert's assertion is a conjunction, making accurate inferences about the person in the range of 77%–89% in the conditions of the three experiments, as Table 5 shows, they experience difficulty in making inferences when the expert's assertion is true and it is a disjunction: their accuracy falls within the range of 25%–51% in the conditions of the three experiments, and they frequently infer erroneously that an object was found at the scene and that the person is a suspect when in fact there is insufficient information to make either inference. More strikingly, although they can reason very well from the disclosure that an expert's testimony is false when the expert's assertion is a disjunction, making accurate inferences about the person in the range of 61%–72% in the conditions of the three experiments, as Table 5 shows, they experience significant difficulty in making accurate

inferences when an expert's testimony is false and their assertion is a conjunction, making accurate inferences about the person in the range of only 4%–12% in the conditions of the three experiments, frequently inferring erroneously that an object was not found at the scene and that the person is not a suspect when again there is insufficient information to make either inference. The results show that if an expert witness says two things co-occurred and a jury is told that the expert's testimony is false, they cannot infer accurately what follows from it. The results are difficult to explain if participants have access to elementary inferential rules such as De Morgan's laws to guide inferences from negated conjunctions and negated disjunctions (Rips, 1994). But they follow from the idea that participants attempt to envisage alternative possibilities (e.g., Johnson-Laird & Byrne, 2002; Khemlani, Byrne, & Johnson-Laird, 2017). A conjunction such as 'A and B' requires them to think about a single possibility:

A   B

And its negation requires them to envisage multiple possibilities by constructing the complement set,

Not-A   Not-B
A   Not-B
Not-A   B

A disjunction 'A or B or both' requires them to think about multiple possibilities:

A   Not-B
Not-A   B
A   B

And its negation requires them to envisage a single possibility,

Not-A   Not-B

Hence, it is easier to reason about true conjunctions than true disjunctions, but easier to reason about false disjunctions than false conjunctions (e.g., Byrne & Handley, 1992; Khemlani et al., 2012). In all three experiments, people made more correct inferences from true conjunctions than disjunctions but more correct inferences from false disjunctions than conjunctions, and their errors corresponded to envisaging a single possibility with both elements negated.

People made more correct inferences, and they made the inferences more quickly, when the truth or falsity of the assertion was disclosed immediately rather than delayed, as Experiment 1 shows. The result is consistent with

suggestions that mock jurors' attempt to construct a coherent model of the evidence (Holyoak & Simon, 1999; Lagnado & Harvey, 2008). Immediate disclosure of the falsity of expert testimony enables its negation to be combined accurately with later information; delayed disclosure of its falsity results in its combination with later information and the subsequent need for additional steps to disentangle the combined information and recombine the falsity of the expert's testimony with the later information. There is no advantage to disclosing the truth or falsity of the expert's testimony prior to the testimony, compared to immediately after it, as Experiment 2 shows. The result may suggest that people do not rely on computing their prior beliefs in the truth or falsity of an expert's testimony. Finally, the pattern of inferences that people make when they were given no information about the truth or falsity of the expert's testimony mirrors the pattern of inferences they make when they are told that the expert's testimony is true rather than the pattern of inferences they make when they are told that it is false, as Experiment 3 shows. The result is consistent with the general linguistic conventions that govern communication as well as the idea that people tend to think naturally about what is true rather than what is false (e.g., Johnson-Laird & Byrne, 2002; Sperber & Wilson, 1986).

Studies about warnings to mock jurors to disregard information have focused on how people's judgements of guilt are influenced by such warnings, and some of the results indicate that the attribution of guilt is influenced by the time at which the instructions to disregard information is given (e.g., Sommers & Kassin, 2001; see also Kassin & Sommers, 1997; Lagnado & Harvey, 2008). In contrast, we have focused on the specific inferences people make when they are informed about the truth or falsity of compound assertions in testimony. Our results are intended primarily to contribute to knowledge about how people reason about the negation of compound assertions such as conjunctions and disjunctions; their generalisation to jurors' decision-making is limited by the comparatively sparse material, compressed timeframe, and individual setting of the task that we provided for participants, compared to the rich material, prolonged duration, and group setting of a trial. Nonetheless, our results may add to the growing body of evidence that jurors reason about evidence by attempting to combine it in a coherent model of the events (Holyoak & Simon, 1999; Lagnado & Harvey, 2008; Pennington & Hastie, 1992). Their attempt to combine evidence in a consistent model leads to systematic errors when they discover late in the process that some of the evidence was not true. The three experiments reported here indicate that people experience considerable difficulties in making deductions from disclosures that an expert's testimony is true or false, for compound assertions that contain conjunctions and disjunctions.

Acknowledgments

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

ORCID

Sergio Moreno-Ríos http://orcid.org/0000-0001-5553-207X
Ruth M. J. Byrne http://orcid.org/0000-0003-2240-1211

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Appendix

The task in the three experiments was of the following sort:

> Expert's testimony: 'At the crime scene there is a glove and a stone'.
> The expert's testimony is false.
> According to this information, was there a glove?
> (1) Yes (2) No (3) We cannot conclude.
> Rule: If and only if there is a glove, the person will be declared a suspect.
> We can conclude that the person:
> (1) is a suspect (2) is not a suspect (3) we cannot conclude.

> Translated from the original Spanish:
> Informe del perito: 'En la escena del crimen hay un guante y una piedra'.
> El informe del perito es falso.
> Según dicha información, en la escena habría un guante?
> 1. Sí 2. No 3. No podemos concluir.

Directrices: Sí y sólo sí había un guante, la persona será declarada sospechosa.
Podemos concluir sobre la persona que:
1. Es sospechosa 2. No es sospechosa 3. No podemos concluir.

The 32 pairs of objects used in the three experiments in the original Spanish and translated into English.

silla	medias	chair	stockings
peine	cartera	comb	purse
guitarra	pluma	guitar	feather
anillo	venda	ring	band
mantel	abrigo	tablecloth	coat
trompeta	pulsera	trumpet	bracelet
disco	cuchara	disk	spoon
bastón	muñeco	walkingstick	doll
radio	bombilla	radio	bulb
tarjeta	pinza	card	pin
plato	carpeta	plate	folder
jersey	agenda	jersey	diary
caja	chaqueta	box	jacket
cuerda	sueter	string	sweater
lapicero	compás	pen	compass
saxofón	tenedor	saxophone	fork
perfume	reloj	perfume	watch
pantalón	pistola	pants	gun
flauta	maleta	flute	bag
cuchillo	libro	knife	book
camisa	sombrero	shirt	hat
gorra	cepillo	cap	brush
piedra	pañuelo	stone	handkerchief
cojín	jarrón	cushion	vase
bota	ajedrez	boot	chessboard
cubo	calcetín	cube	sock
altavoz	cigarro	speaker	cigar
guante	cinturón	glove	belt
revista	vaso	magazine	glass
botella	gafas	bottle	glasses
violín	cajón	fiddle	drawer
mochila	dados	backpack	dice