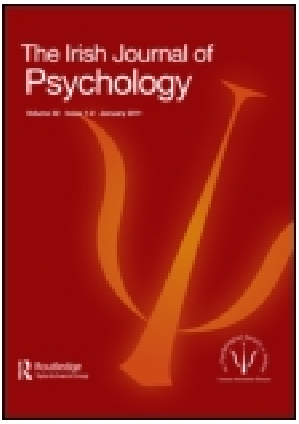

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Switching attention incurs a cost for counterfactual conditional inferences

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People often reason hypothetically in everyday life, for example, from conditionals such as 'if there is a circle there is a triangle'. They find some inferences easy, e.g., 'there is a circle, therefore there is a triangle', and others difficult, e.g., 'there is no triangle, therefore there is no circle'. We report an experiment that applies attention switching methods to reasoning from counterfactuals, e.g., 'if there *had* been a circle, there *would have* been a triangle'. The results show that even the simplest inference is adversely affected if reasoners must switch attention from a preceding difficult inference. Asymmetrical inference switching costs occur not only for indicative but also for counterfactual conditionals: the easy inference takes longer when reasoners must switch attention from the difficult one compared to when they switch attention from another easy one; the difficult inference remains difficult whether reasoners switch from an easy or difficult inference.

Keywords: conditional reasoning; counterfactuals; attention; task switching; inferences

Introduction

People often reason about hypothetical matters e.g., 'If he left home at his usual time, he caught the train. But if he didn't catch the train, he won't meet me at the restaurant on time. In fact I know he didn't catch the train'. They can reason through a sequence of possibilities, e.g., 'So, he didn't leave home at his usual time' and they can switch attention from one sort of inference to another, 'And he won't meet me at the restaurant on time'. Yet, most studies focus on single inferences and little is known about the effect of switching attentional resources from one to another. We report an experiment that shows that even the simplest inference is adversely affected if reasoners switch attention to it from a more difficult inference, for counterfactuals, e.g., 'if there *had been* a triangle there *would have been* a circle', and not only for indicative conditionals, e.g., 'if there is a triangle there is a circle' (Milán, Moreno-Ríos, Espino, Santamaría, & González-Hernández, 2010; Pereda, 2007).

Given a conditional, e.g., 'if there is a circle then there is a triangle', and the information 'there is a circle', almost everyone makes the *modus ponens* (MP) inference 'there is a triangle'. But given 'there is not a triangle', only about half of experimental

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participants make the *modus tollens* (MT) inference, 'there is not a circle'. The finding is so robust that all theories of reasoning explain it (for a review see Byrne & Johnson-Laird, 2009).

One view is that people construct a 'mental model' of the true possibility 'there is a circle and a triangle' – the simple inference can be made readily whereas the difficult inference requires imagining alternative possibilities, such as 'there is not a circle and there is not a triangle' (e.g., Johnson-Laird & Byrne, 2002). A different view is that people possess a mental inference rule – abstract or content sensitive – for the simple inference, but none for the difficult one which requires a mental derivation consisting of several steps (e.g., Braine & O'Brien, 1998; Cosmides, Tooby, Fiddick, & Bryant, 2005). Or people may add the 'if' part of the conditional to their beliefs and calculate the probability of the 'then' part (Evans & Over, 2004; Oaksford & Chater, 2007). Most of the explanations share the idea that MP is based on implicit heuristic processes, whereas MT is based on explicit reflective processes (e.g., De Neys, Vartanian, & Goel, 2008).

Although the theories can explain the differences between MP and MT, few have considered how people switch attention from one to the other as they must do in everyday life. Yet it is well known that switching attention incurs a cost, in accuracy or latency, and so it is crucial to establish whether inferences are also affected.

Switching attention between inferences

Switching costs occur when people switch between different operations or objects (e.g. Garavan, 1998; González, Milán, Pereda & Hochel, 2005). A task-switching cost is a difference in accuracy or latency of responses between 'repeat' and 'shift' trials, usually taken to reflect a tendency to keep active just one object or task-set in working memory (e.g., Rogers & Monsell, 1995).

Task-switching asymmetries reflect the counterintuitive observation of a larger cost (e.g., longer latencies) for the easier task after the harder task. Asymmetrical switching costs are observed in various domains (e.g., Allport & Wylie, 2000; Vandierendonck, Liefooghe, & Verbruggen, 2010). For example, bilingual speakers incur a cost when switching between languages (e.g., for picture naming) which is greater when switching into the first language compared to the second language (e.g., Costa & Santesteban, 2004). It may be due in part to more inhibition being needed when speaking in a second language to suppress the first language (e.g., Arbuthnott, 2008; cf. Yeung & Monsell, 2003).

We examine whether reasoners take longer to make MP when they must switch attention to it from a more difficult MT inference, for counterfactuals, e.g., 'if there *had been* a triangle there *would have been* a circle'. They take longer to do so for indicative conditionals, and no attention switching costs occur for MT (Milán et al., 2010; Pereda, 2007). Although the inference task remains the same for indicative MP and MT, the difference in the specific processes leads to attention switching costs. The attention switching asymmetry is distinct from priming. Repeating the same inference may prime that inference, but *asymmetrical* switching costs show a cost for MP when attention is switched from MT, but *not* for MT when attention is switched from MP.

Attention switching and counterfactuals

We extend the examination of switching costs to counterfactuals. People readily create counterfactual alternatives (e.g., Kahneman & Tversky, 1982). Philosophers, linguists and psychologists have long identified that a counterfactual, e.g., 'if there *had been* a circle there *would have been* a triangle' seems to mean something quite different from its indicative counterpart (for a review see Byrne, 2005). The difference arises because the counterfactual conveys the presupposition that its 'if' part and its 'then' part are both false – there is no circle and no triangle. When people understand a counterfactual, they are primed to read rapidly a negative conjunction 'there was no circle and no triangle' as well as an affirmative one 'there was a circle and a triangle' whereas for an indicative they are primed to read rapidly only the affirmative conjunction (Santamaría, Espino, & Byrne, 2005).

People make MT about twice as often from a counterfactual as from an indicative conditional and MP as frequently from both (for a review see Byrne 2005). The MT inference remains a difficult inference even from a counterfactual, as evidenced by the greater frequency of MP than MT for counterfactuals (Egan, Garcia-Madruga, & Byrne, 2009). Hence, if MP is made by a heuristic process and MT by a reflective one, we expect asymmetrical attention switching costs even for counterfactuals.

The experiment

The experiment tests the hypothesis that assymmetrical switching costs occur for counterfactuals. An example of MP for a counterfactual is:

> If there had been a triangle then there would have been a circle.
> There was a triangle.
> Therefore there was a circle.

for which the correct response is 'valid'.

Method

Participants

The participants were 24 undergraduate psychology students from Trinity College Dublin, untrained in logic (10 men, 14 women) who received course credits for their participation. Their ages ranged from 22 to 45 years (mean age 24 years). They were assigned at random to the indicative or the counterfactual group ($n = 12$ in each group).

Design, materials and procedure

The design was based on two inference types – MP or MT, and two switching conditions – repeat (MP after MP, MT after MT) or shift (MP after MT, MT after MP), manipulated within-participants; and the between-participants variable of two conditional types (indicative, counterfactual), and so there were eight conditions. The materials consisted of a main premise based on conditionals in the indicative mood and past tense, or counterfactuals in the subjunctive mood and past tense. The conditionals did not contain negatives and the minor premise and conclusion contained explicit negatives where appropriate. The conditionals were based on one of four contents: shapes (e.g., if there was a circle then there was a triangle), numbers (e.g., if there was a 4 then there was a 7), letters (e.g., if there was a B then there was an R) and coloured patches (e.g., if there was red then there was blue), and each content occurred in each condition.

The materials were presented on a computer screen controlled by a PC (Pentium III) that recorded participants' responses. Every trial began with a conditional at the top and centre of the screen, immediately after which the premise and the conclusion appeared one beneath the other on separate lines. The three sentences were presented sequentially. All three sentences remained on the screen until a response was made. Trial latency was recorded from the time the conditional premise appeared on screen to the time when participants pressed a response key. Feedback was shown on screen for half a second before the next trial began.

Participants performed 120 trials – 15 trials for each of the eight possible types. There were 6 blocks of 20 trials each. The order of the trials was randomised within each block. The first block was designed as practice and discarded prior to data analyses. The experimental session lasted approximately 30 minutes. Approval for the experiment was received in advance from the Ethics Committee of the School of Psychology, Trinity College Dublin.

Results

Accuracy was 96.5% overall, i.e., 99% for MP and 94% for MT. Although accuracy for MT was high, it was significantly lower than that of MP, $F(1,\ 22) = 23.72$, $p < 0.004$; no other effects or interactions were significant in the accuracy data (all were $F < 1$, except the inference by inference switching non-significant interaction, $F(1,\ 22) = 2.57$, $p < .155$). Only correct trials with response times that occurred between two standard deviations around each participant's mean were included in the latency analyses.

There was a main effect of inference, $F(1, 22) = 11.639$, $p < 0.003$, $\eta_p^2 = .346$, due to responses to MP inferences being 227 ms. faster than responses to MT inferences (1589 and 1816 ms.) as shown in a 2 (MP, MT) $\times$ 2 (repeat, shift) $\times$ 2 (indicative, counterfactual) ANOVA. There was no main effect of inference switching ($F < 1$), but inference switching interacted with inference, $F(1,\ 22) = 8.372$, $p < 0.008$, $\eta_p^2 = .276$, stemming from an inference switching cost that was significant only for MP, although the difference was somewhat marginal $F(1, 22) = 3.952$, $p < 0.059$. MP inferences were 147 ms. faster on repeat trials, that is, when they followed another MP, compared to MP inferences on shift trials, that is, when they followed MT (1515 and 1662 ms.), as shown in Table 1. For MT inferences there was no such switching

Table 1. Latencies in ms for inferences (and standard deviations in parentheses) in the experiment.

Inference	Modus ponens	Modus tollens
Repeat		
Indicative	1606 (851)	1891 (1377)
Counterfactual	1424 (479)	1824 (599)
Mean	1515 (682)	1857 (1039)
Shift		
Indicative	1783 (1253)	1837 (1404)
Counterfactual	1541 (546)	1711 (639)
Mean	1662 (954)	1774 (1069)

effect when they followed another MT, compared to when they followed MP (1857 and 1774 ms), $F(1, 22) = 2.825$, $p < 0.107$.

Importantly, there was no main effect of conditional type (indicative vs. counterfactual) and the variable did not interact with inference or inference switching and there was no three-way interaction (all $F < 1$). The inference switching costs observed for indicative conditionals are present also for counterfactual conditionals, as shown in Table 1.

We repeated the analysis excluding trials for which an error occurred on a previous trial given that participants made more errors on MT than MP, to rule out the possibility that the asymmetric switching costs result from the established effect of increased response latencies in trials following an error. It showed the same results: a main effect of inference $F(1, 22) = 11.921$, $p < 0.002$, $\eta_p^2 = .351$, no main effect of inference switching, $F < 1$, but an interaction of the two, $F(1, 22) = 7.159$, $p < 0.014$, $\eta_p^2 = .246$; no main effect of conditional type and no interaction of conditional type with inference or inference switching and no three-way interaction (all $F < 1$). The interaction stemmed from an inference switching cost that was significant only for MP, $F(1, 22) = 7.577$, $p < 0.012$; there was no effect for MT inferences $F(1, 22) = 1.402$, $p < 0.249$.

The experiment yields an important discovery: asymmetrical attention switching costs occur for counterfactuals, not only for indicative conditionals.

Discussion

In everyday life, people switch attention from one sort of inference to another. Our experiment contributes the finding that even the simplest MP inference can be impeded if it occurs after a MT one, not only for indicative conditionals but also for counterfactuals (Pereda, 2007). Although MT is made more often from counterfactuals, the result implies that it continues to require a deliberative process.

The revelation that even the simplest inference can be disadvantaged if attention is switched from a difficult inference has important consequences for understanding human reasoning. It highlights the role of cognitive control and it lends support to the idea that MP is made by a heuristic process, whereas MT requires a reflective process. The discovery also has implications for the assessment of reasoning ability. The difficulty of some inferences may have been mis-estimated, given that the randomised presentation of inferences may unduly affect the latency of the easier inferences.

These data also have implications for understanding human attention. The finding of asymmetric effects in an inference task demonstrates a similarity between inference switching and other types of task switching, and suggests that each of the two types of inference can be considered a distinct 'task' (Milán et al., 2010). It also shows that what is known about lower-level attentional processes can be applied to understanding some of the dynamics of higher level reasoning. There is wide agreement that a limiting factor in reasoning performance is working memory capacity (e.g., Johnson-Laird & Byrne, 2002), but little effort has been directed at exploring the role played by low-level attention processes such as switching that deal with these capacity limitations. The discovery of inference switching costs for MP and MT, for both indicative and counterfactual conditionals, suggests that the study of attention switching in conditional reasoning is a fruitful avenue for future research.

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