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Disabling conditional inferences: An EEG study

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ABSTRACT

Although the Modus Ponens inference is one of the most basic logical rules, decades of conditional reasoning research show that it is often rejected when people consider stored background knowledge about potential disabling conditions. In the present study we used EEG to identify neural markers of this process. We presented participants with many and few disabler conditionals for which retrieval of disabling conditions was likely or unlikely. As in classic behavioral studies we observed that participants accepted the standard MP conclusion less for conditionals with many disablers. The key finding was that the presentation of the standard MP conclusion also resulted in a more pronounced N2 and less pronounced P3b for the many disabler conditionals. This specific N2/P3b pattern has been linked to the violation and satisfaction of expectations, respectively. Thereby, the present ERP findings support the idea that disabler retrieval lowers reasoners' expectations that the standard MP conclusion can be drawn.

1. Introduction

The ability to reason with conditional statements is considered one of the cornerstones of human cognition (Bonnefon, Haigh, & Stewart, 2013; Evans & Over, 2004). However, the conditional inferences that people draw are not always logically appropriate (Manktelow, 1999; Markovits, 2010). Consider for example the classic Modus Ponens (MP) inference, one of the most basic conditional inferences. A conditional (e.g., If P, then Q) links a specific antecedent (e.g., P) with a specific consequent (e.g., Q). The MP rule simply tells us that whenever the antecedent of a conditional occurs, we should conclude that the consequent will also occur. For example, when given an arbitrary rule such as "If the figure is a square, then it is red" (i.e., the major premise) and the information that "The figure is a square" (i.e., the minor premise) standard logic tells you to conclude that the figure is red. It is long established that people have little trouble drawing the MP inference when reasoning about such arbitrary (i.e., abstract or belief-neutral) conditionals (Braine & O'Brien, 1998; Byrne, 1989; Markovits, Doyon, & Simoneau, 2002). However, a key observation has been that things change dramatically when people are asked to reason with realistic, thematic conditionals about which they have prior beliefs (e.g., Byrne, 1989; Cummins, 1995; Cummins, Lubart, Alksnis, & Rist, 1991; Manktelow, 1999; Markovits & Barrouillet, 2002). For example, when presented with a conditional such as "If John studies hard, he will pass the test" people will often reject the logically equivalent MP inference that "john passes the test" when told that he studied hard. The point is that reasoners will readily consider additional considerations or so-called disablers (i.e., conditions that prevent the consequent from occurring despite the presence of the antecedent). Examples of such disablers in this case are the fact that John might have a very low IQ, that the test was unfairly hard, or that John got ill and could not make it to the exam (e.g., Cummins, 1995). This general tendency to reject the MP inference after consideration of disablers is often referred to as the *suppression effect* (e.g., Byrne, 1989).

Numerous studies have shown that the ease with which disablers can be retrieved from long term memory directly determines the likelihood that the MP inference will be accepted (e.g., Cummins, 1995; De Neys, Schaeken, & d'Ydewalle, 2002, 2003a, 2005a; Markovits & Quinn, 2002; Simoneau & Markovits, 2003). For example, in one of the classic studies, Cummins (1995)

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(see also Cummins et al., 1991, for an early precursor) asked participants to generate as many disablers as they could for a set of conditionals. Cummins then selected conditionals for which it was most (e.g., If John studies hard, he will pass the test) and least likely (e.g., If John strikes a match, it will light) that people would spontaneously think of disablers (i.e., so-called conditionals with many or few disablers, respectively). Next, these conditionals with few or many disablers were presented to a second group of participants who were asked to evaluate conditional inferences. A key observation was that inferences such as the MP were far less accepted for the many disabler conditionals.

Myriad follow-up studies have confirmed the effect and the more general modulation of our inference process by stored background knowledge when reasoning with realistic, thematic conditionals (Byrne, Espino, & Santamaria, 1999; De Neys, 2010; De Neys & Everaerts, 2008; Grosset, Barrouillet, & Markovits, 2005; Markovits, 2010). Indeed, this content modulation has become one of the main foci of interest in the conditional reasoning field (e.g., Johnson-Laird & Byrne, 2002; Markovits, 2010). However, while the behavioral effects are well documented, their neural implications have not been studied. In recent years, a growing number of EEG, fMRI, and MEG studies have started exploring the neural basis of conditional reasoning (e.g., Bonnefond et al., 2013, 2012; Bonnefond & Van der Henst, 2009, 2013; Houde et al., 2000; Monti, Osherson, Martinez, & Parsons, 2007; Noveck, Goel, & Smith, 2004; Prado, Kaliuzhna, Cheylus, & Noveck, 2008; Prado & Noveck, 2007; Reverberi et al., 2007). However, none of these studies has examined the critical impact of disabler retrieval when reasoning with realistic, thematic conditionals. The present study starts to address this challenge.

Our specific goal was to identify neural markers of the impact of disabler retrieval modulation on the MP inference. Therefore, we presented participants with carefully pretested few and many disabler conditionals, as in Cummins's (1995) study, and recorded their electroencephalogram while they were evaluating MP inferences. Based on previous studies (see below), our hypotheses primarily focused on two specific event-related potentials: the N2 and P3b.

The N2 is a frontal negative deflection observed between 200 ms and 300 ms after stimulus onset. The P3b on the other hand, is a centroparietal positive deflection observed in the 250–450 ms time window.[2] Critically, the N2 and P3b have been related to the violation and satisfaction of expectations, respectively (Folstein & Van Petten, 2008; Verleger, 1988). For example, in working memory tasks in which participants get to expect that a newly presented stimulus matches a previously presented one, presentation of a non-matching stimulus elicits an N2 whereas a matching stimulus will elicit a P3b (Wang, Wang, Cui, Tian, & Zhang, 2002; Zhang, Wang, Li, & Wang, 2003). The N2 and P3b were also observed in EEG studies that focused on conditional reasoning with abstract conditionals (e.g., Bonnefond et al., 2013, 2012; Bonnefond & Van der Henst, 2009, 2013). For example, Bonnefond and Van der Henst (2009) presented the major (e.g., If P then Q) and minor premise (e.g., P) of MP arguments sequentially and contrasted activation for standard, so-called matching MP conclusions (e.g., Thus, Q) and non-matching conclusions (e.g., Thus, Z). They observed that the standard MP conclusions gave rise to a more pronounced P3b and less pronounced N2 when contrasted with the non-matching conditions. This has been interpreted as indicating that after being presented with the major (e.g., If P then Q) and minor (e.g., P) premises of an MP argument, people will readily infer and get to expect that the standard MP conclusion (i.e., Thus, Q) will follow. When this expectation is met and the conclusion "Q" is subsequently presented, as is the case in the matching condition, this will give rise to a decreased N2 and increased P3b, in contrast with a condition where this expectancy is violated by the presentation of a non-matching conclusion.

The link between the N2/P3b and conclusion expectancy gives us a straightforward means to examine the impact of disablers when reasoning with thematic conditionals. In the present study, we used both conditionals with few and many disablers. As in the studies with abstract conditionals, we presented the major and minor premises of our MP arguments sequentially. Our key question was what would happen when the (logically equivalent) standard MP conclusion is presented in both cases. As we noted, behavioral studies already established that whereas the MP conclusion is typically accepted for conditionals with few potential disablers, the increased likelihood of finding a disabler results in increased questioning or rejection of the MP conclusion for the many disabler conditionals. Hence, because people will consider disablers, the standard MP conclusion "Q" should be expected less for conditionals with many disablers. Consequently, the expectation modulated N2 and P3b should differ for the many and few disabler conditionals. More specifically, since it is unlikely that people will consider disablers for the few disabler conditionals, they should have strong expectations that the logical conclusion will occur after being presented with the major and minor premises. Hence, satisfying this expectation by the presentation of the standard MP conclusion should result in a clear P3b just as it has been observed with abstract conditionals. However, the hypothesized disabler retrieval with the many disabler conditionals should lower the expectation that the standard MP conclusion will follow and may give rise to a greater N2 amplitude. In sum, we can predict that disabler modulation when reasoning with thematic conditionals will result in a more pronounced N2 and less pronounced P3b for MP inferences with many vs. few disabler conditionals.

2. Methods

2.1. Participants

Twenty-four healthy native French-speaking volunteers with no history of neurological or psychiatric disorders participated in the study. Seven participants were excluded from the analyses due to excessive eye movements/blinks or muscle artifacts (> 33% of contaminated trials) in the EEG signal.[3] The remaining participants (13 females) were aged between 20 and 30 (mean age: 22.8 years). All subjects were right-handed as measured by the Edinburgh Handedness Inventory.

2.2. Material

2.2.1. Pretest

Our goal of studying thematic conditionals in this study implied that we needed to go through extensive material pretesting. We first created 256 conditionals based on the following criteria: (i) As in Cummins (1995), we used thematic conditionals that were causal in nature (i.e., the antecedent specifies a cause and the consequent an associated effect). (ii) We used only verbs that could be employed in an intransitive manner, i.e., without object following, so as to control for the moment of the inference (when the verb is presented as a minor premise). (iii) The verb tense used was the simple present in the active or passive form. (iv) The subject of the antecedent and the consequent was the same.

[2] The sign (negative or positive) of the deflection only indicates which side of the dipole (i.e., a portion of active cortex) is picked up by the EEG electrodes. A stronger positive or negative deflection is likely to indicate a stronger activity of underlying sources. The P3b component has been shown to be elicited by a large fronto-parietal network (Bocquillon et al., 2011). There is however no clear consensus in the literature regarding the underlying sources of the mismatching-related N2 component (Folstein & Van Petten, 2008).

[3] The participants were asked to blink as little as possible but the lengthy nature of the trials might have made this difficult to accomplish.

Next, following Cummins (1995), we ran a pretest to identify conditionals for which it would be most and least likely that participants would retrieve disablers (i.e., many and few disabler conditionals). The disabler generation task was based on Cummins's procedure. For each conditional, participants were presented with the following instruction:

Rule: If butter warms then it melts.
Fact: The butter warms but it does not melt.

They were then asked to write down as many circumstances as possible that would make the situation possible. If they were unable to provide such circumstances they were required to write "0". Participants also rated the strength of the causal relation that the conditional expressed and the ease of disabler retrieval on a scale from 1 (difficult) to 5 (very easy). We created four random sets of 64 conditionals. For each set, ten participants were recruited via an internet tool.

We eventually selected the 64 best conditionals for which disabler retrieval was least and most likely (i.e., 32 few and 32 many disabler conditionals, see Appendix Table A3 for an overview). The average number of retrieved disablers for these two groups was .53 (SD =0.51) and 2.48 (SD =0.67), respectively. The average rated ease of retrieval was 1.53 (SD =0.8) for the few and 3.7 (SD =0.81) for the many conditionals. The causality rating for the selected few and many conditionals was 4.3 (SD =0.74) and 3.9 (SD =0.65), respectively. Note that the less appropriate remaining 192 conditionals were used as filler items in which non-MP arguments were presented in the actual reasoning study (see Section 2.3).

For completeness, the expert reader might note that we also made sure to test the number of available alternative conditions (i.e., alterative causes) for our 256 conditionals. These alternative conditions are potential alternative causes for the effect specified in the conditional (e.g., for the conditional "If John studies hard, he passes the test" possible alternative causes are "John is a genius" or "John cheated"). Behavioral studies established that such alternatives have little impact on the MP inference (Byrne, 1989; Cummins, 1995; De Neys, Schaeken, & d'Ydewalle, 2003b; De Neys et al., 2002). Nevertheless, to minimize any potential confounding effects (e.g., Markovits & Potvin, 2001) we made sure that the 32 few and 32 many disabler conditionals that we ended up selecting for our study all had few potential alternatives. Therefore, an independent group of raters were asked to generate potential alternatives for the 254 conditionals. The average number of alternatives in our group of selected many and few disabler conditionals was 0.71 (SD =0.81) and .83 (SD =0.8), respectively. The average rated ease of alternative retrieval was 1.62 (SD =0.79) and 1.8 (SD =0.9), respectively.

2.3. Procedure

Stimuli were displayed with Presentation 10.2 software (Neurobehavioral Systems, http://www.neurobs.com/) on a computer screen. In the instruction set, participants were informed that they would have to evaluate conclusions of conditional statements. As in the study of Bonnefond and Van der Henst (2009), the major premise, minor premise, and conclusion were presented sequentially (see Fig. 1 for example). To optimize EEG recording, the verb and subject of the minor premise and conclusion were also presented sequentially (see Fig. 2).

As Fig. 2 shows, each trial started with a visual central mark (a dot) displayed in the centre of the screen for 800 ms. The conditional (i.e., major premise) was then presented. Participants had to press the space key to continue the trial. Then, a dot appeared on the screen for 800 ms, followed by the presentation of the subject of the minor premise for 400 ms and another dot for 800 ms. The verb of the minor premise was then presented for 1000 ms. Finally, after a dot fixation period of 800 ms, the subject of the conclusion was presented for 400 ms, followed by another dot fixation period of 800 ms and the verb of the conclusion for 1000 ms. Participants had to respond only when the sentence "your response" appeared on the screen. Participants were asked to indicate whether the conclusion followed from the premises. There were three response keys corresponding to three possible

Major premise	Minor premise	Conclusion
Conditionals with few disablers		
If the butter warms then it melts	The butter warms	The butter melts
Conditionals with many disablers		
If a fire bursts out then it spreads	A fire bursts	A fire spreads

Fig. 1. Experimental design. The underlined verbs correspond to the analyzed stimuli.

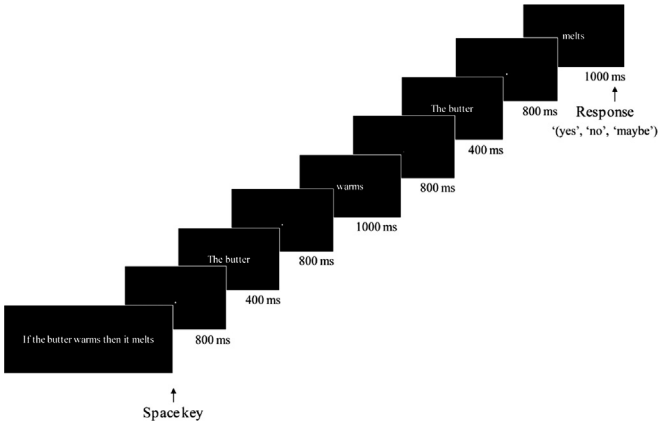

Fig. 2. Illustration of the experimental procedure.

evaluations of the conclusion: "yes", "no" and "maybe". As in Cummins (1995) and follow-up studies (De Neys et al., 2005b) participants were instructed to evaluate the conclusion by the criteria they personally judged relevant. This should encourage participants to reason as they would in everyday situations (Cummins, 1995; Evans, 2002).

There were 64 critical experimental trials in the experiment in which an MP argument was presented (32 with a few disablers conditional and 32 with a many disablers conditional). To avoid repetition and keep participants engaged these 64 experimental trials were mixed with a total of 192 filler trials in which non-MP arguments were presented. These filler trials were constructed by presenting the antonym of the antecedent and/or consequent of the conditional (e.g., "If butter warms, it melts. Butter cools. Thus, it melts" or "If butter warms, it melts. Butter cools. Thus, it hardens"). Note that we made sure to use a different conditional and hence different thematic content for all 256 trials that were presented.

Participants performed the experiment in four blocks (64 trials in each block). Trial order within each block was randomized and the block order within each task was counterbalanced across participants. Participants were asked to avoid making eye movements or vocal articulations (audible or inaudible) during the trial. The task began with 10 training trials.

2.4. EEG data recording and preprocessing

Subjects were seated in a dimly lit, electrically shielded, sound-attenuating room. The EEG signal was recorded with a 64 channel NetAmps.200 system (Electrical Geodesics Inc.). Amplified analog voltages (0.1–200 Hz bandpass) were sampled at 500 Hz. Electrode impedance was kept below 40 KΩ. All channels were referenced to Cz during recording, and off-line re-referenced to the average mastoids. ERP analyses were conducted using ELAN-Pack software developed at INSERM U821 (Lyon, France). They consisted in averaging the EEG segments in synchronization with the onset of the verb of the conclusion (or minor premise, see further) over a 800 ms period including a 100 ms pre-stimulus interval. The signals were low-pass filtered (20 Hz) and a baseline correction was calculated from the 100 ms preceding the display of the verb. Trials contaminated by blinks or eye movements (threshold: $\pm 100\,\mu V$) were discarded (mean percentage of trials rejected: 5.8%, i.e., ~2 trials per condition). All remaining trials were included in the reported ERP analyses.

2.5. EEG data analysis

For the N2 and the P3b components, we computed the peak value of theses components relative to the peak of the previous component. Note that our hypotheses concerned differential expectations about the presented MP conclusion. Consequently, the N2 and P3b components were defined relative to the onset of the (verb) of the conclusion. However, we also ran control analyses in which the N2 and P3b were defined relative to the onset of the (verb) of the minor premise. Whereas disabler retrieval might modulate the expectation of the MP conclusion for few and many disabler conditionals, it should not affect expectations about the presentation of the minor premise. Hence, if our predicted effects reflect differential disabler retrieval and not some unrelated factor associated with the different conditionals, the differential N2 and P3b effects should be restricted to the analyses at the conclusion level. Consequently, we also entered the Argument Level (minor premise or conclusion) as an additional control factor in our analyses.

All analyses were run with the same electrode positions. Twelve representative electrodes of the 10–20 system were chosen to define four different scalp regions (frontal: F3, Fz and F4; central: C3, Cz and C4; centroparietal: CP3, CPz and CP4 and parietal: P3, Pz and P4). We ran 2 (Type of Conditional: few vs. many disablers

condition) × 2 (Argument Level: premise vs. conclusion) × 3 (Laterality: left, midline, right) × 4 (Anterior–Posterior location: frontal, central, centroparietal, parietal) ANOVAs. A Greenhouse–Geisser adjustment was used to correct for violations of sphericity. Relevant post hoc comparisons were computed with Tukey HSD tests which correct for multiple comparisons (Zar, 1984).

3. Results

3.1. Behavioral results

At the behavioral level, our results replicated the classic effects observed by Cummins (1995): Although the MP conclusion was typically accepted for the few disabler conditionals (83% "yes" responses), participants tended to doubt (63% "maybe" responses) or reject (9% "no" responses) the conclusion for the many disabler conditionals. For clarity, we rescored the "yes", "maybe", and "no" responses as 1, 0, and −1, respectively, and calculated the average level of conclusion acceptance. This figure reached 78% for the few, and 24% for the many disabler conditionals, $t(16)=12.6$, $p<0.001$. Hence, in line with the classic findings (e.g., Byrne, 1989; Cummins, 1995; De Neys et al., 2003a) this indicates that considering disablers results in a decreased acceptance of the MP conclusion.[4]

3.2. ERPs results

3.2.1. N2 component

The visual inspection of waveforms presented in Fig. 3 revealed that the frontocentral N2 component did not seem to differ for conditionals with many and few disablers at the premise level. On the other hand, Fig. 4 shows that as expected, this component was indeed larger for the conditionals with many disablers at the conclusion level.

The four-way ANOVA (see Section 2) computed for the amplitude of the N2 component revealed a main effect of Anterior–Posterior location, $F(1.55, 24.73)=39.29$, $p<0.001$, $\eta^2=0.71$, and of Laterality, $F(1.85, 29.65)=4.83$, $p<0.05$, $\eta^2=0.2$. This analysis also showed a significant interaction between the Argument Level and the Anterior–Posterior location, $F(1.28, 20.55)=34.84$, $p<0.001$, $\eta^2=0.68$, between the Argument Level and Laterality, $F(1.64, 26.28)=7.82$, $p<0.01$, $\eta^2=0.33$, as well as between the Type of Conditional, the Argument Level, and the Anterior–Posterior location, $F(1.54, 24.63)=4.01$, $p<0.05$, $\eta^2=0.18$. Post hoc Tukey HSD tests revealed that this last effect resulted from a larger N2 component on frontal ($p<0.05$) electrodes for the conclusion of conditionals with many disablers compared to the conclusion of conditionals with few disablers. All other main effects and interactions were not significant (all p values >0.08, see Table A1 for an overview).

3.2.2. P3b component

As illustrated in Fig. 3, there was also no difference between the two types of conditionals at the premise level for the P3b component. However, in line with our predictions, the inspection of Fig. 4 shows a larger P3b component at the conclusion level for the conditionals with few disablers.

The four-way ANOVA computed for the amplitude of the P3b component showed a main effect of Anterior–Posterior location, $F(1.42, 22.7)=4.03$, $p<0.05$, $\eta^2=0.2$. It also revealed a significant interaction between Anterior–Posterior location and Laterality, $F(3.05, 48.90)=3.35$, $p<0.05$, $\eta^2=0.17$, between Anterior–Posterior location and the Argument Level, $F(1.23, 19.66)=5.76$, $p<0.05$, $\eta^2=0.26$, and between Anterior–Posterior location, Laterality, the Type of Conditional, and Argument Level, $F(3.87, 61.93)=2.55$, $p<0.05$, $\eta^2=0.13$. All other main effects and interactions were not significant (all p values >0.11, see Table A2 for an overview).[5] Post hoc Tukey HSD tests revealed that the P3b component was larger for conclusions of conditionals with few disablers compared to conclusions of conditionals with many disablers at the middle centroparietal ($p<0.05$) and parietal sites ($p<0.05$).

3.2.3. Other components

We also explored whether there were other components that might differ for the few and many disabler conditionals. Visual inspection of the waveforms hinted at a somewhat larger late frontal component for the many disabler conditionals at the premise level (see Fig. 3). However, the four-way ANOVA computed for the amplitude of this frontal component (window 450–800 ms) revealed only a main effect of Anterior–Posterior location, $F(1.54, 24.73)=39.28$, $p<0.001$, $\eta^2=0.7$. Hence, this component was not affected by the critical disabler modulation at the conclusion level.

4. General discussion

In the present study we used EEG to identify neural markers of the impact of disabler retrieval on the MP inference. We presented participants with many and few disabler conditionals for which disabler retrieval was likely or unlikely, respectively. As in the classic behavioral studies (e.g., Cummins, 1995) we observed that participants were less likely to accept the MP conclusion for conditionals with many disablers. However, our key finding was that presentation of this MP conclusion also resulted in a more pronounced N2 and less pronounced P3b for many disabler conditionals. In the ERP literature this specific N2/P3b pattern has been linked to the violation and satisfaction of expectations, respectively (e.g., Bonnefond & Van der Henst, 2009; Folstein & Van Petten, 2008; Verleger, 1988; Wang et al., 2002; Zhang et al., 2003). Thereby, the present ERP findings support the idea that disabler retrieval specifically modulates our expectations that the standard MP conclusion will follow.

Note that the increased P3b (and decreased N2) that was currently observed for few disablers conditionals was also observed in previous EEG studies with abstract conditionals (e.g., Bonnefond et al., 2012; Bonnefond & Van der Henst, 2009). This observation is interesting for at least two reasons. First, by definition, disabler retrieval is impossible for abstract conditionals. Hence, the fact that we find the same pattern for few disabler and abstract conditionals suggests that our material pretesting was successful and that participants did not retrieve disablers for the few conditionals. Consequently, this also strengthens the claim that our ERP effects for the many conditionals are indeed driven by disabler retrieval. Second, the finding suggests that thematic content does not necessarily alter people's expectations or inferences per se. When people reason with thematic conditionals for which disabler retrieval is unlikely, they will get to expect the MP conclusion just as with abstract conditionals. Consequently, for both abstract and few disablers conditionals presentation of the

[4] All trials were included in the reported ERP analyses. For completeness, note that we also ran additional control analyses in which many disabler trials that were accepted (i.e., 28% of trials) and few disabler trials that were not accepted (i.e., 17% of trials) were discarded. However, findings were not affected.

[5] Following one reviewer's suggestion, we also tested for a potential correlation between the behavioral changes in conclusion acceptance in the many disablers vs. few disablers condition and the P3b (and N2) conclusion level effect. However, both for the P3b and N2 we only found non-significant trends (P3b: $r=0.37$, $p=0.13$; N2: $r=0.32$, $p=0.19$). Obviously, the small number of subjects in this initial study prevents us from drawing clear conclusions here.

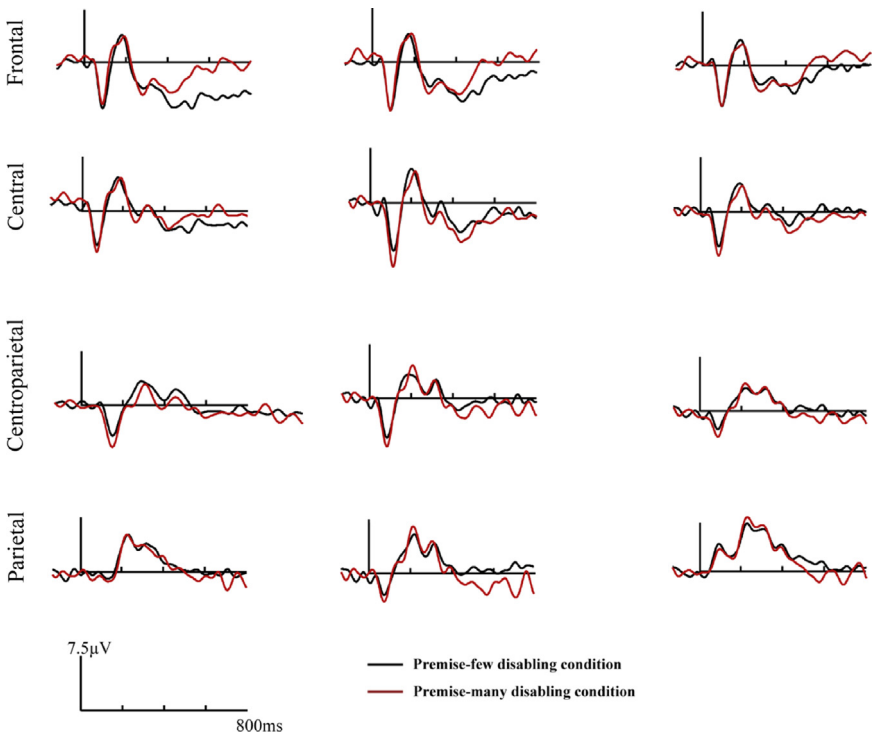

Fig. 3. Minor premise results. Stimulus locked grand-average waveforms evoked by the presentation of the minor premise for conditional with few (black line) and many (red line) disablers across the 12 sites of interest. Left electrodes are shown in the left column, midline electrodes in the middle column, and right electrodes in the right column. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

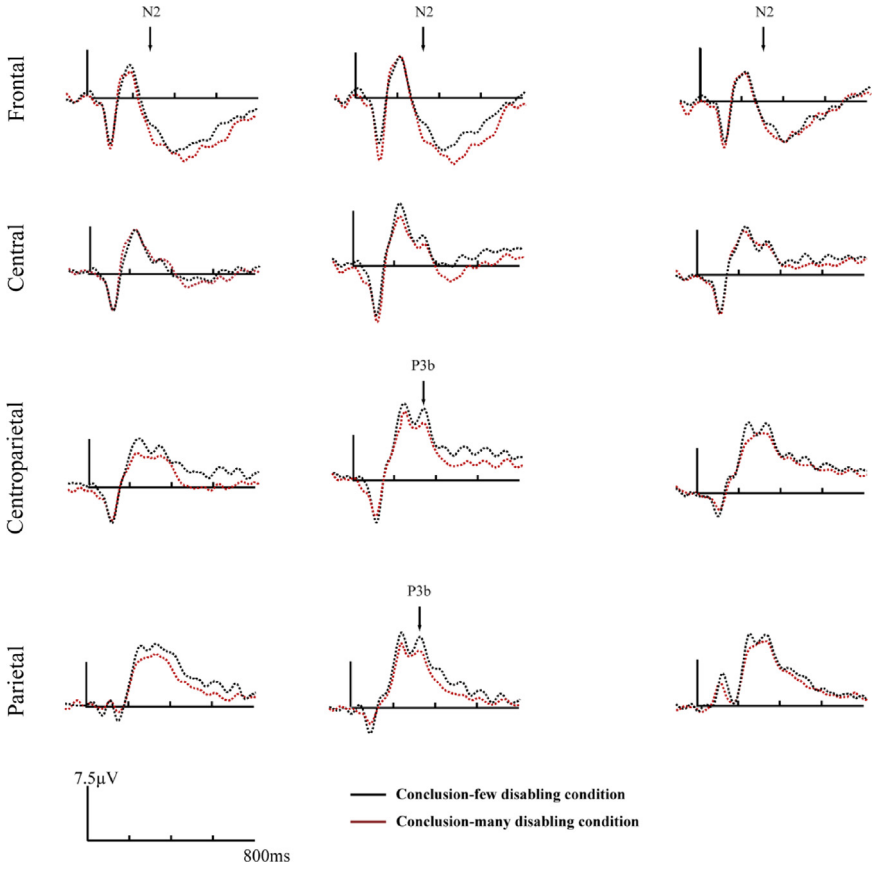

Fig. 4. Conclusion results. Stimulus locked grand-average waveforms evoked by the presentation of the conclusion for conditionals with few (dashed black line) and many (dashed red line) disablers across the 12 sites of interest. Left electrodes are shown in the left column, midline electrodes in the middle column, and right electrodes in the right column. The components of interest are shown with an arrow, and only indicated on electrodes showing statistically significant effects. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

expected MP conclusion will give rise to a clear P3b (and acceptation of the presented conclusion). Bluntly put, despite the presence of thematic content, the few disabler conditionals seem to behave like abstract conditionals. Hence, our point is not that adding thematic content necessarily changes the way we draw MP inferences. It is specifically the retrieval of disablers (which is cued by the content) that is modulating our inferences in the present case.

Note that although the N2/P3b component has been clearly linked to expectancy modulation, it is worthwhile to consider potential alternative data interpretations. The N2, for example, has also been associated with cognitive conflict and executive control (e.g., De Neys, Novitskiy, Geeraerts, Ramautar, & Wagemans, 2011; Johnstone, Barry, & Clarke, 2007; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). For example, the N2 is typically observed in go/no-go tasks in which participants must withhold an habitual "go" response to press a button whenever a "no-go" cue appears. Hence, the no-go stimulus conflicts with the "go" response and dealing with and/or solving this conflict is known to generate an N2 (e.g., Nieuwenhuis et al., 2003). Interestingly, during conditional reasoning, disabler retrieval with many disablers conditionals can be conceived to give rise to a related conflict between a formally or logically cued response and a response cued by the content of the conditional. That is, as the findings with abstract conditionals suggest, on one hand a reasoner might be intuitively tempted to accept the MP conclusion based on abstract logical knowledge (De Neys, 2012; De Neys & Bonnefon, 2013). However, on the other hand, consideration of potential disablers cued by the content of the conditional might prompt one to reject that very same conclusion. Hence, in theory the more pronounced N2 for many disablers conditionals could also reflect the presence of such conflict. Note that these expectancy and conflict interpretations need not be mutually exclusive (e.g., it has been suggested that conflict effects can be conceived as expectancy violations, e.g., Brown, 2013; Oliveira, McDonald, & Goodman, 2007). However, in the current context we feel that a pure expectancy explanation is more parsimonious. In theory, the conflict sketched above can arise as soon as the minor premise is presented. As we clarified, conclusion expectancy effects should arise when reasoners are presented with the conclusion. In the current study, the N2/P3b effects were indeed primarily located at the conclusion level. Clearly, this does not imply that there are no conditions under which such conflict-mediated N2 effects will be more prevalent. For example, as in Cummins (1995) original study and follow-up work (De Neys et al., 2002, 2003a), participants in the present study were not explicitly instructed to reason logically. It has been observed that under strict logical reasoning instructions reasoners can try to actively suppress potential disablers (e.g., Evans, 2002; Vadeboncoeur & Markovits, 1999). Under these conditions (i.e., explicit attempts at overriding potential disablers) conflict might be more pronounced too and occur at the premise stage.

We stressed that previous imaging studies of conditional reasoning predominantly focused on abstract or neutral material and failed to examine the critical impact of disabler retrieval when reasoning with thematic material. It should be clear that such an initial focus on abstract conditionals is not unreasonable given the methodological complexity and challenges of working with thematic conditionals (e.g., the need for meticulous material generation and extensive pretesting). Note that the behavioral literature has also seen a similar initial historical focus on abstract reasoning (Evans, 2002; Manktelow, 1999). Nevertheless, it is generally agreed that the key goal for any theory of reasoning is to account for people's everyday inferences which typically involves thematic conditionals (Johnson-Laird & Byrne, 2002; Manktelow, 1999). Hence, our point is that it is paramount to start examining the critical disabler modulation to test the generalization of the findings. We believe that the present study presents an important advance in this respect. In general, we hope that the study can also serve as a stepping stone or catalyst. Clearly, besides disabler retrieval there are various other content factors that may affect our conditional thinking. For example, it is well established that retrieval of alternative causes can help to avoid the Affirmation of the Consequent fallacy (Braine, Reiser, & Rumain, 1984; Cummins, 1995; Markovits, 1984, 2010). Behavioral studies have also focused on the impact of different types of conditionals (e.g., tips, warnings, promises, and causal statements, e.g., Dieussaert, Schaeken, & d'Ydewalle, 2002; Evans & Over, 2004). We belief that the present study will pave the way for a further exploration of the neural basis of these content factors in future studies.

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Appendix

See Tables A1–A3.

Table A1
Overview ANOVA results for N2 component.

Effect	*F*	*G*–*G* – *df*1	*G*–*G* – *df*2	*G*–*G* – *p*
Anterior–Posterior (AP)	39.2857	1.5457	24.7320	0.0000
Laterality (L)	4.8323	1.8532	29.6518	0.0171
Type of Conditional (TC)	1.2735	1.0000	16.0000	0.2757
Argument Level (AL)	4.3792	1.0000	16.0000	0.0527
AP × L	2.3942	2.9854	47.7674	0.0802
AP × TC	2.1507	1.305	20.8891	0.1536
L × TC	0.5527	1.3782	22.0516	0.5195
AP × AL	34.8428	1.2846	20.5545	0.0000
L × AL	7.8179	1.642351	26.2776	0.0035
TC × AL	0.4453	1.0000	16.0000	0.5140
AP × L × TC	1.0942	3.2043	51.2689	0.3623
AP × L × AL	1.4657	3.7288	59.6622	0.2264
AP × TC × AL	4.0130	1.5392	24.6273	0.0404
L × TC × AL	0.2403	1.6956	27.1310	0.7518
AP × L × TC × AL	1.4337	4.3549	69.6795	0.2288

Table A2
Overview ANOVA results for the P3b component.

Effect	*F*	*G*–G – *df*1	*G*–*G* – *df*2	*G*–*G* – *p*
Anterior–Posterior (AP)	4.0318	1.4189	22.7032	0.0440
Laterality (L)	0.7726	1.9215	30.7447	0.4657
Type of Conditional (TC)	0.4804	1.0000	16.0000	0.4981
Argument Level (AL)	2.5187	1.0000	16.0000	0.1320
AP × L	3.3546	3.0560	48.8970	0.0255
AP × TC	0.2965	1.1719	18.7513	0.6285
L × TC	0.4968	1.4503	23.2050	0.5558
AP × AL	5.7617	1.2288	19.6622	0.0210
L × AL	0.8000	1.9164	30.6624	0.4536
TC × AL	2.8758	1.0000	16.0000	0.1092
AP × L × TC	1.5491	3.6201	57.9230	0.2044
AP × L × AL	0.9170	3.2255	51.6081	0.4448
AP × TC × AL	1.1408	1.5385	24.6170	0.3225
L × TC × AL	0.1099	1.7724	28.3593	0.8739
AP × L × TC × AL	2.5505	3.8704	61.9265	0.0496

Table A3
List of the many and few disaber conditionals selected for the study.

Few disablers (translated from French)	
1.	If a candle burns then it melts
2.	If a bell is struck then it rings
3.	If iron oxides then it rusts
4.	If a cow grazes then it ruminates
5.	If a terrestrial snake moves then it crawls
6.	If a soda is shaken then it foams
7.	If a bulb is lit then it heats
8.	If a person lives then they breathe
9.	If green clay dries then it cracks
10.	If a factory runs then it produces
11.	If a sandwich loaf dries then it hardens
12.	If a grape ages then it ferments
13.	If a hen's egg rots then it stinks
14.	If the blood dries then it coagulates
15.	If a young man works out then he strengthens
16.	If a banana rots then it turns black
17.	If a volcano wakes up then it growls
18.	If a gangster squeals then he betrays
19.	If cocaine is inhaled then it stimulates
20.	If a plane takes off then it flies
21.	If a sugar piece is moistened then it dissolves
22.	If a believer practices then they pray
23.	If butter warms then it softens
24.	If pure water boils then it evaporates
25.	If a refrigerator works then it cools down
26.	If a piece of paper ignites then it burns
27.	If a kangaroo moves ahead then it jumps
28.	If a lizard's tail is cut off then it reforms
29.	If plastic overheats then it melts
30.	If sugar water is heated then it caramelizes
31.	If a bouquet fades then it tarnishes
32.	If water is frozen then it solidifies
Many disablers (translated from French)	
1.	If an athlete trains then they triumph
2.	If a match is rubbed then it lights up
3.	If a piece of art ages then it deteriorates
4.	If a television is connected then it works
5.	If an anti-wrinkle is used then it rejuvenates
6.	If a poster is taped then it will hold
7.	If a snake bites then it kills
8.	If a politician argues then they convince
9.	If a person thinks then they understand
10.	If a car starts then it hums
11.	If a flag is planted then it waves
12.	If the TV is on then it is watched
13.	If a food is expired then it poisons
14.	If the sun rises then it dazzles
15.	If a dog barks then it attacks
16.	If a student works then they succeed
17.	If a researcher seeks then they discover
18.	If a snake attacks then it bites
19.	If a horse expert bets then they pockets
20.	If a doctor treats then they heal
21.	If a patient consults then they pay
22.	If a clown juggles then they catch
23.	If a plant dries then it dies
24.	If the river water rises then it floods
25.	If a scorer shoots on target then they scores
26.	If a boat is pierced it flows
27.	If a glass falls then it breaks
28.	If an alarm sounds then it wakes up
29.	If a person sweats then they smell
30.	If a robber robs then they are arrested
31.	If a diplomat negotiates then they conclude
32.	If a fire bursts out then it spreads
Few disablers (French)	
1.	Si une bougie brûle alors elle fond
2.	Si une cloche neuve est frappée alors elle sonne
3.	Si du fer s'oxyde alors il rouille
4.	Si une vache broute alors elle rumine
5.	Si un serpent terrestre bouge alors il rampe
6.	Si un soda gazeux est secoué alors il mousse
7.	Si une ampoule est allumée alors elle chauffe
8.	Si une personne vit alors elle respire
9.	Si de l'argile verte sèche alors elle craque

Table A3 (*continued*)

10.	Si une usine tourne alors elle produit
11.	Si du pain de mie dessèche alors il durcit
12.	Si du raisin vieillit alors il fermente
13.	Si un œuf de poule pourrit alors il pue
14.	Si du sang sèche alors il coagule
15.	Si un jeune homme se muscle alors il forcit
16.	Si une banane moisit alors elle noircit
17.	Si un volcan se réveille alors il gronde
18.	Si un gangster bascule alors il trahit
19.	Si de la cocaïne est inhalée alors elle stimule
20.	Si un avion décolle alors il vole
21.	Si du sucre en morceaux est humidifié alors il mollit
22.	Si un croyant pratique alors il prie
23.	Si du beurre tiédit alors il ramollit
24.	Si de l'eau pure bout alors elle s'évapore
25.	Si un réfrigérateur fonctionne alors il refroidit
26.	Si un bout de papier s'enflamme alors il se consume
27.	Si un kangourou avance alors il saute
28.	Si une queue de lézard est coupée alors elle se reforme
29.	Si du plastique surchauffe alors il fond
30.	Si de l'eau sucrée est cuite alors elle caramélise
31.	Si un bouquet se fane alors il ternit
32.	Si de l'eau est congelée alors elle se solidifie
Many disablers (French)	
1.	Si un athlète s'entraîne alors il triomphe
2.	Si une allumette est frottée alors elle s'allume
3.	Si une œuvre d'art vieillit alors elle s'abime
4.	Si une télévision est branchée alors elle fonctionne
5.	Si un antiride est utilisé alors il rajeunit
6.	Si une affiche est scotchée alors elle tient
7.	Si une vipère mord alors elle tue
8.	Si un politicien argumente alors il convainc
9.	Si une personne réfléchit alors elle comprend
10.	Si une voiture démarre alors elle vrombit
11.	Si un drapeau est planté alors il flotte
12.	Si la TV est allumée alors elle est regardée
13.	Si un aliment est périmé alors il empoisonne
14.	Si le soleil se lève alors il éblouit
15.	Si un chien aboie alors il attaque
16.	Si un étudiant travaille alors il réussit
17.	Si un chercheur cherche alors il découvre
18.	Si un serpent attaque alors il mord
19.	Si un expert hippique parie alors il empoche
20.	Si un docteur traite alors il guérit
21.	Si un patient consulte alors il paye
22.	Si un clown jongle alors il rattrape
23.	Si une plante s'assèche alors elle meurt
24.	Si l'eau de la rivière monte alors elle inonde
25.	Si un buteur cadre alors il marque
26.	Si un bateau se perce alors il coule
27.	Si un verre tombe alors il casse
28.	Si une alarme sonne alors elle réveille
29.	Si une personne transpire alors elle sent
30.	Si un brigand cambriole alors il est arrêté
31.	Si un diplomate négocie alors il conclut
32.	Si un incendie éclate alors il s'étend

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