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John E. Kiat
University of Nebraska-Lincoln, johnemmanuelkiat@gmail.com

Robert F. Belli
University of Nebraska-Lincoln, bbelli2@unl.edu

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An exploratory high-density EEG investigation of the misinformation effect: Attentional and recollective differences between true and false perceptual memories

John E. Kiat [*], Robert F. Belli

University of Nebraska-Lincoln, United States

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The misinformation effect, a phenomenon in which eyewitness memories are altered via exposure to post-event misinformation, is one of the most important paradigms used to investigate the reconstructive nature of human memory. The aim of this study was to use the misinformation effect paradigm to investigate differences in attentional and recollective processing between true and false event memories. Nineteen participants completed a variant of the misinformation paradigm in which recognition responses to true and misinformation based event details embedded within a narrative context, were investigated using high-density (256-channel) EEG with a 1-day delay between event exposure and test. Source monitoring responses were used to isolate event-related-potentials (ERPs) associated with perceptual (i.e. event) source attributions. Temporal-spatial analyses of these ERPs showed evidence of an elevated P3b and Late-Positive Component, associated with stronger context-matching responses and recollective activity respectively, in true perceptual memories relative to false misinformation based ones. These findings represent the first retrieval focused EEG investigation of the misinformation effect and highlight the interplay between attention and retrieval processes in episodic memory recognition.

1. Introduction

Memory researchers have long known episodic (i.e. event) memory to be vulnerable to distortion, often with serious consequences (see Loftus, 2003 for a review). Of particular interest is the phenomena of false recollection-based recognition, instances wherein inaccurate source information is retrieved, evaluated as veridical and subsequently used as the basis for endorsement (see Yonelinas, 2002 for a review).

A key approach in investigating this class of false memories is the misinformation paradigm. In this experimental design, individuals witness an event, receive misleading post-event information, and are later tested on their memories for the original event (Loftus, 2003). During testing, participants frequently misreport misinformation based details as being part of the original event. These false memories are often accompanied by perceptual recollections comparable with (Belli, Lindsay, Gales, & McCarthy, 1994; Mitchell & Zaragoza, 1996), although weaker, than that of true memories (Schooler, Gerhard, & Loftus, 1986). The ease in which perceptual false memories can be created on the misinformation paradigm have had far reaching real-world consequences, calling into question the reliability of eyewitness reports and recovered memories of childhood abuse (Loftus, 2003).

In recent years, there has been significant interest in developing a deeper understanding of the neural processes that differentiate between these accurate and inaccurate event memories (Johnson, Raye, Mitchell, & Ankudowich, 2012). Thus far, the sole neuroimaging investigation of memory retrieval involving the misinformation effect has been an fMRI study by Stark, Okado, and Loftus (2010) which found increased activation in early visual and inferior parietal regions, in true relative to false memories. However, as true memories in Stark et al. (2010) were defined as event memories recognized as being true even after being subject to misinformation, the extent and nature to which the neural signature of event memories not targeted by misinformation vary from misinformation-based memories remains uncertain. Furthermore, the relative roles attention and retrieval related processes play in distinguishing between true event and misinformation based memory recognition remains unknown.

Given the importance of these issues, it is surprising that the sole EEG investigation involving the misinformation effect has

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[*] Corresponding author at: University of Nebraska–Lincoln, Department of Psychology, 34 Burnett Hall, Lincoln, NE 68588-0308, United States.

E-mail addresses: johnkiat@huskers.unl.edu (J.E. Kiat), bbelli2@unl.edu (R.F. Belli).

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been an investigation by Meek, Phillips, Boswell, and Vendemia (2013). Meek et al. (2013) were primarily interested in the neural correlates of deception and with that goal in mind, incorporated design parameters such as multiple presentations of the same two control and misinformation items, short retention intervals, a focus on response event-related potentials (ERPs) as opposed to recognition processing, a lack of source monitoring judgments and the use of a two alternative-forced-choice testing format without a "guess" or "don't know" option. These design choices, although clearly suitable for studying deception detection, limit the generalizability of Meek et al.'s (2013) findings to issues of false memory recognition.

In the present study, we utilize an EEG-suitable version of the misinformation paradigm to investigate differences between true and misinformation based recognition memories. Participants viewed several events depicted in a series of picture slides before receiving misinformation on those events 30 min later. Recollection of the originally viewed events was tested 1-day later using a novel paradigm in which neural responses to critical item details embedded within a narrative context were recorded using EEG and contrasted based on subsequent true/false and source attribution judgments.

One of the major challenges in adapting the misinformation effect paradigm for neuroimaging is establishing a tradeoff between a sufficient number of trials for an acceptable signal-to-noise ratio while maintaining the integrity of the paradigm by not having an excessive number of events and misinformation that may overly emphasize processes as discrepancy detection, minimizing the observation of false recollections of misinformation. Thus in line with prior neuroimaging investigations of retrieval activity on the misinformation effect (Stark et al., 2010), our analyses focus on three response categories, perceptual misinformation endorsements (False Alarms), perceptual true memory endorsements (Hits) and perceptual misinformation rejections (Correct Rejections) given that an unreasonable number of items would be needed to assess neural responses to perceptual true memory rejection (Misses). Within our target response categories, our neural components of primary interest are the Late Positive Component (LPC) and the P300, specifically the P3b subcomponent.

A third component often involved in memory ERP studies is the FN400, a component associated with higher levels of familiarity memory (Curran, 1999). However, given that misinformation effect paradigm involves prior exposure to both true event and misinformation details, both these memory traces have relatively high levels of familiarity. This is supported by behavioral studies which indicate misinformation effect responses are associated with high levels of familiarity (Lindsay & Johnson, 1989; Mitchell & Zaragoza, 1996, 2001). This notion that both true and misinformation endorsements are associated with equivalent levels of familiarity, in addition to our use of a source monitoring test which requires participants to actively retrieve source information instead of relying on familiarity based strategies (Lindsay & Johnson, 1989; Zaragoza, Belli, & Payment, 2007), make it unlikely that true and false memories to be distinguished by familiarity related processed indexed by the FN400.

Our first component of interest, the LPC, is a positive ERP modulation maximal over medial posterior recording sites, with a tendency to be more focused over the left hemisphere (Friedman & Johnson, 2000), around 400 to 800 ms post-stimulus which has been associated with the recollection of accurate source information from both a threshold (Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Rugg, Schloerscheidt, & Mark, 1998; Vilberg, Moosavi, & Rugg, 2006; Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1996) and graded perspective (Leynes & Phillips, 2008; Paller, Kutas, & McIsaac, 1995; Wilding, 2000; Woroch & Gonsalves, 2010), mapping onto phenomenological reports of recollection-based recognition (Woodruff, Hayama, & Rugg, 2006). In line with its proposed role in memory related processing, the episodic memory related LPC has been associated with activity in the left medial temporal (Duzel et al., 2001) and parietal regions (Caplan, Glaholt, & McIntosh, 2009; Pérez-Mata, López-Martín, Albert, Carretié, & Tapia, 2012).

Given the links between the LPC and source recollection, evidence for reduced reliance on verbatim (Brainerd, Reyna, & Ceci, 2008) and source features (Mather, Henkel, & Johnson, 1997) in false memories suggests that the LPC triggered by the presentation of true event memory probes will be more positive than that of false misinformation based ones. This hypothesis also draws support from prior investigations into false perceptual memories utilizing reality monitoring paradigms which have shown false perceptual memories for word items (i.e. presented as word, classified at test as being presented as a picture) to have reduced LPC levels relative to true perceptual memories (i.e. presented as picture, classified as picture) (Gonsalves & Paller, 2000). Misinformation rejections made on the basis of retrieving conflicting perceptual event information are also likely to show elevated LPC levels relative to false memories, though to weaker degree relative to true memory recognition in which the true event detail is provided as a retrieval cue.

Our second ERP component of interest, the P3b, is a subcomponent of the P300 complex, a positive ERP component maximal over parietal recording sites, peaking between 250 to 500 ms post-stimulus presentation associated with enhanced focal attention for a target stimulus (Polich, 2007). The P3b has been associated with memory operations involved in assessing the degree to which incoming targets match (or do not match) internal pre-activated representations in working memory for subsequent action-taking (Fogelson & Fernandez-del-Olmo, 2011; Kok, 2001; Molinaro & Carreiras, 2010; Thatcher, 2012). Elevated P3b levels are linked with both a strong match between pre-activated contextual expectations and presented cues (Molinaro & Carreiras, 2010) as well as unexpected deviations between contextual expectations and actual outcomes (Kopp & Lange, 2013; Seer, Lange, Boos, Dengler, & Kopp, 2016; Sutton, Braren, Zubin, & John, 1965). In contrast, stimuli that receive low levels of attentional processing illicit a considerably weaker P3b response (Alperin et al., 2013; Ciesielski, Knight, Prince, Harris, & Handmaker, 1995). Prior source localization of the P3b response have highlighted the role of the inferior parietal lobe and temporoparietal junction in generating this component (Linden, 2005).

In the context of episodic memory recognition, the P3b has been shown to play a key role in concealed memory detection investigations in which images or probe sentences are presented with a subset of items being part of a previously studied mock crime event (Gamer & Berti, 2012) or other recent episodic experiences of participants (Ganis & Schendan, 2012; Meixner & Rosenfeld, 2014). In these studies, probes linked with true episodic memories are associated with elevated P3b levels, relative to neutral (Gamer & Berti, 2012; Meixner & Rosenfeld, 2014) and non-episodic (Ganis & Schendan, 2012) probes.

The likelihood of stronger context-item matches in true memory responses and the fact that false event memory rates are associated with more liberal responding (Luna & Migueles, 2008; Van Damme, 2013) and less stringent monitoring (Loftus, Donders, Hoffman, & Schooler, 1989; Parker, Garry, Engle, Harper, & Clifasefi, 2008) suggests that misinformation based false memories will be associated with reduced P3b levels relative to true episodic memories. However, it is also possible that some level of discrepancy detection will be present even for endorsed misinformation memories elevating the P3b voltage for these responses. It is also possible that prior exposure to true and misinformation details in the event slides and misinformation narrative respectively, will result in a largely equivalent context-match signal in both true and false memories. The case for perceptual misinformation rejections is similar as while the link between elevated P3b levels and discrepant outcome processing (Kopp & Lange, 2013; Seer et al., 2016) suggests these responses will be associated with elevated P3b levels, it is unclear if this discrepancy detection response will exceed the context-match response in true memories or be at a similar level. Given the known value of the P3b response in differentiating between various classes of episodic memory (Gamer & Berti, 2012; Ganis & Schendan, 2012; Meixner & Rosenfeld, 2014), our investigation represents an important test of these possibilities.

To summarize, holding the attribution of recollection to a perceptual (i.e. event) source constant, the two primary hypotheses of our study is that relative to misinformation based details, narrative context primed recognition of (1) true episodic details and (2) rejection of misinformation details will be associated with higher levels of source retrieval activity as indexed by elevated LPC levels. Our study will also investigate P3b response differences between true memory endorsements, misinformation rejections and misinformation based endorsements, tentatively hypothesizing elevated P3b levels in the first two response categories relative to the third.

2. Methods

2.1. Participants

Nineteen participants (12 female, 4 left-handed, mean age = 19.84, SD = 2.49, range 18–23) participated in this study. The local IRB approved all procedures with subjects providing informed consent and receiving research credit for their participation. The sample size was determined based on power analyses of LPC and P3b differences in prior ERP investigations contrasting true and false memory perceptual memories (Gonsalves & Paller, 2000), as well as relevant and irrelevant event item (Gamer & Berti, 2012) and word probe (Meixner & Rosenfeld, 2014) concealed information test differentiation.

2.2. Paradigm

This experiment had three phases, event study, misinformation exposure and test. There was a 30-min retention interval between event and misinformation exposure and a one-day interval between misinformation exposure and test. In the study phase, participants viewed four events sequentially, each depicted in a series of 50 digital color slides (Okado & Stark, 2005). These separate events depicted (1) a man breaking into a car, (2) a woman's wallet being stolen, (3) a repairman stealing office supplies and (4) two friends getting into a fight. Presentation order of the events was randomized across participants. Each slide was presented for 3500 ms with a 500 ms blank screen between slides. Twenty-four slides from each series contained critical details, half of which served as targets of misinformation and half as control items during a later narrative phase.

The event phase was followed by a 30-min retention interval during which participants completed a filler task involving viewing and evaluating the functions of several everyday objects (none of which were present on the event slides). After this interval, participants studied four narratives with each purportedly redescribing one of the previously presented events. Each narrative consisted of 50 sentences, one for each event slide, each presented on screen for 3500 ms with a 500 ms blank screen between sentences. Twelve of those details were described inaccurately (misinformation) with the other twelve described accurately (consistent control).

Testing was conducted between 12 pm and 5 pm on the following day. The decision to temporally group event and misinformation study together with a 1-day delay was to ensure that differences between the neural signature towards event and misinformation based memories would not be attributed to differences in retention interval which would have been the case if the misinformation had been presented prior to testing.

During the testing phase, participants were tested on all 48 misinformed details (12 from each event) and, due to testing time constraints, 40 randomly selected details from the 48 control items (10 from each event). The testing procedure is presented in Fig. 1. Participants were instructed to make source judgments by indicating seen, read, seen and read, or guess, on the basis of the recalled source in which they were basing their True/False evaluation. All responses were made on a 4-key buttonbox. A blank screen was presented for 2000 ms between each trial. Participants were instructed to abstain from blinking in slides A through D and permitted to blink during Slides E & F. Test items were blocked by event and presented in random non-chronological order within blocks. A short sentence reinstated the context of each event at the start of each block.

2.3. Procedure

The study consisted of two sessions. In the first session, participants completed the event and misinformation study phases. In this session, participants were instructed that the goal of the study was to investigate the neural processes of event memory. They were then seated in individual testing rooms where they viewed the events slides and misinformation narratives on a computer screen. At the end of the session, the participants were dismissed and reminded to return and attend the testing session on the next day.

EEG activity was recorded during second session in which participants were tested on their memory for the presented events.

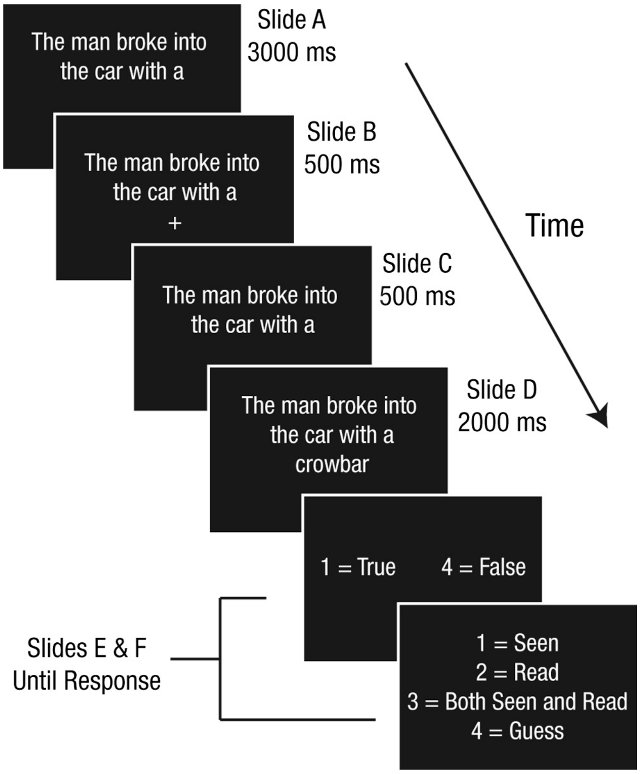

Fig. 1. Testing procedure and presentation durations.

Participants were tested individually with two experimenters monitoring the participant and real-time waveforms for ocular and movement artifacts. Participants were seated in a quiet dark room facing a computer monitor placed 1 m away with a 4-button buttonbox in their hands. EEG data was recorded using a 256 high-density AgCl electrode Hydrocel Geodesic Sensor Net connected to a NetAmps 300 amplifier on Netstation version 4.4.2. Electrode impedances were below 45 kΩ, a level appropriate for the high impedance system. Incoming data was analogue filtered from 0.1 to 100 Hz and digitized at 250 Hz.

2.4. EEG preprocessing

First, the continuous EEG was digitally filtered using a 0.3–30 Hz zero-phase shift finite impulse response bandpass filter (0.2 Hz transition band width, −53 dB stop-band attenuation, 0.0022 max passband deviation). The filtered data was then segmented to the onset of the critical item presentation (Slide D in Fig. 1), beginning 100 ms before onset and continuous for 1000 ms thereafter.

The Automatic Artifact Removal (AAR) toolbox (Delorme & Makeig, 2004; Gomez-Herrero et al., 2006) was then used to remove ocular and electromyographic artifacts using spatial filtering and blind source separation. Bad channels were then identified and interpolated in ERP PCA Toolkit (version 2.49; Dien, 2010). Bad channels were identified across the entire session via poor overall correlation (<0.40) between neighboring channels and identified within each segment via unusually high differences between an electrode's average voltage and that of their neighbors (>30 μV) and/or via extreme voltage differences within electrode channels (>100 μV min to max). A channel was also marked as bad for the entire session if >20% of its segments were classified as being bad. All identified bad channels were replaced using whole head spline interpolation. After bad channels were identified and interpolated, trials with >10% interpolated channels were removed from the analysis set. Segments were then re-referenced to an average reference and baseline corrected using the 100 ms pre-stimulus average.

As anticipated, there was an insufficient number of Perceptual Control Rejections (Mean = 7.16, *SD* = 2.79) for reliable analysis. The average number of clean trials in the three critical categories (Control Endorsement, Control Rejection, Misinformation Endorsement, Misinformation Rejection), all of which were included in subsequent analyses, was 13.21 (*SD* = 4.21) in the Perceptual Misinformation Endorsement Category, 20.07 (*SD* = 5.20) in the Perceptual Control Endorsement Category and 16.02 (*SD* = 4.08) in the Perceptual Misinformation Rejection category.

3. Results

3.1. Temporal-spatial analysis

ERP components were quantified using temporal-spatial PCA in ERP PCA Toolkit. First a temporal PCA was performed on the data using all time points from each participant's averaged ERP as variables, considering participants, condition and recording sites as observations. This step reduced the temporal structure of the ERP data (275 measurement points) to a set of temporal components. Promax rotation was used and nineteen temporal components (92% of total variance) were extracted based on parallel analysis (Horn, 1965).

The spatial distribution of these components was then decomposed using spatial PCA. This PCA used all recording sites as variables, considering participants, conditions and temporal factor scores as observations. This step reduced the electrode structure (257-channels) to a set of virtual electrodes on which the original electrodes loaded on. Infomax rotation was used and six spatial components (72% of total variance) were extracted based on parallel analysis.

Standardized Low Resolution Brain Electromagnetic Tomography (sLORETA; Pascual-Marqui, Michel, & Lehmann, 1994) was used to estimate the standardized distribution of current density of the grand-average waveform (averaged across all response conditions) during the peak time point of all components. The significance threshold was estimated using a statistical non-parametric mapped permutation test (Nichols & Holmes, 2002), utilizing 10,000 randomizations of 6430 voxels (3-shell spherical head model, 5 mm resolution) with subject-wise normalization.

Selection of the LPC and P3b components was done in a two-step process. First, components that accounted for at least 40 ms of temporal-spatial variance were identified. Three components met this criterion, a posterior positivity with a peak timespan (component temporal loadings > 0.8) 288–416 ms post-onset (4.2% of total variance), a posterior positivity peaking 444–616 ms post-onset (6.7% of total variance), and a weak late positivity spanning 772–900 ms post-onset onset (4.2% of total variance). Based on their time-course and topography in light of prior P3b (see Polich, 2007 for a review) and LPC work (Curran, Schacter, Jonson, & Spinks, 2001), the first component (288–416 ms) was classified as the P3b whereas the second was classified as a LPC (444–616 ms). An analysis of the third component (see Appendix A) showed its voltage levels were not significantly moderated by response category.

The source localization of these components supported the classifications of the P3b and LPC. The P3b component localized to the right inferior parietal lobule, a region repeatedly associated with the P3b (Linden et al., 1999), e.g. (Hesselmann, Flandin, & Dehaene, 2011) and attentional processing (see Singh-Curry & Husain, 2009 for a review). The LPC localized to the left parahippocampal gyrus, a region associated with LPC activity e.g. (Hoppstädter, Baeuchl, Diener, Flor, & Meyer, 2015; Klaver et al., 2005) and episodic memory retrieval (see Wais, 2008 for a review) as well as true and false item memory differentiation (Cabeza, Rao, Wagner, Mayer, & Schacter, 2001; von Zerssen, Mecklinger, Opitz, & von Cramon, 2001). Critically, both these regions have been previously implicated in differentiating between response categories in the misinformation effect paradigm (Stark et al., 2010).

The time course and scalp topographies of these components are shown in Fig. 2 while the grand average waveforms for electrodes with high loadings on the components are shown in Fig. 3.

3.2. Behavioral data

Test performance is presented in Tables 1 and 2. Table 1 shows the breakdown of control items as a function of endorsement versus rejection and subsequent source judgment. Table 2 presents the same breakdown for misinformed items. "Seen" and "Seen & Read" responses (i.e. perceptual attributions), was the critical response category focused on in subsequent analyses.

Pairwise *t*-tests indicated that participants made more control endorsements than misinformation endorsements with perceptual attributions ($t(18) = 7.405$, $p < 0.001$), and a greater number of perceptual based misinformation rejections than misinformation endorsements ($t(18) = 5.012$, $p < 0.001$). An analysis of the response time data showed that participants took longer to respond to misinformation endorsements (M = 1926 ms (ms) SD = 1027) relative to misinformation rejections (M = 1647 ms SD = 854, $t(18) = 3.100$, $p = 0.006$) and control endorsements (M = 1614 ms SD = 936, $t(18) = 3.098$, $p = 0.006$) which did not differ significantly from each other ($t(18) = 0.330$, $p = 0.745$).

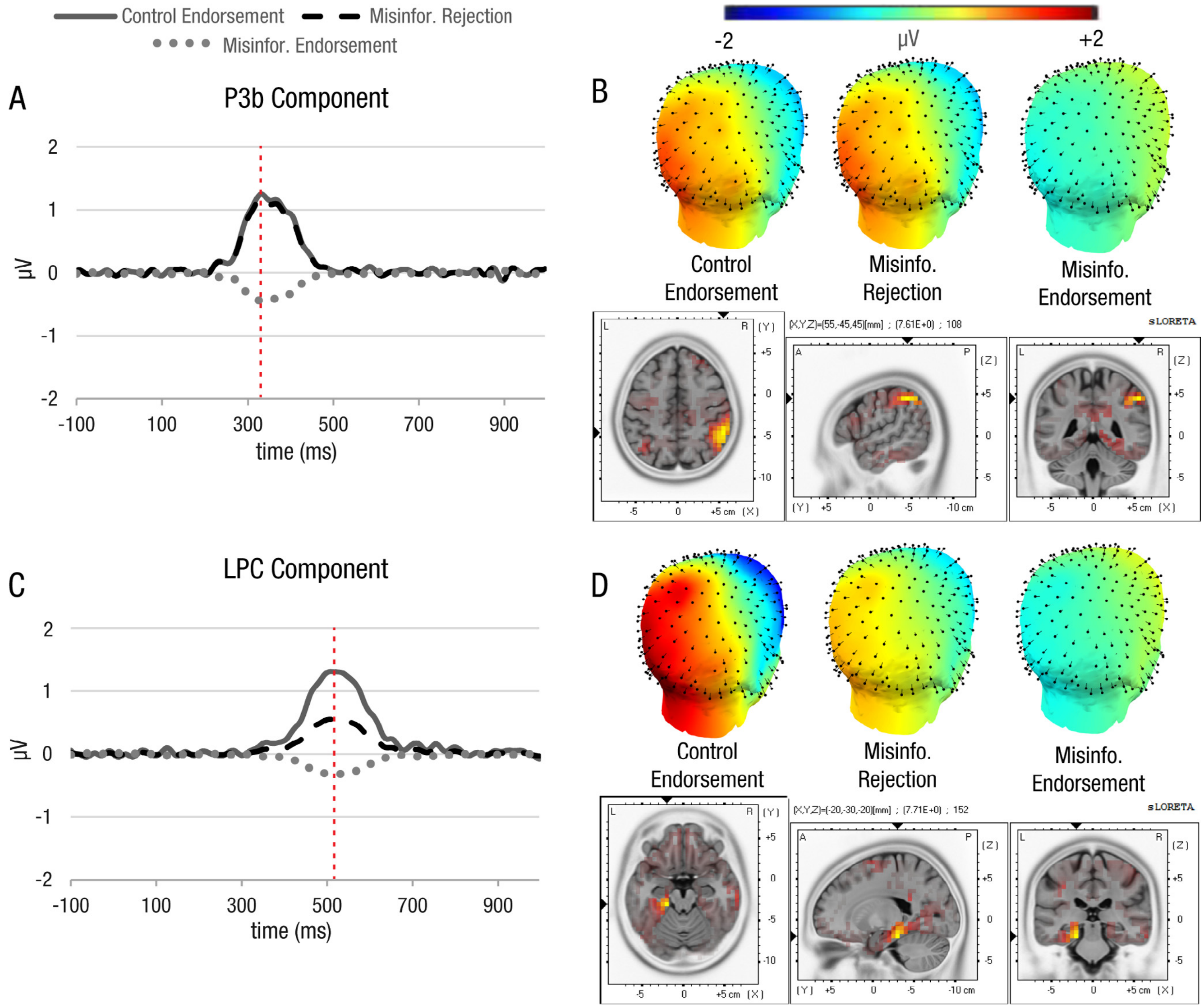

Fig. 2. Component waveforms, scalp topographies and sLORETA localization solutions. (A) P3b component waveforms at the highest loading electrode (see Fig. 3A). (B) P3b Component Scalp Topographies by condition and sLORETA solution at the component's peak time-point (marked by the red dotted line: 332 ms). (C) LPC component waveforms at its highest loading electrode (see Fig. 3A). (D) LPC Scalp Topographies by condition and sLORETA solution at the component's peak time-point (508 ms).

3.3. Component data

LPC and P3b component peak (i.e. their PCA waveform voltage at the highest loading temporal-spatial point) voltage means and standard errors are presented in Table 3.

A one-way repeated measures ANOVA was conducted to contrast P3b component scores across conditions. The assumption of sphericity was met $\chi^2 = 2.66$, $df = 2$, $p = 0.264$. The ANOVA indicated that P3b voltages were significantly different across conditions, F(2,36) = 3.35, p = 0.046, $\eta_p^2 = 0.157$. Follow-up pairwise comparisons were conducted via pairwise *t*-tests with effect sizes estimated via Cohen's *d* statistic. The results of this analysis showed Control Endorsements had a significant higher mean P3b voltage than Misinformation Endorsements (MD (Mean Difference) = 1.69 μV, SE = 0.80 μV, t(18) = 2.13, p = 0.048, d = 0.688) and did not vary significantly from Misinformation Rejections (MD = 0.07 μV, SE = 0.58 μV, t(18) = 0.12, p = 0.903, d = 0.037). The mean P3b voltage for Misinformation Rejections was marginally higher than that for Misinformation Endorsements (MD = 1.62 μV, SE = 0.82 μV, t(18) = 1.98, p = 0.063, d = 0.639).

A one-way repeated measures ANOVA was conducted to contrast LPC scores across conditions. As the assumption of sphericity was not met $\chi^2 = 10.21$, $df = 2$, $p = 0.006$, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.689$). The ANOVA indicated LPC voltages were significantly different across conditions, F(1.38,24.80) = 4.08, p = 0.043, $\eta_p^2 = 0.185$. Follow-up pairwise comparisons showed Control Endorsements had a higher mean LPC voltage than both Misinformation Endorsements (MD = 2.42 μV, SE = 1.03 μV, t(18) = 2.34, p = 0.031, d = 0.775) and Rejections (MD = 1.12 μV, SE = 0.51 μV, t(18) = 2.22, p = 0.040, d = 0.502). The difference between Misinformation Endorsements and Rejections was not statistically significant (MD = 1.30 μV, SE = 0.91 μV, t(18) = 1.43, p = 0.172, d = 0.404).

4. Discussion

The main finding of this study is that relative to misinformation based memories, recognition of accurate event memories embedded in their narrative context appear to be associated with stronger

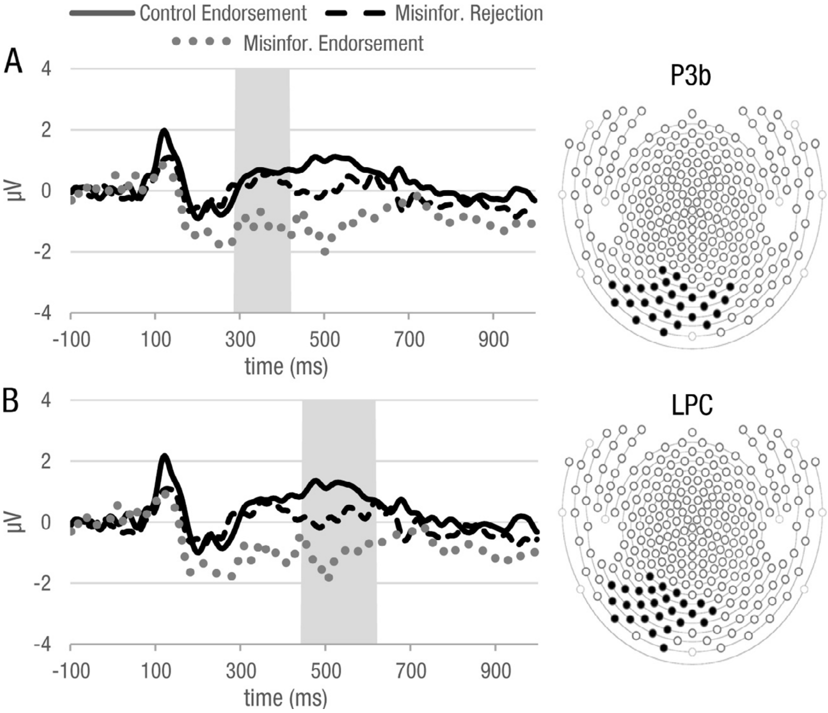

Fig. 3. Grand average waveforms for electrodes with high loadings (>0.80) on the (A) P3b and (B) LPC components. The highest loading electrode for each component is marked in gray while high loading (>0.80) time points are shaded on each waveform plot.

Table 1
Control items: response proportions and standard deviations.

Condition	Seen	Seen & Read	Perceptual Attribution	Read	Guess
Endorsement	0.279 (0.113)	0.261 (0.133)	**0.539 (0.127)**	0.086 (0.093)	0.091 (0.066)
Rejection	0.125 (0.070)	0.056 (0.043)	**0.181 (0.069)**	0.029 (0.051)	0.073 (0.598)

Table 2
Misinformed items: response proportions and standard deviations.

Condition	Seen	Seen & Read	Perceptual Attribution	Read	Guess
Endorsement	0.151 (0.092)	0.128 (0.074)	**0.281 (0.084)**	0.139 (0.097)	0.054 (0.044)
Rejection	0.278 (0.087)	0.114 (0.087)	**0.393 (0.085)**	0.057 (0.057)	0.076 (0.070)

Table 3
LPC and P3b component mean voltages and standard errors.

	LPC voltage	P3b voltage
Control Endorsement	1.97 μV (0.52)	1.26 μV (0.42)
Misinfo. Rejection	0.84 μV (0.53)	1.19 μV (0.54)
Misinfo. Endorsement	−0.45 μV (0.90)	−0.43 μV (0.89)

context-matching (more positive P3b) and recollection related (more positive LPC) neural activity. This study represents the first EEG investigation of the misinformation effect aimed at investigating retrieval related processes that differentiate between event and misinformation based memories. To the best of our knowledge, the present study is also one first to investigate recollective differences between true versus false recognition of episodic details embedded in their narrative context. The primary hypothesis of our study was supported with true memory endorsements being associated with higher levels of recollective activity as indexed by the LPC relative to misinformation endorsements. Our second hypothesis of misinformation rejections based on the retrieval of conflicting perceptual information being associated with higher LPC levels was directionally supported though not supported by statistical significance. Our P3b hypotheses were partially supported with the P3b response to true memories and misinformation rejections being more positive, albeit marginally so for the latter, than misinformation based endorsements.

The localization of the observed P3b to the right inferior parietal lobule, a region repeatedly associated with the P300 (Linden et al., 1999), e.g. (Hesselmann et al., 2011) and attentional processing (see Singh-Curry & Husain, 2009 for a review) lends support to the proposed attention related role of this component in this study's paradigm. The localization of the LPC to the left parahippocampal gyrus a region strongly linked with episodic memory retrieval (see Wais, 2008 for a review) as well as true versus false memory differentiation (Cabeza et al., 2001; von Zerssen et al., 2001) also lends support to the view of the observed LPC being associated with retrieval related processing.

Our LPC findings are consistent with extensive work that has linked greater positivity in the LPC with superior source monitoring performance (Leynes & Phillips, 2008; Paller et al., 1995; Rugg et al., 1996, 1998; Vilberg et al., 2006; Wilding, 2000; Wilding & Rugg, 1996; Wilding et al., 1995; Woroch & Gonsalves, 2010). There are two factors likely driving the LPC difference observed in our results. The first is that relative to narrative study of the misinformation details, perceptual exposure provides true event memories with a stronger perceptual and verbatim memory traces. Thus, the observed LPC difference between true versus false memories observed in our study are likely to be reflective of perceptual memory trace strength differences between true relative to false perceptual memories (Brainerd et al., 2008; Gonsalves & Paller, 2000; Mather et al., 1997).

The second complementary factor, resides in the type of control being used to assess "true" memories. All control items in this study were "consistent controls" (i.e. test items that were consistent with both the event and the narrative), a type of control commonly used in many misinformation effect investigations e.g. (Calvillo, 2014; Wang, Paterson, & Kemp, 2014; Zhu, Chen, Loftus, Lin, & Dong, 2013; Zhu et al., 2010). Thus, it is possible that part of the observed LPC differences between control and misinformation items may be due to participants being exposed to control items twice (once in the event and once in the narrative) but only exposed to the misinformation items once (in the narrative). Building on these findings by contrasting the memory signature of consistent versus pure control (i.e. test items consistent with the event and mentioned in a neural fashion in the narrative) items would represent an important contribution to the field given the largely interchangeable use of these types of control items.

Our hypothesis of the LPC for misinformation rejections being midway between misinformation and true memory endorsements while directionally present, was not supported by statistical significance. It is possible perhaps that either the frequency of retrieval or amount of recollection was insufficient to distinguish between these response classes. Classifying responses based on a measure of source recollection strength (Zaragoza & Lane, 1994) administered after the source judgement in future studies could potentially help shed light on this issue.

The less positive P3b response in misinformation based endorsements relative to true memory endorsements are in line with theoretical proposals that false memory reports are associated with a weaker context-item memory match (Molinaro & Carreiras, 2010) as well as more liberal responding (Luna & Migueles, 2008; Van Damme, 2013) and less stringent monitoring (Loftus et al., 1989; Parker et al., 2008). These findings indicate that the recognition response associated with misinformation endorsements are not accompanied by significant levels of discrepancy detection or strong context-item match responses. Our results also found evidence to support the idea of discrepancy detection (Kopp & Lange, 2013; Seer et al., 2016), as indicated by the P3b, playing an important role in the rejection of misinformation with misinformation rejection responses being associated with elevated P3b levels relative to misinformation endorsements, although this difference was only marginally significant. Our P3b findings extend research utilizing the P3b in concealed memory detection (Gamer & Berti, 2012; Ganis & Schendan, 2012; Meixner & Rosenfeld, 2014), suggesting that in addition to distinguishing between cues associated with prior memories and neutral content, elevated P3b levels may also distinguish between memory cues associated with true event memories and those associated with false ones.

In conjunction with our localization results, our findings also extend fMRI work by Stark et al. (2010) who found increased activation in the right inferior parietal lobe (the most likely source of our P3b) in critical correct rejections relative to misinformation endorsements and increased activation in the left parahippocampal cortex (the most likely source of our LPC) in control endorsements relative to correct rejections. Our findings suggest that the parietal activation observed by Stark et al. (2010) may be related to differences in attentional processing between the two response classes and lends support to their hypothesis of left parahippocampal activity being linked with recollection. While Stark et al. (2010) did not find a difference in left parahippocampal activity between true and false memories, true memories in Stark et al. (2010) were defined as event memories recognized as being true even after being targeted by misinformation presented shortly before testing as opposed to our focus on event memories recognized as being true without being targets of misinformation. This presence of additional interference in Stark et al. (2010) may have reduced differences in recollective strength between true and misinformation based memories. It may be interesting to test this hypothesis in the future via the use of contradictory versus additive misinformation (Nemeth & Belli, 2006).

There are several limitations in the present study, the most apparent ones being the number of false memory trials and the absence of counterbalancing in the assignment of items to the misinformation versus control item conditions. With regard to the number of trials work showing late slow ERP components to have a level of reliability that allows them to be quantified in as few as 8 trials (Moran, Jendrusina, & Moser, 2013) provides support for the reliability of the ERP measurements of this investigation. An assessment of the measurement split-half reliability of the raw ERP activity at the single trial level in the time-windows of interest within the electrode region windows highlighted in Fig. 3 also showed reasonable levels of reliability in all three response conditions (Misinformation Endorsement P300: $r(19) = 0.70$, $p < 0.001$, Misinformation Rejection P300: $r(19) = 0.57$, $p = 0.011$, Control Endorsement P300: $r(19) = 0.70$, $p < 0.001$, Misinformation Endorsement LPC: $r(19) = 0.58$, $p = 0.008$, Misinformation Rejection LPC: $r(19) = 0.56$, $p = 0.013$, Control Endorsement LPC: $r(19) = 0.60$, $p = 0.006$). As these estimates were based on the raw data prior to temporal-spatial decomposition (which removes a significant amount of noise and artifact related activity), they represent the worst-case scenario for the true reliability of the final extracted component scores. Nonetheless, due to the exploratory nature of this investigation, we recommend that our reported findings be considered not only from a stance of significance testing but also in view of the effect sizes reported in Section 3.3. These statistics suggest that some of the marginal effects reported may surpass conventional significance thresholds if assessed in more statistically powerful investigations. Our findings point to the promise in such further study and provide an important justification for their pursuit.

The lack of counterbalancing of item status was implemented due to the scarcity of well validated materials with a sufficiently high number of critical items. Item related effects cannot account for the intriguing differences observed between misinformation endorsements and rejections. While we consider it unlikely that an item related effect could account for the differences observed between control and misinformation responses given (1) the sampling of a large number of items used in both conditions and (2) the match between the encoding conditions for control and misinformed items as items from each condition were presented in just a single slide (with one control and one misinformed item appearing on two), it would be ideal for future investigations to assess this possibility.

There are several interesting lines of research that build off the findings presented in this paper. One interesting direction for future studies would be to investigate neural processes that are more strongly associated with perceptual false memories relative to true ones. Given the evidence and theoretical arguments for the role of reconstructive processes (see Schacter, 2012 for a review) and elaborative reasoning (Johnson, Foley, Suengas, & Raye, 1988; Schooler et al., 1986) in false memory formation, it is possible that increased levels of neural activity associated with these processes may be observed during the decision making phase. While this could not be investigated in the current study as participants were allowed to blink and take a break if necessary during the response phase, it is intriguing to note that Meek et al. (2013) found increased P3b and LPC activity in the evaluation of misinformation based items relative to the evaluation of true event items during the response selection stage. A second methodological direction of interest would be to assess possible differences between the use of consistent (i.e. event items described accurately in the narrative) versus pure control items (i.e. details not mentioned or mentioned neutrally in the narrative).

5. Conclusions

The findings of this study suggest that the initial recognition response to true event memories in their original narrative context is associated with elevated levels of attentional and retrieval related activity, as indexed by the P3b and LPC respectively, relative to false event memories. The rejection of false memory details was also found to be associated with marginally higher levels of attentional processing relative to false memory acceptances.

Our findings make important confirmatory contributions to our understanding of the phenomenology of false memories (Johnson et al., 1988; Mather et al., 1997). They also demonstrate the potential value of utilizing the P3b and LPC response to distinguish between true and false memories, although additional work is needed to assess the value of using these components to classify responses at the single-trial level.

Memory researchers have been studying the misinformation effect behaviorally for almost four decades (Loftus, Miller, & Burns, 1978, see Loftus, 2005 for a review). We strongly believe the application of neuroimaging techniques to the misinformation effect paradigm (Baym & Gonsalves, 2010; Okado & Stark, 2005; Stark et al., 2010), particularly a relatively accessible method such as EEG, holds considerable potential in extending prior work as well as opening exciting new avenues of research.

Conflict of interest

None declared.

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Appendix A

A one-way repeated measures ANOVA was conducted to contrast component scores of the third component, a weak late positivity, across conditions. The assumption of sphericity was met $\chi^2 = 0.978$, $df = 2$, $p = 0.613$. The ANOVA indicated that scores on this component did not differ significantly between conditions, $F(2,36) = 0.231$, $p = 0.795$, $\eta_p^2 = 0.013$. Follow-up pairwise comparisons showed voltages on this component did not differ between control and misinformation endorsements (MD = 0.56 μV, SE = 0.84 μV, $t(18) = 0.67$, $p = 0.512$), misinformation endorsements and rejections (MD = 0.12 μV, SE = 0.97 μV, $t(18) = 0.12$, $p = 0.902$) or misinformation rejections and control endorsements (MD = 0.44 μV, SE = 0.80 μV, $t(18) = 0.55$, $p = 0.587$). The component's localization to the left medial frontal gyrus, a region linked with general recollection activity (Addis, McIntosh, Moscovitch, Crawley, & McAndrews, 2004; McDonough, Cervantes, Gray, & Gallo, 2014), and effort (Elliott & Dolan, 1998) suggests that activity in this component may be reflective of memory retrieval efforts common to all three response classes (see Fig. A.1).

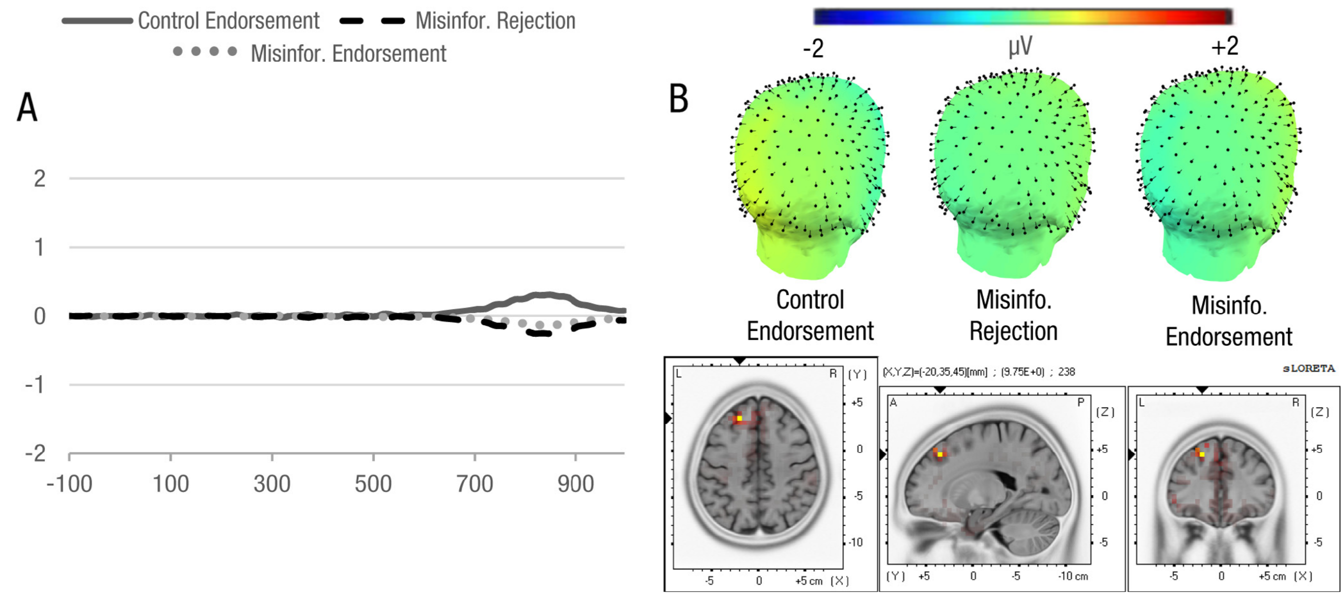

Fig. A.1. (A) Weak Late Positivity component waveforms at the highest loading electrode (see Fig. 3A). (B) Weak Late Positivity Component Scalp Topographies by condition and sLORETA solution at the component's peak time-point (marked by the red dotted line: 332 ms). (C) Weak Late Positivity component waveforms at its highest loading electrode (see Fig. 3A). (D) Weak Late Positivity Scalp Topographies by condition and sLORETA solution at the component's peak time-point (508 ms). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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