How does an alternative explanation reduce the continued influence effect of misinformation? An ERP investigation

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Abstract

The continued influence effect of misinformation (CIE) occurs when misinformation affects memory and decision making even after it has been corrected. Here, we focused on how providing an alternative explanation reduces the CIE by examining the neurocognitive processes underlying the correction and subsequent veracity judgements of misinformation. Employing electroencephalography (EEG), we examined event-related potentials (ERPs): the P300 during encoding of corrections, and the P300 and FN400 during subsequent veracity judgement. We compared ERPs between three conditions: misinformation that was retracted (retraction only), misinformation that was retracted with a correct alternative cause provided (retraction + alternative), and true information that was later confirmed (confirmation). Results showed that alternatives reduced the CIE significantly. During veracity judgements, the retraction + alternative condition exhibited a higher P300 than the retraction only condition, suggesting enriched episodic retrieval of alternative causes when re-encountering misinformation. In contrast, both retraction only and retraction + alternative conditions elicited a more positive FN400 compared to the confirmation condition, suggesting higher processing fluency of misinformation. Moreover, we found that greater P300 when encoding retraction and alternative causes in the retraction + alternative condition was associated with reduced CIE. Together, these findings suggested that when providing an alternative cause in correcting misinformation, both recollection and encoding processes contributed to reduced CIE. This study provided insights into the mechanisms of misinformation correction and how to reduce unwanted influence of misinformation.

Keywords: Misinformation, EEG, ERP, Continued Influence Effect, Memory

Introduction

Misinformation runs rampant in our society and permeates a wide range of topics, ranging from politics to science and public health (Bennett & Livingston, 2018; Freed et al., 2010; Friggeri et al., 2014; Kull et al., 2003; Lewandowsky et al., 2023; Poland & Spier, 2010). Identifying and correcting misinformation is crucial for making rational decisions using valid information. However, even when people are explicitly informed about misinformation, it continues to influence our attitudes, judgements, and decision making (Ecker et al., 2022), a phenomenon known as the continued influence effect (CIE, Wilkes & Leatherbarrow, 1988). The CIE is typically induced by first providing a crucial piece of misinformation (e.g., a causal explanation for an event), then subsequently retracting it. The outdated misinformation often continues to exert influences on decision making despite intact memory for the correction (Ecker et al., 2022; Wilkes & Leatherbarrow, 1988).

Mounting research has examined various factors that may reduce the CIE (Ecker et al., 2011, 2014, 2022; Lewandowsky et al., 2012; Rich & Zaragoza, 2020). These findings consistently showed that providing an alternative explanation can reduce the CIE compared to mere retracting misinformation, presumably filling the gap in understanding caused by a retraction (Chan et al., 2017, Ecker et al., 2010, 2022, Johnson & Seifert, 1994, Kendeou et al., 2019). However, the mechanism underlying the effectiveness of an alternative explanation remains unclear. Extant literature proposes two theoretical models to explain the CIE, and the role of correction in its reduction (Ecker et al., 2022). The integration model (also known as the mental model) posits that the extent of the CIE is mediated by encoding processes, such that successful encoding and integration of retractions with misinformation is necessary to reduce the CIE (Blanc et al., 2008; Ecker et al., 2017; Kendeou et al., 2014). According to this model, a retraction by itself may lead to gaps in understanding, and an alternative explanation can fill this gap during encoding. This alternative explanation would lead to a coherent model of the event and subsequently reduced CIE (Ecker et al., 2022). On the other hand, the selective retrieval model (also known as concurrent storage, retrieval failure or activation model) posits that the CIE depends on biased memory retrieval (Ecker et al., 2022). If misinformation is highly familiar, it can be automatically reactivated by retrieval cues, giving rise to the CIE when strategic monitoring fails. This strategic monitoring often implicates contextual recollection of misinformation and its corrections, when people judge the veracity of misinformation (Ayers & Reder, 1998; Butterfuss & Kendeou, 2019; Ecker et al., 2022; Schwarz et al., 2007). According to this model, providing an alternative explanation may decrease activation of misinformation and improve the efficacy of strategic monitoring processes, thus reducing the CIE. While the two models have been previously represented as competing explanations, they also complement each other, because the CIE can arise from both encoding and retrieval failures (Ecker et al., 2022). The present study aims to use electroencephalography (EEG) to investigate both encoding and retrieval processes in the CIE paradigm (retraction, correction, and veracity judgment) in order to examine how and why alternative explanations can better reduce the CIE.

Although previous neuroimaging studies using functional magnetic resonance imaging (fMRI) and EEG have examined the CIE (Brydges et al., 2020; Gordon et al., 2017, 2019; Jin et al., 2022; Lee et al., 2022), none have explored the mechanisms underlying provision of an alternative explanation in misinformation correction. While Gordon et al. (2019) examined differences between confirmations and corrections, they were unable to explore how corrections differed from retractions. Furthermore, regarding the neurocognitive mechanisms of CIE, results have been mixed. fMRI studies have found evidence for both the integration model and selective retrieval model (Gordon et al., 2017, 2019; Jin et al., 2022), while EEG studies have only provided support for the selective retrieval model (Brydges et al., 2020; Lee et al., 2022).

Discrepancies could be due to different task demands, as some studies required participants to simply comprehend the material (Brydges et al., 2020; Gordon et al., 2017; Jin et al., 2022), while others instructed participants to actively verify incoming information (Gordon et al., 2019). Additionally, some studies do not explicitly discuss the reliability of corrections presented in the experiment (Brydges et al., 2020; Gordon et al., 2017; Jin et al., 2022), which may have led to varying levels of belief and conflict detection in participants (Ecker & Antonio, 2021). In the present study, we ensured that participants would pay attention and actively process misinformation corrections, by instructing them that their memory for the corrections would be tested later. Moreover, to minimize individual differences in beliefs on correction reliability, participants were explicitly told that information presented later would always be more accurate.

To elucidate the effect of alternative explanations during both encoding and retrieval of misinformation, we designed a new EEG-based CIE paradigm with a few notable changes from previously established CIE studies (Brydges et al., 2020; Johnson & Seifert, 1994; Wilkes & Leatherbarrow, 1988). Firstly, our study included three conditions: 1) misinformation that was merely retracted (i.e., retraction only), 2) retracted but with an alternative (i.e., retraction + alternative), or 3) correct information that was confirmed (i.e., confirmation). Secondly, our paradigm uses single word stimuli instead of sentences to present key information such as causes of an event, retractions, and alternative causes – this ensures that mental processes related to encoding retractions and alternatives are precisely time locked to the event-of-interest. Thirdly, many previous studies tested the CIE on a trial-by-trial basis, immediately after encoding each event that may tax short-term memory (Brydges et al., 2020; Gordon et al., 2017; Gordon et al., 2019; Jin et al., 2022). However, oftentimes when we re-encounter misinformation, we rely on long-term memory to determine its veracity. Our study separated encoding and testing trials with longer delays (20 - 30 minutes) than previous studies, which would better separate the encoding and veracity judgement processes.

Aided by the EEG's millisecond temporal resolution in unraveling on-going information processes, we aim to investigate how encountering misinformation, retractions and alternatives may modulate event related potential (ERP) activity, especially those highly related to encoding and retrieval processes (Friedman & Johnson, 2000; Mecklinger, 2010; Mecklinger et al., 2007; Rugg & Curran, 2007). Specifically, during the encoding task, we planned to focus on the encoding P300 while presenting misinformation, its corrections, or its alternatives. The encoding P300 indexes depth of memory encoding and degrees of context updating (Brydges & Barceló, 2018; Donchin, 1981; Polich, 2007, cf. Rac-Lubashevsky & Kessler, 2019). During the subsequent veracity judgment task, we planned to investigate the retrieval P300 and the FN400, with each component focusing on different retrieval orientations. Specifically, mounting evidence suggests that the retrieval P300 is linked to episodic recollection processes, with higher P300 amplitudes indicating richer contextual retrieval of an early encoding episode (Curran, 2000; Finnigan et al., 2002; Yang et al., 2019). On the other hand, the retrieval FN400 has been linked to conceptual fluency and familiarity, with lower FN400s tracking higher processing fluency or familiarity even when conscious recollection is absent(Curran, 2004; Danker et al., 2008; Mecklinger, 2006; Mecklinger & Bader, 2020; Nie et al., 2021; Strózak et al., 2016; Stróżak et al., 2016; Wolk et al., 2006).

The integration model posits that updating an event model with retractions recruits integration processes, and that alternative explanations reduce the CIE by filling in gaps in understanding (Kendeou et al., 2014). Integration likely recruits memory encoding processes, reflected in the P300. If this is the case, we would expect greater P300 levels to correlate with better subsequent accuracy in both retraction only and retraction + alternative conditions. The selective retrieval model hypothesizes that the CIE arises due to failed strategic monitoring processing and increased misinformation fluency during memory retrieval (Ayers & Reder, 1998; Schwarz et al., 2007). Accordingly, we would expect greater recollection and less fluency (higher P300 and more negative FN400) to misinformation that has an alternative explanation compared to misinformation without an alternative.

Methods and Materials

Participants

We recruited 59 students from the University of Hong Kong (39 female; *M* = 21.0 years, *SD* = 3.5). Participants reported normal or corrected-to-normal vision, no colorblindness, chronic medical conditions, or history of severe mental illness or neurological disorders. They were pre-screened on English fluency (must be a native speaker and received education primarily in English starting from high school). Participants either received monetary compensation (at approximately 10 USD/hour) or course credit for participation. Participants were recruited through mass emails as well as from participant pools. Three participants were excluded due to errors in data collection (*n*=1) or due to low scores on the word familiarization task (*n*=2, described below). Participants were further excluded if they had fewer than 20 clean EEG epochs for EEG analysis (see below). We also examined potential outliers using the 3 median average deviations criteria, yet no outliers were identified. For results, we reported behavioral analyses from 56 participants, encoding EEG analyses from 41 participants and veracity judgment EEG analyses from 48 participants. This research was approved by the Human Research Ethics Committee of the University of Hong Kong (EA210341).

Experimental Procedure

The experiment was administered through PsychoPy version 2020.2.10 (Peirce et al., 2019). Participants completed two tasks in order: a word familiarization task, followed by an EEG-based Continued Influence Effect (CIE) task. In the word familiarization task, participants read words that would be used in the CIE task. In the EEG-based CIE task, participants completed encoding and veracity judgment tasks. During encoding, participants memorized a set of news stories and were then given ‘fact checks’ about each story (Figure 1A). Afterward, participants completed a 3-back task (around 5 minutes) as a distractor. During subsequent veracity judgement, they had to discern if the cause for a given news event was true or false (Figure 1B). The CIE task was split into two rounds with different stimuli to reduce participants’ memory load and have a more varied task set to maintain concentration throughout the experiment.

Word Familiarization task. In the task, participants were shown one word (that would later appear as causes for events) at a time on a computer screen (3s) and had to indicate whether they knew the word or not using either the ‘a’ or the ‘l’ key. Key presses were counterbalanced between participants. This familiarization task was set up to attenuate novelty-related EEG responses and ensure that participants understood the meaning of the words presented in the CIE task. Two participants were excluded from the experiment as they recognized less than 80% of the words. For remaining participants, they recognized 96.8% of the words on average, with a standard deviation of 3.7%. Moreover, trials containing unrecognized words were excluded from later behavioral and EEG analysis.

EEG-based CIE task. The task consisted of two encoding-veracity judgement rounds. In each round, participants first encoded 60 images and events divided into four conditions (Figure 1A). Participants then completed a veracity judgment task, in which they judged whether the causes of the events were true or false (Figure 1B). Between encoding and veracity judgement, participants completed a five-minute 3-back working memory distractor task, during which participants determined if the current number on screen was the same or different than the number presented three trials ago. Participants received accuracy feedback on their performance in the middle of the distractor task. Each participant completed two rounds of the encoding, 3-back, and veracity judgement tasks, each time with different stimuli. Participants were given practice trials for both encoding and veracity judgement prior to the CIE task.

Figure 1. Example procedural flows for encoding and veracity judgement trials, in the retraction + alternative condition. **A.** Each trial in the encoding block begins with an image and a short descriptive phrase. Then, an initial cause is presented, followed by an emotion rating stage. Afterwards, participants read information about what the cause is not, and finally what the correct cause is. The task ends with a second emotion rating stage identical to the first. **B.** Each veracity judgement trial begins with an image from the previous encoding task, followed by a cause word. Participants discerned whether the cause was true or false, and

rated their confidence in their answer. Red outlines denote epochs where ERP data are analyzed.

Encoding

In each of the two encoding tasks, participants learnt 60 events and their causes. During each encoding trial, participants first viewed an image in the center of the screen with a short descriptive phrase below (3s). Afterward, the word “CAUSE” appeared on screen (0.5s), followed by a fixation cross. Then, the initial cause of the event was presented on the screen (2s). Participants were then given a maximum of 2 seconds to rate their emotional reaction to the situation (image, phrase and cause together) using the 1 (most negative emotion) to 5 (most positive emotion) keys. After this, they received additional information about the causes of the event. Firstly, in the update stage, they saw the cue “Cause is NOT” (0.5s) followed by a fixation cross, signifying that the next word that would appear is not the actual cause of the event (2s). Secondly, in the final cause stage, they saw the cue “Cause IS” (0.5s) followed by a fixation cross, signifying that the next word that would appear is the actual cause of the event (2s). Finally, participants rated their emotional reaction on the same 1-5 scale to the situation again (2s). The inter-trial-interval (ITI) was set to be 2 seconds. The duration of fixation varied between 1 to 1.5 seconds. Each encoding task contained 60 trials, and participants took a break after every 15 trials.

Depending on the update stage (cause is not) and the final cause (cause is), there were four different within-subject conditions. Table 1 shows an example encoding and veracity judgement trial, with each column representing a different condition. Stimuli that do not differ between conditions span multiple columns.

Table 1. Example stimuli presented to participants during encoding and veracity judgement tasks in each of the four experimental conditions.

Condition	Retraction Only	Retraction + Alternative	Confirmation	Alternative Only[3]
Example encoding trial				
Image + Story	 "Building Collapse"			
Initial Cause	Explosion			
Update (Cause is **NOT**…)	Explosion (*Retraction*)		Earthquake (*Non-retraction*)	
Final cause (Cause **IS** …)	Unknown[1] (*No alternative*)	Earthquake (*Alternative*)	Explosion (*No alternative*)	Structure (*Alternative*)
Example veracity judgement trial				
Image				
Cause 1	Explosion[2]			Explosion[2]
Cause 2	Earthquake[2]			Structure[2]

Note. [1]The word "Unknown" is presented as the final cause in every trial in the retraction only condition. [2]Participants saw each of these cues on different trials in the veracity judgement task (order randomly determined). [3]The Alternative Only condition was used to control participants' expectations and thus the data were not examined.

Trials were randomly distributed evenly among the four conditions so that participants' expectations were controlled – they were unable to predict whether a retraction or a non-retraction, or a retraction-alternative trial would be presented until they read the last word in a trial. Note that the alternative-only condition was only included so that participants would not immediately assume a subsequent confirmation after reading a non-retraction, thus data from the final cause and veracity judgement in the alternative-only condition were not used in either ERP or behavioral analysis. However, as the update stage was identical in confirmation and alternative-only conditions, ERP data in the alternative only condition was merged with the confirmation condition for analysis.

Veracity Judgement

Each of the two veracity judgement tasks contained 120 trials in total, with the two causes tested for each of the 60 events from the corresponding encoding task. Each veracity judgement trial started with the event image as a cue (2s), during which participants were instructed to recall the event and the associated correct cause. After a fixation cross, a cause word appeared on screen (2s). Each event was tested twice, each time with a different cause. In the retraction only condition, participants were tested on the original misinformation and a word they had only seen during the initial familiarization task. In the three other conditions, participants were tested on one true and one false cause from the encoding task (Table 1). After another fixation cross, participants were given up to 4 seconds to respond true or false using the ‘a’ and ‘l’ keys on the keyboard, counterbalanced between participants. After this, participants were given up to 3 seconds to rate the confidence of their previous answer from low to high using the ‘a’, ‘s’, ‘k’, ‘l’ keys. A blank screen was shown for 1 second before the next trial. The duration of fixation crosses varied between 0.5 and 0.8 seconds. No feedback was given.

To equalize the temporal gap between encoding and veracity judgement for all stimuli, each third of the encoding trials shuffled and presented in the corresponding third of veracity judgement trials. For example, if an event appeared in the first 20 trials of encoding, the image cue for that event would appear in the first 20 trials of veracity judgement. Therefore, the temporal distance between the encoding and retrieval of each stimulus would be around 20-30 minutes.

Materials Pilot

Since we designed this new paradigm, we conducted a pilot study to choose materials before data collection. Eleven student volunteers from the University of Hong Kong completed an image and word rating task. Volunteers were shown an image, a short sentence describing an event related to the image, and two plausible cause words of the preceding event. Volunteers viewed 150 trials in total. For each trial, on a 1-3 continuous scale, participants rated their emotional reaction and arousal to the images, the degree of relatedness of each image to its accompanying short sentence, and their emotional reaction and arousal to the two cause words. Finally, they completed likelihood ratings – indicating which of the two causes was more likely to cause the event. Among the 150 trials tested, one event was removed due to feedback from participants that it was too similar to another event. Then, we removed events with an average rating greater than 2.5 or less than 1.5 in the relatedness and likelihood ratings (n = 22), the most emotionally positive and negative image and causes (n = 6), and the event with the highest likelihood rating standard deviation (n = 1). 120 stimulus sets (comprising of an image, short sentence and two causes) remained for the CIE task (for remaining ratings, see Table S1).

EEG Acquisition

Continuous EEGs were recorded with a 64-channel Waveguard cap, connected to an EEGO amplifier (10/20 system; ANT Neuro, Enschede, Netherlands). The online sampling rate was 500Hz, with the AFz electrode as the ground and the CPz electrode as the online reference during recording. To record eyeblink activity, a horizontal electrooculogram (EOG) was placed 1.5cm beside the left canthus. The impedance of all electrodes was kept below 20 kΩ during recording.

EEG Preprocessing

EEG data were processed with MATLAB 2021b, utilizing EEGLAB 2022.0 and ERPLAB 9.00 (Delorme & Makeig, 2004; Lopez-Calderon & Luck, 2014). The EOG, M1 and M2 electrodes were removed from the EEG data before analysis. The data were downsampled to 250Hz and bandpass filtered between 0.05 and 30Hz using an IIR Butterworth filter. A notch filter at 50Hz was applied to remove line noise. Bad channels were detected visually, removed, and interpolated before re-referencing to a common average. Interpolated channels were subsequently removed from the data after re-referencing. Continuous EEG were segmented into [-1000, 3000 ms] epochs, relative to the onset of stimuli-of-interest. Epochs containing large movement-related artifacts were rejected manually by visual inspection. To improve Independent Component Analysis (ICA) performance, a 1Hz high pass filter was passed prior to ICA, and components corresponding to eye movement and blink artefacts were first identified visually with the ICLabel toolbox (Pion-Tonachini et al., 2019) then corrected. Automatic artifact rejection was performed on channels and time windows in regions of interest (ROI) – any epoch containing amplitudes over ±75μV were rejected, and epochs containing peak to peak differences of over 75µV in a sliding window length of 200ms with a step size of 100ms were rejected.

In the update stage, the retraction only and retraction + alternative conditions were merged into a single retraction condition (*M* = 50.27 trials, *SD* = 5.76), and the confirmation and alternative only conditions were merged into a single non-retraction condition (*M* = 50.10 trials, *SD* = 6.16). The final cause stage consisted of the following conditions: retraction only (*M* = 25.39 trials, *SD* = 2.80), retraction + alternative (*M* = 26.49 trials, *SD* = 2.61), and confirmation (*M* = 25.44 trials, *SD* = 2.94). The veracity judgement epoch consisted of the following conditions: retraction only (*M* = 27.06 trials, *SD* = 2.57), retraction + alternative (*M* = 26.75 trials, *SD* = 2.59), and confirmation (*M* = 26.48 trials, *SD* = 2.68).

ERP Quantifications

A left parietal ROI (P1, P3, P5, PO3) and frontal ROI (Fz, F1, F2, F3, F4) were defined based on Brydges et al. (2020), (Kiat & Belli, 2017; Volz et al., 2019). For the encoding task, 15 participants with fewer than 20 trials in any condition were excluded. For the veracity judgement task, 8 participants with fewer than 20 trials while viewing correct information in the confirmation condition, or viewing misinformation in the retraction only, or viewing misinformation in the retraction + alternative conditions were excluded. Before creating ERPs, epochs were further segmented into [-200, 1000 ms] epochs, with the [-200 to 0 ms] pre-stimulus amplitude used for baseline correction.

Encoding and retrieval P300 windows were defined from 300 - 1000ms, and adaptive means were obtained in this window. FN400 adaptive means were obtained from a 300-500ms window. Adaptive means were calculated as the mean amplitude spanning 50 ms before and after the peak value within a time window for the P300, and 25ms before and after the peak for the FN400 (Nielsen & Gonzalez, 2020).

Results

Given our primary interests in the CIE, we first presented behavioral and EEG results from the veracity judgment task.

Veracity Judgement Behavior Results

Because both true causes (in the confirmation and retraction + alternative conditions) and misinformation (in the retraction only and retraction + alternative condition) were presented during the veracity judgement task, we conducted separate comparisons for veracity judgements to true information and misinformation. We examined hit rates (true responses to true causes in the retraction + alternative and confirmation conditions), and correct rejection rates (false responses to misinformation in the retraction only and retraction + alternative conditions).

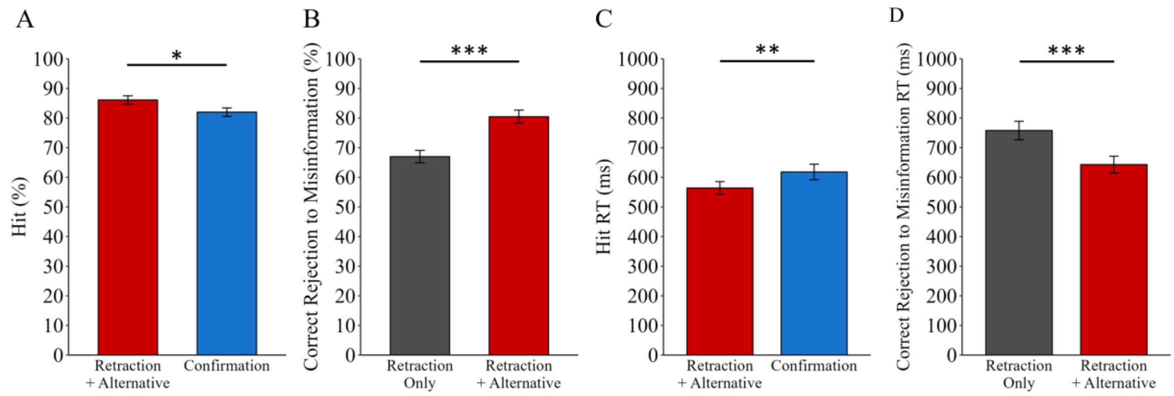

Figure 2. A. Hit rates of retraction + alternative and confirmation conditions. **B.** Misinformation correct rejection rates of retraction only and retraction + alternative conditions. **C.** Response time for hits in the retraction + alternative and confirmation conditions. **D.** Response time for correct rejection to misinformation in the retraction only and retraction + alternative conditions. Error bars represent standard error of the mean. *: $p < .05$. **: $p < .01$. ***: $p < .001$.

Paired sample t-tests showed that hit rate in the retraction + alternative condition (M = 86.11%, SE = 1.40%) was significantly higher than in the confirmation condition (M =

82.00%, *SE* = 1.42%), *t*(55) = 2.46, *p* = .017, *d* = 0.39 (Figure 2A). Regarding correct rejection of misinformation, the retraction + alternative condition (*M* = 80.47%, *SE* = 2.20%) showed a significantly higher correct rejection rate than the retraction only condition (*M* = 66.98%, *SE* = 2.10%), *t*(55) = 8.09, *p* < .001, *d* = 0.83 (Figure 2B).

Paired sample t-tests showed that response time for hits in the retraction + alternative condition (*M* = 571ms, *SE* = 21.5ms) was significantly faster than in the confirmation condition (*M* = 618ms, *SE* = 26.2ms), *t*(55) = 2.81, *p* = .007, *d* = 0.26 (Figure 2C). For correct rejection of misinformation, responses in the retraction + alternative condition (*M* = 643ms, *SE* = 28.3ms) were significantly faster than the retraction only condition (*M* = 758, *SE* = 31.2ms), *t*(55) = 5.47, *p* < .001, *d* = 0.51 (Figure 2D).

In addition, we computed sensitivity (*d'*: Z(hit) – Z(false alarm)) values for the retraction + alternative and confirmation conditions. Sensitivity could not be obtained in the retraction only condition, as hits were not possible due to the absence of a correct cause in that condition. Paired sample t-tests showed that sensitivity in the retraction + alternative condition (*M* = 2.27, *SE* = 0.15) was significantly greater than in the confirmation condition (*M* = 1.88, *SE* = .011), *t*(55) = 2.53, *p* = .014, *d* = 0.40.

These accuracy and RT results provided consistent evidence suggesting that providing both a retraction and an alternative together was more effective than providing only a retraction in reducing the CIE, as evidenced by higher accuracies in identifying true causes and in rejecting false causes, and by faster RTs in these judgments. We next examined the underlying neurocognitive processes.

Veracity Judgement EEG Results

In the veracity judgement task, we examined the FN400 and the P300 in the following three conditions: viewing misinformation in the retraction only condition, misinformation in the retraction + alternative condition, and correct information in the confirmation condition. A repeated measures ANOVA revealed a significant condition effect for the retrieval P300, $F(2,94) = 4.76$, $p = .011$, $\eta_p^2 = .092$ (Figure 3A and C). Planned comparisons revealed that the confirmation condition elicited a significantly higher P300 amplitude than the retraction only condition, $t(47) = 3.00$, $p = .004$, $d = 0.39$, but not higher than the retraction + alternative condition, $t(47) = 0.98$, $p = .331$, $d = 0.14$. Most importantly, the retraction + alternative condition elicited a significantly larger P300 amplitude compared to the retraction only condition when viewing misinformation, $t(47) = 2.29$, $p = .027$, $d = 0.26$. This suggests the retraction + alternative condition exhibits a higher level of recollection and contextual retrieval than the retraction only condition, despite both conditions viewing the same misinformation during veracity judgement.

The same ANOVA on FN400 revealed a significant difference among conditions, $F(2,94) = 4.20$, $p = .018$, $\eta_p^2 = .082$ (Figure 3B and D). Planned comparisons revealed a significantly greater (more negative) amplitude for confirmation compared to retraction only conditions, $t(47) = 2.74$, $p = .009$, $d = 0.21$. The confirmation condition also elicited a significantly greater amplitude compared to the retraction + alternative condition, $t(47) = 2.14$, $p = .038$, $d = 0.18$. However, There was no significant difference between retraction + alternative and retraction only conditions, $t(47) = 0.41$, $p = .683$, $d = 0.03$. The differences between confirmation and retraction conditions suggest that greater conceptual fluency is associated with misinformation compared to correct information.

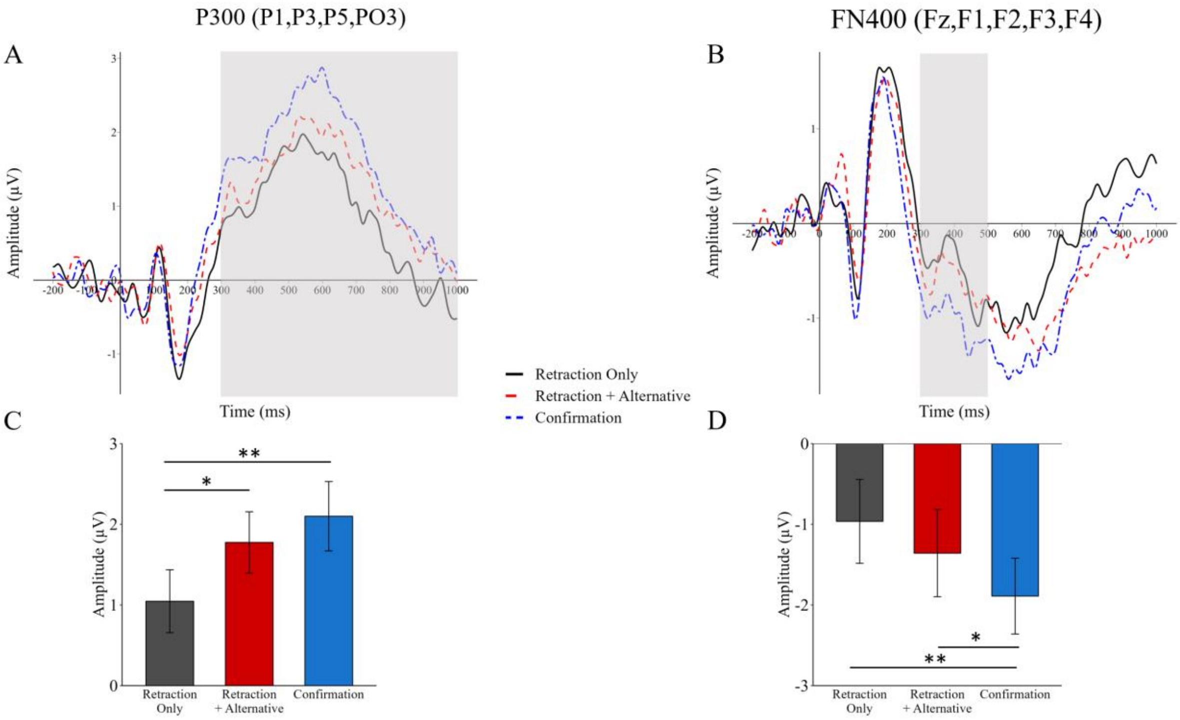

Figure 3. Grand average ERP waveforms showing activity in the left parietal region (**A**) and frontal region (**B**) while participants viewed misinformation (retraction only and retraction + alternative conditions) or correct information (confirmation condition) during veracity judgements. Adaptive mean amplitudes for the P300 (**C**) and FN400 (**D**) components. Error bars denote standard error. *: $p < .05$. **: $p < .01$.

Results from both behavioral and EEG analyses supported the idea that providing alternatives accompanying the misinformation retraction would reduce the CIE. To further examine this effect, we now analyzed EEGs from the encoding task: when participants encoded misinformation retractions and alternatives.

Encoding: Update-Related ERP Results

During the encoding update stage, we first examined EEG responses to retraction (merging retraction only and retraction + alternative conditions for the update cause) and to non-retractions (merging the confirmation and alternative only conditions for the update cause). No significant P300 differences in the left parietal region were found between retraction and non-retraction, $t(40) = 0.12$, $p = .906$, $d = 0.02$ (Figure 4A and C). Visual inspection of the

ERPs also reveals a potentially delayed peak for the non-retraction condition relative to the retraction condition. However, it must be noted that the two conditions also differed in terms of repetition, such that retractions necessarily repeated previous misinformation while non-retractions did not. Therefore, we did not further investigate the ERPs during update causes.

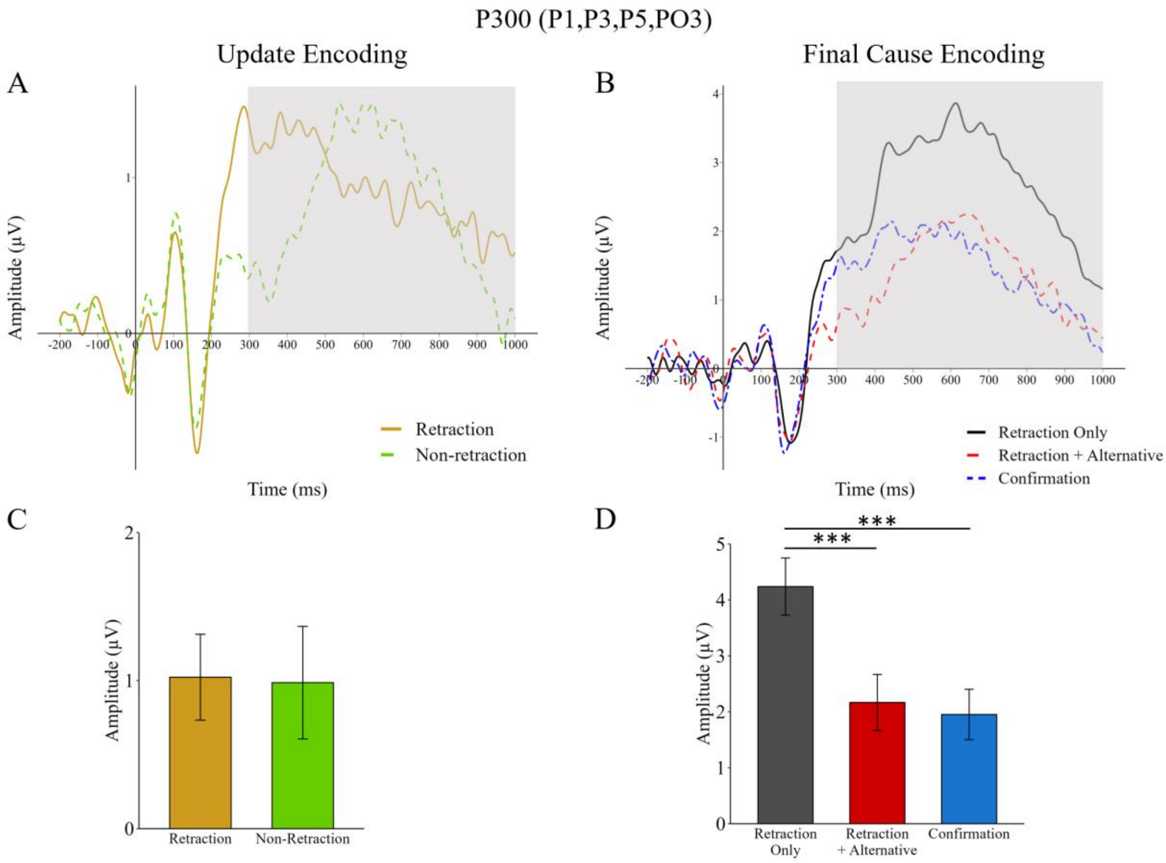

Figure 4. A) Grand average ERP waveforms showing activity in the left parietal region during the encoding update stage. **B)** Grand average ERP waveforms showing activity in the left parietal region during final cause encoding. Shaded regions indicate time windows of interest. Adaptive mean amplitudes for the P300 during encoding update (**C**) and final cause encoding (**D**). Error bars denote standard error of the mean. ***: p < .001.

Encoding: Final Cause EEG Results

In the final encoding epoch, a 3-level (retraction only vs. retraction + alternative vs. confirmation) repeated measures ANOVA results revealed a significant main effect, $F(2,80) = 16.7$, $p < .001$, $\eta_p^2 = .295$ (Figure 4B and D). Planned comparisons revealed that in the retraction only condition, seeing the word “unknown” elicited significantly higher P300 amplitude in the left parietal region than in the retraction + alternative condition, $t(40) = 3.87$, $p < .001$, $d = 0.63$, and the confirmation condition, $t(41) = 6.96$, $p < .001$, $d = 0.74$. There was no significant difference in P300 amplitude between the retraction + alternative and confirmation conditions, $t(41) = 0.51$, $p = .614$, $d = 0.07$. Once again, repetition effects may account for the P300 differences: in the retraction only condition, the final cause is always “unknown”, which may elicit stronger P300 than other conditions.

ERP-Behavioral Correlation

Although between-condition encoding ERP differences were difficult to interpret, we focused on the individual differences within each condition to account for effects of repetition. Therefore, we next examined the relationship between ERPs and veracity judgment performance. In the encoding update stage (Figure 5A, C), we first examined the relationship between P300 amplitude and sensitivity in the retraction + alternative and confirmation conditions. In the retraction only condition, since hits were not possible, correct rejection rates to misinformation and unrelated causes were used.

A positive correlation between update P300 amplitude and sensitivity was found in the retraction + alternative condition ($r(41) = .31$, $p = .046$), but not in the confirmation condition ($r(41) = .22$, $p = .163$). In the retraction only condition, update amplitude and correct rejection were not significantly correlated ($r(41) = .15$, $p = .350$)

In the final cause encoding stage (Figure 5B, D), we again found a significant positive correlation between P300 amplitude and sensitivity in the retraction + alternative condition ($r(41) = .31$, $p = .049$) but not in the confirmation condition ($r(41) = .17$, $p = .276$). Again, no significant correlation was found in the retraction only condition ($r(41) = .16$, $p = .302$).

In the veracity judgement task, no significant correlations were found between retrieval P300 amplitude, FN400 amplitude, and veracity judgement accuracy (see Supplementary Materials).

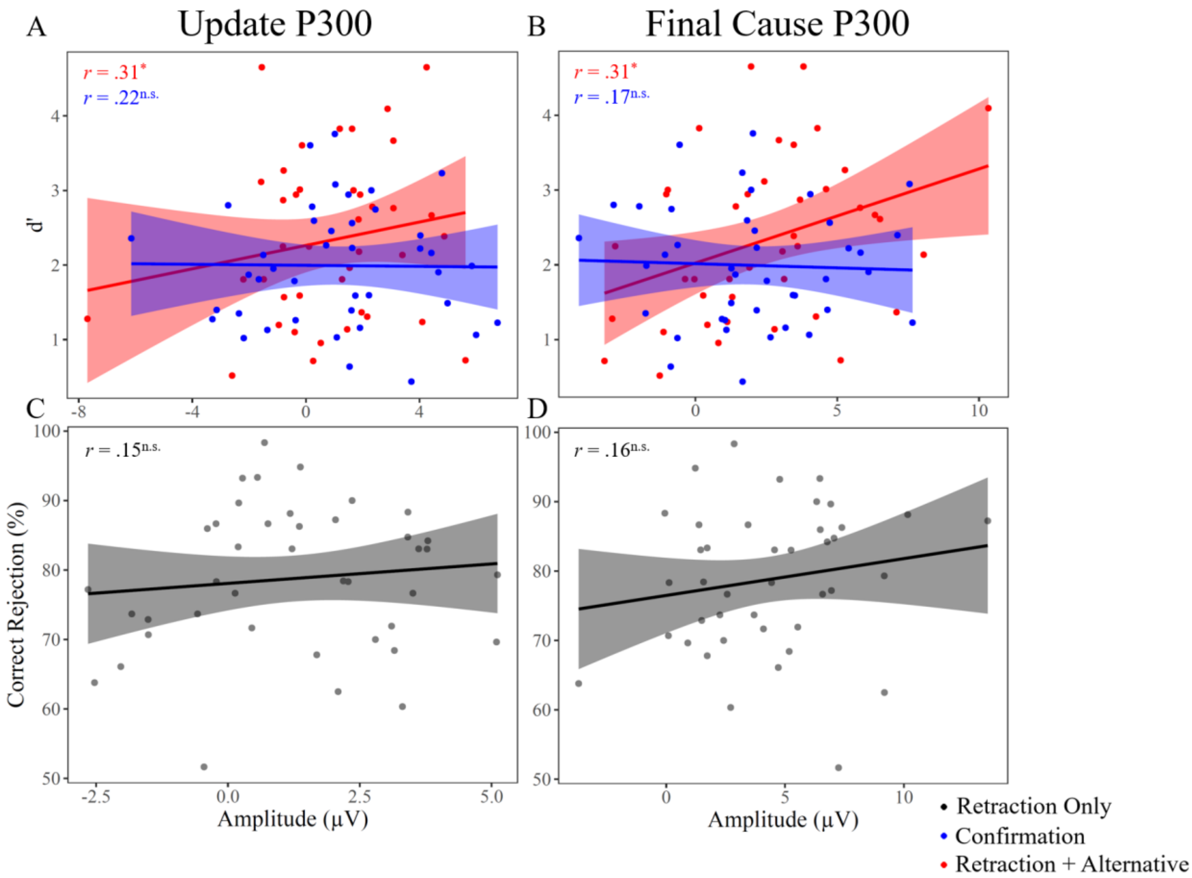

Figure 5. Correlation between sensitivity and **A.** Update P300 amplitude **B.** Final cause P300 amplitude in the retraction + alternative and confirmation conditions. Correlation between correct rejection rate and **C.** Update P300 amplitude **D.** Final cause P300 amplitude in the retraction only condition. *: $p < .05$, n.s.: $p > .05$.

Discussion

Misinformation can have long-lasting negative influences on our judgments even when it is retracted, a phenomenon known as the continued influence effect (CIE, Ecker et al., 2022). In combatting misinformation's continued influences, we found that providing an alternative cause with a retraction significantly reduced the CIE than only providing a retraction, as evidenced by higher accuracies and faster response times in discerning between true and false causes (see also Ecker et al., 2022; Johnson & Seifert, 1994; Lewandowsky et al., 2012; Wilkes & Leatherbarrow, 1988). Elucidating the underlying neurocognitive mechanisms, we found that misinformation elicited a greater P300 when it was provided with an alternative explanation, compared to when only a retraction was provided, reflecting improved contextual recollection of the true causes. Moreover, within this retraction + alternative condition, we also found that larger P300 during encoding was associated with higher veracity judgment accuracies, suggesting that effective encoding of both retraction and alternative may be an important prerequisite to reducing the CIE.

Beginning with results of greatest importance, we found that retrieval P300 to misinformation was higher in both retraction + alternative and confirmation conditions than the retraction only condition during veracity judgements. Prior research on memory retrieval suggests that P300 tracks conscious episodic recollection, with higher P300 being associated with richer contextual recall and more episodic details (Allan et al., 1998; Curran, 2000; Finnigan et al., 2002; Voss & Paller, 2009; Yang et al., 2019). Consistent with the selective retrieval model, these results suggested that providing an alternative cause during encoding led to enhanced strategic monitoring processes during subsequent veracity judgements to misinformation. (Ayers & Reder, 1998; Butterfuss & Kendeou, 2019; Ecker et al., 2022; Schwarz et al., 2007). The recollection of an alternative could then aid misinformation detection by a recall-to-reject process (Morcom, 2015). Moreover, events that were confirmed have a more coherent event model than events without a clear cause (Ecker et al., 2022), which could also lead to improved recollection during veracity judgement. Judging misinformation in the retraction only condition was associated with the smallest P300 and thus lowest levels of recollection, potentially a result of an incoherent event model. Overall, P300 results during veracity judgement suggest that retracting the cause of an event may lead to weaker memory recollection for the event, and that providing an alternative during encoding facilitates misinformation rejection through strategic monitoring processes.

Examination of FN400 amplitude – associated with conceptual processing fluency or familiarity (Nie et al., 2021; Rugg & Curran, 2007; Strózak et al., 2016; Voss et al., 2010; Voss & Paller, 2008) – during veracity judgement revealed a more negative FN400 for confirmation than retraction only condition. This suggested that misinformation in the retraction only condition was processed with greater conceptual fluency than correct information in the confirmation condition. This provides evidence for claims that misinformation may be preferentially selected due to its increased fluency (Ayers & Reder, 1998). However, no differences were found between the retraction only and the retraction + alternative condition, suggesting that providing an alternative during encoding may not influence subsequent conceptual fluency of misinformation.

Individual difference analyses during the encoding stage provided additional insight into the mechanisms behind the CIE. We found that when alternative causes were provided, larger P300s during the encoding (both update and final cause) were associated with better sensitivity in veracity judgments and thus lower CIE. This suggests that in the retraction + alternative condition, encoding during both the updating and alternative cause stage were integral to veracity judgement. Successful hits may rely on encoding alternatives, and correct rejections may rely on encoding retractions.

The above findings can elucidate mechanisms behind how providing alternative causes could decrease the CIE: an alternative provides boosts strategic monitoring processes during veracity judgement but does not necessarily alter the conceptual fluency of misinformation itself. The comparable FN400 suggests similar levels of misinformation fluency between retraction only and retraction + alternative conditions, which means correct alternatives may not weaken misinformation representation; they may be encoded alongside each other instead. The extent to which an alternative reduces CIE may be moderated by the level of memory encoding for both retractions and alternatives during encoding: if retractions and alternatives are encoded weakly, the CIE persists.

The current study focused on similar ERP components to a recent EEG-CIE study (Brydges et al., 2020), but contradict some of their findings. In their study, viewing misinformation elicited increased P300s compared to correct information during veracity judgement. In a similar comparison, our study found that viewing correct information and misinformation that had an alternative enhanced P300s compared to viewing misinformation without an alternative during veracity judgement. This discrepancy between studies could be due to repetition: in Brydges et al., 2020, correct information only appeared one time and was not confirmed or retracted later in the story. However, in our confirmation condition, correct information was shown twice – once initially, and once at the end of the trial as a confirmation, which may have strengthened subsequent recollection. Another contradictory finding lies in the FN400 results: whereas Brydges et al. found that FN400 for misinformation was more negative than correct information, we found that FN400 was more positive for misinformation compared to correct information. Such a discrepancy could once again be due to stimuli repetition: in Brydges et al., misinformation was presented twice whereas correct information was presented once during encoding. In our study, however, both misinformation and confirmed information were presented twice. Thus, the results may not be directly comparable between these two studies.

The current study has limitations that may affect how the above findings can be interpreted. Stimulus repetition during encoding may have obscured the effects of retraction, making it difficult to draw conclusions from the encoding ERP, as previous studies have shown that repetition of a stimulus may influence its amplitude and latency (Bentin & Peled, 1990). Furthermore, given the limited number of trials in each condition, we could not perform analyses examining ERPs differences based on whether CIE emerged or not, i.e., by comparing correct rejection vs. incorrect acceptance ERPs. Future studies could use a larger number of trials, adopting a subsequent memory approach to provide insights into when CIE happens. Finally, more nuanced measures of the CIE – such as inference questions that are commonly used in traditional studies of the CIE – can also be implemented to investigate more ecologically valid measures of how outdated information can influence decision making from a neural perspective.

Conclusion

By adapting the CIE paradigm for EEG, we illuminate neurocognitive processes during encoding of retractions/corrections to misinformation and subsequent veracity judgments, particularly when alternatives were provided to correct misinformation. We found that although providing an alternative reduced the CIE via enhancing strategic memory recollection processes during veracity judgement, strong encoding of retractions and alternatives was an important prerequisite. To better combat undesirable aftereffects of misinformation, merely providing a retraction is not enough – it is important to provide alternatives for people to encode and to retrieve during veracity judgments.

Author Contributions

S.G.: Conceptualization, Investigation, Methodology, Resources, Software, Formal Analysis, Visualization, Writing – Original draft, Writing – Review & Editing. **D.C.:** Conceptualization, Methodology, Validation, Writing – Review & Editing. **X.H.**:

Conceptualization, Methodology, Funding Acquisition, Supervision, Writing – Review & Editing.

Conflicts of Interest

All authors have no conflicting interests to declare.

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Data Availability

The raw behavior data and preprocessed ERP data are available at: https://osf.io/k2my5/

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