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Familiarity in source memory

Matthew V. Mollison*, Tim Curran

University of Colorado, Boulder, Department of Psychology & Neuroscience, Muenzinger D244, 345 UCB, Boulder, CO 80309, USA

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ABSTRACT

Familiarity and recollection are thought to be separate processes underlying recognition memory. Event-related potentials (ERPs) dissociate these processes, with an early (approximately 300–500 ms) frontal effect relating to familiarity (the FN400) and a later (500–800 ms) parietal old/new effect relating to recollection. It has been debated whether source information for a studied item (i.e., contextual associations from when the item was previously encountered) is only accessible through recollection, or whether familiarity can contribute to successful source recognition. It has been shown that familiarity can assist in perceptual source monitoring when the source attribute is an intrinsic property of the item (e.g., an object's surface color), but few studies have examined its contribution to recognizing extrinsic source associations. Extrinsic source associations were examined in three experiments involving memory judgments for pictures of common objects. In Experiment 1, source information was spatial and results suggested that familiarity contributed to accurate source recognition: the FN400 ERP component showed a source accuracy effect, and source accuracy was above chance for items judged to only feel familiar. Source information in Experiment 2 was an extrinsic color association; source accuracy was at chance for familiar items and the FN400 did not differ between correct and incorrect source judgments. Experiment 3 replicated the results using a within-subjects manipulation of spatial vs. color source. Overall, the results suggest that familiarity's contribution to extrinsic source monitoring depends on the type of source information being remembered.

0. Introduction

Our everyday experiences consist of intricate details encoded from various levels of perception and attention, and memory is the key process in binding them into useful knowledge. Remembering the people, places, and things that we have previously encountered could be as basic as questioning whether you have had a previous experience with one of these, or as specific as needing to remember certain details from a particular previous event. Importantly, we remember different amounts of information for the variety of past situations that we have experienced. For example, you may or may not remember the circumstances, or source, of a particular event, like whether you heard about your graduate school acceptance via an email or a letter. Understanding the psychological processes and patterns of brain activity that correlate with either remembering or failing to remember prior episodes and their assorted contextual details is a basic and important objective to be explored by cognitive psychology and neuroscience.

In the dual-process framework of recognition memory, familiarity and recollection are the two main cognitive processes involved in remembering information (Parks & Yonelinas, 2007; Yonelinas, 2002). Familiarity is typically thought to involve a fast and automatic recognition process that allows for recognition of a previous experience without retrieval of details from the encoding episode, whereas recollection is a slower process that retrieves item-specific episodic information. Recent evidence clearly points to the existence of a dual-process recognition memory system (for reviews, see Curran, Tepe, & Piatt, 2006, Chap. 18; Eichenbaum, Yonelinas, & Ranganath, 2007; Parks & Yonelinas, 2007; Rugg & Curran, 2007; Skinner & Fernandes, 2007; Vilberg & Rugg, 2008; Yonelinas, 2002).

One general class of information that can be recollected about an episode is source information. In addition to recognizing a particular stimulus associated with an event, we also process the temporal, spatial, semantic, and other associated contextual aspects of the event. These aspects are called source information because they make up the circumstances from which an item originated (Johnson, Hashtroudi, & Lindsay, 1993; Mitchell & Johnson, 2009; Senkfor & Van Petten, 1998). Source memory is involved in remembering contextual details such as having a memory for the person from whom you heard a juicy rumor or discriminating between whether you said something out loud or just thought it internally. Source information is part of the array of episodic details to be retrieved from the encoding period, meaning that recollection should, almost by definition, contribute to correct source retrieval (Allan, Wilding, & Rugg, 1998; Cansino, Maquet,

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* Corresponding author. Tel.: +1 720 213 6288; fax: +1 303 492 2967.
E-mail address: matt.mollison@gmail.com (M.V. Mollison).

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Dolan, & Rugg, 2002; Gruber, Tsivilis, Giabbiconi, & Müller, 2008; Rugg, Schloerscheidt, & Mark, 1998; Unsworth & Brewer, 2009; Wilding, 2000; Wilding & Rugg, 1996; Woroch & Gonsalves, 2010; Zimmer & Ecker, 2010). In fact, the retrieval of episodic information has essentially been defined as a property of the recollection process (Rugg et al., 1998; Tulving, 1985; Yonelinas, 2002), and accurate source recognition has been considered a defining feature of recollection (Jacoby, 1991; Wais, Mickes, & Wixted, 2008). However, computational models of familiarity-based recognition have been shown to be capable of supporting source recognition (Elfman, Parks, & Yonelinas, 2008; Ratcliff, Van Zandt, & McKoon, 1995), and a variety of empirical evidence reviewed next has also suggested that familiarity contributes to source recognition under some conditions. These familiarity effects have been indexed behaviorally (e.g., Diana, Yonelinas, & Ranganath, 2008; Duarte, Ranganath, Winward, Hayward, & Knight, 2004; Elfman et al., 2008; Hicks, Marsh, & Ritschel, 2002; Yonelinas, Kroll, Dobbins, & Soltani, 1999), by the FN400 event-related potential (ERP) component (e.g., Ecker, Zimmer, & Groh-Bordin, 2007a, 2007b; Mecklinger, 2006), by activity in the perirhinal cortex (which is thought to be related to familiarity; e.g., Diana, Yonelinas, & Ranganath, 2007; Ranganath et al., 2003; Staresina & Davachi, 2006), and in neuropsychological patients with hippocampal damage thought to impair recollection (e.g., Diana, Yonelinas, & Ranganath, 2010; Quamme, Yonelinas, & Norman, 2007).

A number of experiments have used the remember–know (RK) procedure to assess the correlates of recollection and familiarity in source memory. Here, "remember" and "know" responses are thought to be subjective indices of recollection and familiarity, respectively (Duarte et al., 2004; Düzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Klimesch et al., 2001; Rugg et al., 1998; Smith, 1993; Tulving, 1985; Vilberg, Moosavi, & Rugg, 2006;but see Wais et al., 2008). These experiments have generally shown that accurate source recognition is associated with recollection, but some have suggested that familiarity can contribute to remembering source information. For example, Hicks et al. (2002) used two experiments to investigate familiarity's contribution to source monitoring, one with perceptual source information (words that were either seen or heard) and one with reality monitoring (words that were either seen or generated internally by the participant). In the first, source accuracy for "know" responses was equal to that of "remember" responses, and in the second, "know" was more accurate than "remember" for seen items while the opposite was true for generated words (which were processed at a deeper level);overall, the authors suggest that the results indicate that a sense of familiarity is sufficient to contribute to successful source monitoring. Additionally, Duarte, Ranganath, Trujillo, and Knight (2006) found above chance source accuracy for "know" judgments (in addition to "remember" judgments) made by healthy young adults when remembering the study task for each old probe and interpreted this as both the familiarity and recollection processes contributing to source memory. Wais et al. (2008) also found above chance source accuracy for "know" judgments (where words above the center of the screen were studied in one font color and words below the screen in another font color, and color was the tested source dimension), but they cautioned against equating "remember" and "know" responses with recollection and familiarity processes because they assumed that source memory is necessarily associated with recollection. Related work has considered whether familiarity can contribute to associative recognition in experiments where pairs of items are studied (A–B, C–D, E–F) and participants are required to discriminate between intact (A–B) and rearranged (C–F) pairs at test. Similar to the source memory situation, it is sometimes assumed that associative recognition requires recollection, although some evidence is consistent with accurate familiarity-based associative recognition (e.g., Clark & Gronlund, 1996; Rhodes & Donaldson, 2007; Quamme et al., 2007; Yonelinas et al., 1999).

In addition to subjective behavioral reports, recollection and familiarity have been associated with particular ERP effects (e.g., Curran, 2000; Curran & Cleary, 2003; Curran & Dien, 2003; Duarte et al., 2004; Jäger, Mecklinger, & Kipp, 2006; Tsivilis, Otten, & Rugg, 2001; Wilding & Rugg, 1996; Woodruff, Hayama, & Rugg, 2006; for reviews, see Allan et al., 1998; Curran, Tepe et al., 2006; Friedman & Johnson, 2000; Mecklinger, 2006; Rugg & Curran, 2007). The *parietal ERP old/new effect*, a positive-going component peaking over the parietal scalp between 500 and 800 ms, is thought to reflect recollection. It is an "old/new" effect because it differentiates between correctly identified old (hits) and new (correct rejections) stimuli. It is often left lateralized, and is greater in amplitude when episodic information is correctly recollected compared to correctly identifying either new items or old items without episodic details (Curran, 2000; Rugg & Curran, 2007; Wilding, 2000). Additionally, the parietal old/new effect has been shown to index the amount of episodic information retrieved such that its amplitude varies with the amount of information remembered (Vilberg et al., 2006; Wilding, 2000; Wilding & Rugg, 1996). The other recognition process, familiarity, is thought to be indexed by a relatively early frontally distributed negative-going component that peaks around 400 ms, called the *frontal old/new effect* or the *FN400* because of these properties. Here, correct rejections produce a component with greater negative amplitude than hits. Though amplitude can vary with item recognition confidence (Woodruff et al., 2006; Yu & Rugg, 2010), the FN400 typically shows no differences between recognizing varying amounts of episodic information (Curran, 2000; Mecklinger, 2006; Rugg & Curran, 2007); however, this is not always the case, as is discussed below.

Some researchers have interpreted the FN400 effect as related to conceptual priming (Lucas, Voss, & Paller, 2010; Paller, Voss, & Boehm, 2007; Yovel & Paller, 2004). Specifically, they posited that test probe stimuli that are conceptually similar to those observed during the study period will produce an attenuated FN400 component compared to the component for conceptually different stimuli. However, others have contradicted this perspective by varying the amount of conceptual priming under conditions in which either recollection or familiarity should contribute to the recognition of stimuli (e.g., Stenberg, Hellman, Johansson, & Rosén, 2009; Stenberg, Johansson, Hellman, & Rosén, 2010). FN400 effects are also seen under conditions when there is no conceptual information to encode and instead there is only a perceptual congruency between the study and test presentations (Groh-Bordin, Zimmer, & Ecker, 2006; Speer & Curran, 2007).

Some research has focused on the nature of the encoding processes that determine whether source information and associations can be recognized via familiarity. According to this perspective, associations can be recognized through the familiarity process when study conditions encourage the storage of *unitized* item–source (or item–item) associations that are bound together within a single trace, whereas *non-unitized* associations can only be recognized through recollection (Diana et al., 2007, 2008; Montaldi & Mayes, 2010; Quamme et al., 2007). Depending on the encoding instructions and/or mental encoding processes, an item and its source features (or an associated item) can either unitize into a single bound representation or they can be encoded as unbound, non-unitized representations that are associated in memory. For example, Quamme et al. (2007) manipulated the unitization of word pairs by either promoting or discouraging unitization through different encoding instructions. They found that the patients, who were found to have impaired recollection but preserved familiarity due to medial temporal lobe damage and thus were using only familiarity-based memory, remembered unitized associations like *SEA-HORSE* significantly better than non-unitized stimuli. Another experiment that influenced unitization through instructions was by Diana et al. (2008, Experiment 2), which had participants study nouns on colored backgrounds (non-unitized stimuli) and visualize either each item in that color (promoting unitization) or each item interacting with another item of that color (discouraging unitization). Receiver-operating characteristic (ROC) analyses on the confidence of participants' subsequent source recognition responses revealed a greater contribution of familiarity to items from the unitization condition compared to the non-unitization condition. Regarding ERPs for unitized source information, Diana, Van den Boom, Yonelinas, and Ranganath (2011) examined source memory for high- and low-unitization with color source information. They did not find typical recognition memory effects, but they examined confidence-based familiarity contrasts (source correct vs. source incorrect responses for high- and low-unitization) and reported later ERP effects (750–1000 ms) that were interpreted as familiarity contributing to source memory only for items with high-unitization. However, because there were no effects around the time course of the FN400 (300–500 ms), it seems possible that these later ERP effects might imply different processing than the earlier recognition memory processes would and thus are difficult to interpret regarding their relation to familiarity.

A related distinction has focused more on the properties of encoded stimuli. Ecker et al. (2007a, 2007b) and Zimmer and Ecker (2010) measured FN400 ERP effects to study the potential contributions of familiarity to source memory and hypothesized that source attributes that are intrinsically related to items are more likely to be recognized via familiarity than those that are extrinsically related. Intrinsic source features are intra-item features, meaning they are part of the perceived stimulus, such as the paint color of a car. Extrinsic source features are external (or inter-item) associations, such as the context in which you saw a particular car. Ecker et al. (2007b) manipulated color as either the intrinsic surface feature of an object (e.g., green balloon) or as the extrinsic surrounding context (e.g., balloon enclosed in a green frame), and found a FN400 source accuracy effect for the intrinsic but not the extrinsic case, meaning familiarity was sensitive to recognizing intrinsic features. The authors posited that the intrinsic source information becomes part of the stimulus and is automatically supplied during recognition, whereas this does not occur for extrinsic associations. Nyhus and Curran (2009) also showed that familiarity (as indexed by the FN400) can support the recognition of associations between items and their intrinsic features (words in particular fonts). A recent source memory study by Addante, Ranganath, and Yonelinas (in press) used item property judgments as source information (animacy vs. manmade, which could be construed as intrinsic properties) and showed an FN400 effect for source correct compared to source incorrect trials; the authors posited that this might be due to the familiarity process contributing to source recognition.

Other studies have suggested that familiarity can contribute to memory for extrinsic associations or sources (but see Ecker et al., 2007a). Peters and Daum (2009) manipulated the perceptual content of extrinsic source information that was paired with word stimuli (pictures of scenes, faces, and sounds). While the FN400 (measured between 300 and 400 ms) did not differ between the type of source content remembered at test, it did show a source accuracy effect: correct source recognition ERPs were different from incorrect source recognition ERPs. Speer and Curran (2007) demonstrated that the FN400 could correctly differentiate between old and new item–item associations between fractal images. These are interesting results because, while it has been shown that there are familiarity-based source accuracy effects for unitized associations, there does not seem to be a good reason for extrinsic source information to unitize with the studied items in these cases as participants were instructed to simply memorize the item–item and item–context associations, respectively. Thus, it seems that familiarity can sometimes contribute to source monitoring for extrinsic perceptual attributes.

The cases in which familiarity can contribute to source recognition are clearly particular to both stimulus presentation methods and encoding instructions. The distinction between intrinsic and extrinsic source properties is related to the stimuli themselves, while the degree of unitization between items and their sources is related to encoding processes. Importantly, intrinsic item–source associations may inherently lead to unitization because the associations are already bound at the time of encoding (as in Ecker et al., 2007b), but extrinsic item–source associations may not be encoded in a unitized manner without explicit instructions to do so (as in Diana et al., 2008).

Though familiarity's contribution to extrinsic source memory has only been demonstrated infrequently in the ERP literature (e.g., Addante et al., in press; Peters & Daum, 2009; Speer & Curran, 2007), behavioral work by Elfman et al. (2008) and Caldwell and Masson (2001) also indicated that specific kinds of extrinsic location information can be accurately judged through familiarity. Elfman et al. (2008) showed that spatial source information was able to be recognized in a neural network model that used only a familiarity-based signal. ROC analyses of behavioral participant data revealed that familiarity can contribute to spatial source recognition, confirming the model's predictions and corroborating familiarity's role in remembering extrinsic spatial source information. Caldwell and Masson (2001) showed that familiarity could assist with remembering object–location associations (placing household objects in different rooms in a computer game) by measuring the unconscious (familiarity-based) influence of memory on location recognition using the process-dissociation procedure. In a review by Yonelinas (2002) it was suggested that the effect might be due to the realistic semantic contexts with which the objects were associated, potentially leading to unitization.

It seems unlikely that all source (and item) details are created equally (Aly, Knight, & Yonelinas, 2010; Wixted & Squire, 2011). Perhaps different types of information (e.g., color, location, encoding task) are encoded and remembered differently, possibly processed by separate regions of the medial temporal lobes, their surrounding cortices, and other interacting brain areas (Montaldi & Mayes, 2010; Wixted & Squire, 2011). The only ERP experiments to directly address differences between intrinsic and extrinsic source information have used color as the source attribute (Ecker et al., 2007a, 2007b), but spatial location was considered an extrinsic property by these same researchers (Ecker et al., 2007a). Some source memory experiments have used spatial location and ERPs in the past (e.g., Mecklinger, Johansson, Parra, & Hanslmayr, 2007; Senkfor & Van Petten, 1998; Van Petten, Senkfor, & Newberg, 2000), but these have not focused on the temporal and spatial ERP characteristics typically associated with familiarity (the FN400).

The aim of the present experiments was to test whether familiarity, as indexed by both behavioral measures and the FN400 mid-frontal old/new effect, is able to differentiate certain kinds of extrinsic perceptual features encoded as source information. In the first experiment, spatial location was used as the source detail to investigate the potential role of familiarity in recognizing an extrinsic attribute.

1. Experiment 1

Experiment 1 involved studying pictures of objects in varying spatial locations. During the encoding period, objects were

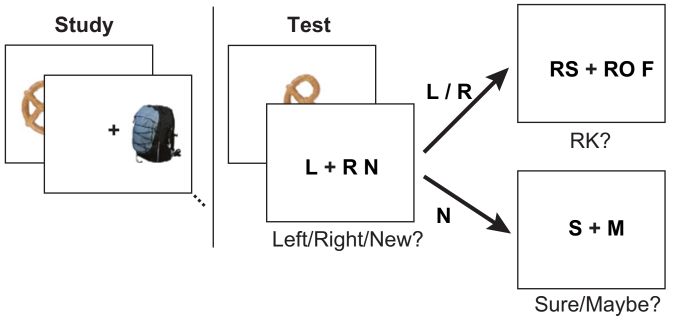

Fig. 1. An illustration of the study and test tasks used in Experiment 1.

presented on either the left or the right side of the computer screen while participants fixated the cross in the center; the location of the object is the perceptually defined source information that participants were told to remember (see Fig. 1). At test, participants saw randomly intermixed old and new items; for each, they made two judgments: (1) a source/new judgment, where source was the presentation location of the item during the study period, and (2) a modified remember–know (RK) judgment. The source judgment had three options: "left", "right", and "new". If a source was identified, participants responded with one of three RK options: whether they remembered the source information, whether they remembered something other than the source information, or whether the item just felt familiar and they could not remember any details regarding viewing the item earlier.

Because the first answer made during test was a source judgment, item recognition was derived from whether the answer to the test question was one of the sources regardless of source accuracy. The RK judgments then specify the type of information remembered (source or other) or whether the item just felt familiar. We predicted that if familiarity, as indexed by the FN400 ERP component, can accurately differentiate spatial source information, old items with correctly and incorrectly identified source information will differ. On the other hand, if familiarity only distinguishes between old and new items regardless of source accuracy, there will be no difference.

The modified RK test procedure was used to identify the different ways that participants can recognize the items. These ratings allowed us to examine the hypothesis that familiarity is likely to support accurate source recognition using behavioral data. More specifically, this modification was made so that the occurrence of recollection of non-source details (non-criterial recollection; Yonelinas & Jacoby, 1996) would not contaminate what would otherwise have been classified as familiarity-based judgments (K judgments in the two-option RK procedure). An example of non-criterial recollection would be remembering at test that studying a picture of an apple made the participant think of how he or she was hungry instead of remembering the source information. Although it is still a subjective measure of recollection, we think that splitting the types of R judgments into *source* and *other* categories can eliminate the occurrence of non-criterial recollection trials in both the R and the K judgment categories, and that this type of test procedure is a good compromise between gathering the subjective responses of the RK procedure and being able to investigate the more objective source accuracy.

1.1. Material and methods

1.1.1. Participants

Thirty University of Colorado undergraduates participated in the experiment for either course credit or payment of $15 per hour (ages 18–28, $M = 21.4$; 17 male, 13 female). All participants were right-handed native-English speakers and had normal or corrected-to-normal vision. Informed consent was obtained from each participant, and the study conformed to the Human Research Committee guidelines.

1.1.2. Materials

The stimulus pool consisted of 1297 color images of physical objects, animals, and people on square white backgrounds collected from http://www.clipart.com, from the stimuli set provided by Brady, Konkle, Alvarez, and Oliva (2008), and through image searching on the Internet. Each image was resized to 240 × 240 pixels and the experiment was presented on a 17-in flat-panel display with a resolution of 1024 × 768 (60 Hz frame rate) placed 1 m in front of the participants. All portions of the display not occupied by stimuli or text were filled with black pixels.

1.1.3. Design

Experiment 1 consisted of four study–test list pairs, created at the time of the experiment for each participant. The session, including application of the electrode net and running in the task, lasted approximately 2.5 hours. From the stimulus pool, 104 items were randomly chosen to make each study list, for a total of 416 studied items. Half of the items were studied to the left of fixation and half were studied to the right. The two stimuli at the beginning and end of each study list were not included in the corresponding test list to lessen the possibility of primacy and recency effects. Each test list was constructed by randomly intermixing the 100 old items from the study list with 50 new items. Thirty-four of the remaining items were used to make a shortened study–test list pair for training purposes.

The study status of each stimulus (left, right, new) was manipulated within subjects such that each participant received a different random assignment of items to the study conditions. Responses were collected using three keys on the bottom row of a standard US English keyboard, pseudo-randomly chosen from the `Z`, `X`, `Period`, and `/` keys. The pseudo-random assignment is explained in more detail after the types of responses are described. Response assignments for the keys were counterbalanced across participants and were consistent within each participant across study and test periods. EEG was recorded throughout the entire experiment.

1.1.4. Procedure

An electrode net was applied to each participant's head, and the session began with a practice list to familiarize participants with the study and test procedures (24 studied and 30 tested items).

During each study list, participants fixated the cross in the center of the screen and observed the items that appeared to the left and right with their peripheral vision. They were instructed to remember the side of the screen on which each item appeared. Stimulus presentation lasted for 1000 ms, and was followed by a 625 ± 125 ms inter-stimulus interval. To prevent after-image effects that could be induced by a stimulus, an image containing visual Gaussian noise was visible in each of the image presentation locations whenever a stimulus was not present; the noise image was precisely occluded by each stimulus. The area containing the possible study image locations subtended a visual angle of 11.4° wide × 5.6° high.

Each test list was presented immediately after its corresponding study list. A centered fixation cross was visible at all times except when a test probe image was presented on top of it, and participants were instructed to keep their eyes focused on the center of the screen. There was a 750 ms period immediately preceding each test probe during which the fixation cross was visible. Each centered probe was then presented for 750 ms. Following a 1500 ms pause with fixation only, participants saw `L+R N` (for Left, fixation cross, Right, New), which lined up with their three response keys, to indicate the source information from the study period for each item. If the response was a source, participants then used three-option RK judgments: on the screen they saw `RS+RO F` (for Remember Side, Remember Other, fixation cross, Familiar). If the participant answered "new", they saw `Maybe+Sure`, to indicate how confident they were about it being a new item. Remember/know instructions were taken from Eldridge, Sarfatti, and Knowlton (2002), and were slightly modified to describe pictures and the RO response. An inter-stimulus interval of 625 ± 125 ms followed each response. The visual angle of each test probe image was 4.3° wide × 4.3° high.

The key assignments were pseudo-random in that the responses were ordered in a sensible manner for the test task, and equal numbers of participants received each possible key layout. The key for a "left" response was always assigned to the left hand (`Z` or `X` key) while the key for a "right" response was always assigned to the right hand (`Period` or `/` key). The "new" key was assigned to one of the outermost keys (`Z` or `/` key). For the RK judgments, the order of keys was always such that the responses went in either ascending or descending memory strength from left to right across the keyboard (with remembering the source being the strongest and familiar being the weakest); F was always assigned to one hand and the RO and RS responses were made by the other hand.

1.1.5. *Electrophysiological recordings*

A 128-channel HydroCel Geodesic Sensor Net^{TM} (GSN 200, v. 2.1; Tucker, 1993) was used to measure the EEG at the scalp using a central vertex reference (Cz) with a sampling rate of 250 Hz and a bandpass hardware filter from 0.1 Hz to 100 Hz. The net was connected to an AC-coupled, high-input impedance amplifier (300 MΩ, Net Amps^{TM}; Electrical Geodesics, Inc., Eugene, OR). The electrodes were adjusted until impedance measurements were less than 40 kΩ.

1.1.6. *Electrophysiological data processing*

Net Station (Electrical Geodesics, Inc.) was used to low-pass filter at 40 Hz and epoch the data into 3000 ms segments, 1 s before the onset of each test stimulus and 2 s after. Only a portion of each epoch was used for analyses, as described below, and all ERP voltages were measured from the onset of the test stimuli. The ERP PCA Toolkit (Dien, 2010) was used as an interface for ICA artifact correction for trials that contained automatically located eye-blink artifacts. Subsequently, the ERP PCA Toolkit's bad channel interpolation and trial rejection algorithms were used. If a channel contained an artifact during a trial, it was interpolated using its six neighboring channels. Interpolation when a neighboring channel was bad was not allowed, and these trials were excluded. Additionally, if more than 10% of the channels were declared bad for a particular trial, that trial was excluded. The 200 ms period prior to stimulus onset was used to baseline correct each epoch, and all analyses were based on referencing to the average of all electrodes (Dien, 1998) using Net Station's PARE correction (Junghöfer, Elbert, Tucker, & Braun, 1999).

Analyses were done in MATLAB (version R2011b; The MathWorks, Inc., Natick, MA) using the FieldTrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011) and in-house scripts. We grouped the electrodes into four *a priori* regions of interest (ROIs) based on those used in other studies (e.g., Curran, 2004; Curran, DeBuse, & Leynes, 2007; Curran, DeBuse, Woroch, & Hirshman, 2006; Curran & Friedman, 2004; Curran & Hancock, 2007). The shaded regions in Fig. 2 illustrate these ROIs, and only data from electrodes that fell into these ROIs were used in the main analyses. The FN400 effect was analyzed over two anterior-superior regions located near the standard F3 and F4 sites (channels 24 and 124 in Fig. 2) from 300 to 500 ms after test stimulus onset. The parietal old/new effect was analyzed over two posterior-superior regions near the standard P3 and P4 sites (channels 52 and 92 in Fig. 2) from 500 to 800 ms after test stimulus onset. The frontocentral (FC) ROI with the dotted outline was used in more pointed FN400 analyses, as described in the results. Grand average ERP waveforms were created by averaging ERPs from the channels within each region and across participants.

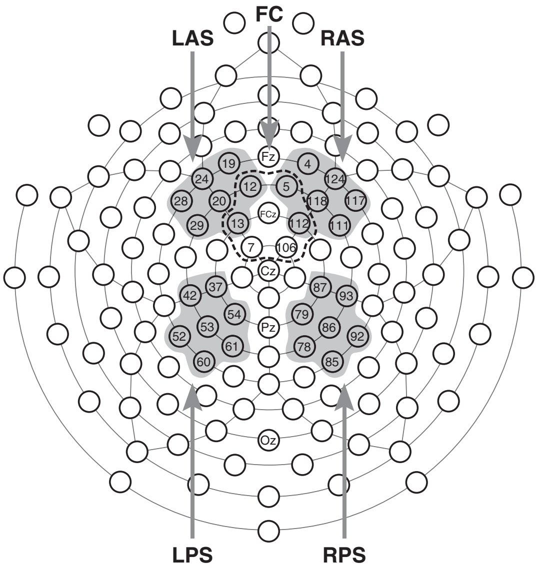

Fig. 2. The 128-channel HydroCel Geodesic Sensor Net^{TM} used to measure the EEG and the regions of interest (ROIs) on which the analyses were based. Each ROI's label describes its position on the skull: R, right; L, left; A, anterior; P, posterior; S, superior; F, frontal; C, central.

1.2. *Results*

Across all experiments and analyses, when an analysis of variance (ANOVA) was conducted, all main effects are reported regardless of significance. Interactions (e.g., hemisphere × condition) are reported only when significant. When an ANOVA contains a factor with more than two levels, the reported values are adjusted for violations of assumptions of sphericity using the Greenhouse and Geisser (1959) procedure even if the factors did not violate Mauchly's test of sphericity.

There are a few key conditions of interest for dissociating between familiarity and recollection: old items with correct source recognition, old items with incorrect source recognition, and correct rejections (correctly identified new items), as well as trials in the first two conditions given "familiar" RK responses. ERPs from other potentially interesting conditions including misses and false alarms were not included in the analyses because of insufficient trial counts, as can frequently be the case in ERP studies of recognition memory.

Four participants were excluded from analyses because they either made no "familiar" responses ($n=2$), had low accuracy (source hit rate was more than three standard deviations below the mean, $n=1$), or had fewer than 15 artifact-free trials in any of the main trial conditions ($n=1$). The remaining 26 participants were included in all behavioral and ERP analyses. Behavioral analyses included all trials, while ERP analyses included only trials without electrical artifacts. Average trial counts for ERP analyses are included in Table 1.

1.2.1. *Behavioral results*

Accuracy values are summarized in Table 2 (collapsing across RK and sure/maybe ratings for "old" and "new" responses), including discrimination (d') and response bias (c, for *criterion*; positive/conservative bias indicates a tendency to say "new", whereas negative/liberal bias indicates a tendency to give a source response, essentially calling the item "old"). The item and source accuracy rates are independent because all old and new items were used for calculating item rates, but only old items with non-new responses (item hits) were used for source rates (Murnane & Bayen, 1996; Nyhus & Curran, 2012). The item hit rate was calculated by dividing the number of old items with non-new responses, regardless of source accuracy, by the total number of old items. Similarly, the item false alarm rate was calculated by dividing the number of new items with non-new responses by the total number of new items. For old items, correct source was identified 77.4% of the time. Source accuracy (for computing discrimination) was calculated such that the Right source is the target distribution (hit: "right" to a Right source item; miss: "left" to a Right source item) and the Left source is the lure distribution (correct rejection: "left" to a Left source item; false alarm: "right" to a Left source item). The designation of the target distribution is arbitrary; the same results would be obtained if the distributions were switched. Response biases for both item and source judgments were no different from zero. The RK responses to old items were divided into the three possible responses and accuracy was measured within each response type (Fig. 3). RS and RO responses were relatively accurate. Importantly, for "familiar" items participants were able to remember spatial source information at levels above chance ($M = 0.56$) [$t(25) = 3.9$, $p < 0.001$].

Reaction times were measured from the onset of the initial source/new judgment prompt following the presentation of the test stimulus to the key press indicating the source/new judgment and are summarized in Table 3. Both correct source and correct rejection judgments were significantly faster than incorrect source judgments [$t(25)$s > 5.2, $ps < 0.0001$]; the former did not differ from each other [$t(25) = 1.0$].

1.2.2. Electrophysiological results

Figs. 4 and 5 show plots of grand average ERPs and average voltages, respectively. Fig. 6 shows topographic contrast plots for the FN400 and parietal old/new ERP effects.

To examine the FN400 effect, we conducted a two-way repeated measures ANOVA comparing with factors of hemisphere (left and right anterior-superior ROIs, see Fig. 2) and trial condition (source correct, source incorrect, and correct rejections). The dependent measure was amplitude averaged over 300–500 ms. There was a main effect of trial condition [$F(1.82,45.38) = 12.5$, $MSE = 1.02$, $p < 0.0001$], but not hemisphere [$F(1,25) < 1$]. A significant interaction between hemisphere and condition indicated that the trial condition effect was larger over the left than the right hemisphere (see Fig. 6) [$F(1.60,39.90) = 3.8$, $MSE = 0.26$, $p < 0.05$]. However, the same pattern was observed within each

Table 1
Average artifact-free trial counts (per participant) for the analyzed accuracy conditions across all three experiments; standard deviations are in parentheses. *Notes: SC, source correct; SI, source incorrect; CR, correct rejections.*

ERP analysis trial counts				
Experiment	Condition	SC	SI	CR
Experiment 1	Location	172.2 (76.1)	45.0 (18.5)	100.1 (35.3)
	Location, familiar	29.2 (10.5)	23.7 (6.1)	110.9 (23.5)
Experiment 2	2 colors	72.5 (24.1)	42.3 (12.2)	46.6 (20.0)
	6 colors	75.2 (27.9)	40.0 (11.3)	49.0 (19.8)
	Collapsed	138.3 (49.7)	72.5 (27.0)	87.5 (38.5)
	Collapsed, familiar	36.6 (18.3)	28.8 (11.8)	99.0 (39.0)
Experiment 3	Color	147.1 (45.1)	82.2 (26.1)	93.1 (37.4)
	Location	167.4 (59.1)	54.0 (26.9)	90.6 (37.2)
	Color, familiar	40.9 (19.1)	38.5 (19.1)	95.3 (42.9)
	Location, familiar	37.9 (13.5)	29.9 (12.7)	99.1 (37.6)

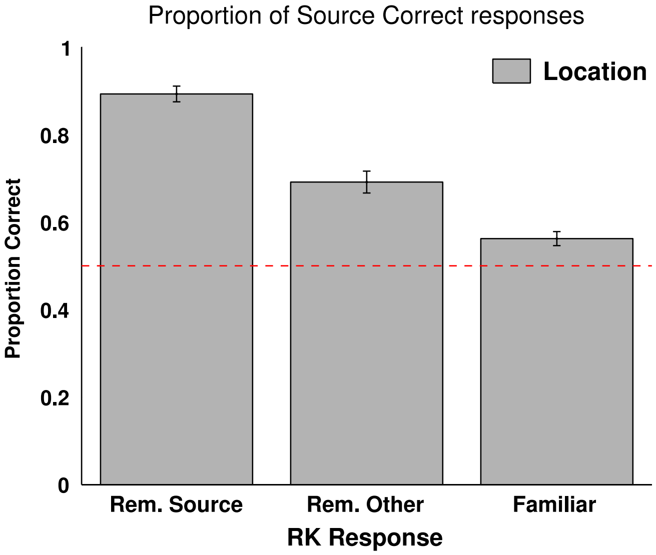

Fig. 3. Experiment 1: Source accuracy within each remember–know response type; error bars are standard errors. The horizontal red line indicates chance-level performance. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

Table 2
Item and source recognition accuracy data for hit rate, false alarm rate, discrimination, and bias across all three experiments; standard errors are in parentheses. *Notes: HR, hit rate; FAR, false alarm rate.*

Recognition accuracy					
Experiment	Condition	HR	FAR	d'	c
Experiment 1	Location: item	0.74 (0.03)	0.27 (0.03)	1.38 (0.09)	−0.03 (0.09)
	Location: source	0.79 (0.02)	0.24 (0.02)	1.57 (0.09)	−0.06 (0.04)
Experiment 2	2 colors: item	0.84 (0.02)	0.32 (0.04)	1.59 (0.14)	−0.26 (0.08)
	2 colors: source	0.66 (0.02)	0.41 (0.03)	0.65 (0.09)	−0.09 (0.05)
	6 colors: item	0.82 (0.02)	0.32 (0.04)	1.53 (0.15)	−0.21 (0.07)
	6 colors: source	0.64 (0.03)	0.37 (0.03)	0.75 (0.11)	−0.02 (0.06)
	Collapsed: item	0.84 (0.02)	0.31 (0.03)	1.65 (0.13)	−0.24 (0.07)
	Collapsed: source	0.67 (0.02)	0.38 (0.02)	0.78 (0.09)	−0.08 (0.03)
Experiment 3	Color: item	0.82 (0.02)	0.32 (0.04)	1.54 (0.11)	−0.21 (0.09)
	Color: source	0.65 (0.02)	0.38 (0.02)	0.71 (0.08)	−0.04 (0.04)
	Location: item	0.79 (0.02)	0.34 (0.04)	1.35 (0.11)	−0.18 (0.09)
	Location: source	0.75 (0.02)	0.27 (0.02)	1.41 (0.13)	−0.03 (0.05)

hemisphere separately: source correct trials were more positive than both source incorrect and correct rejections [*ps* < 0.01], and the latter did not differ [*ps* > 0.08].

To examine the parietal old/new effect, ERPs were averaged over 500–800 ms within the left and right posterior-superior regions. There was a main effect of condition [$F(1.89,47.27)=14.3$, $MSE=1.99$, $p<0.0001$], but no effect of hemisphere [$F(1,25)<1$]. Additionally, there was a significant interaction between hemisphere and condition [$F(1.98,49.58)=3.35$, $MSE=0.2$, $p<0.05$]. Pairwise comparisons revealed that, like the FN400, while source correct trials were more positive than both source incorrect and correct rejections over both hemispheres [*ps* <0.001], and the latter did not differ from each other [*ps* >0.56], the voltage difference between source accuracy conditions was greater over the left hemisphere than the right (see Fig. 6).

Table 3
Average reaction times in milliseconds for initial recognition judgments across all three experiments; standard errors are in parentheses. *Notes: SC, source correct; SI, source incorrect; CR, correct rejections.*

Reaction times Experiment	Condition	SC	SI	CR
Experiment 1	Location	485 (22)	637 (41)	497 (22)
Experiment 2	2 colors	625 (41)	731 (56)	494 (29)
	6 colors	885 (68)	1012 (90)	521 (36)
	Collapsed	770 (48)	913 (68)	537 (33)
Experiment 3	Color	546 (24)	586 (28)	444 (14)
	Location	476 (20)	588 (28)	450 (14)

1.2.3. *Familiar ERPs*

Stronger conclusions regarding familiarity's involvement in source recognition could be drawn if the FN400 was analyzed for items deemed “familiar” during the RK task. In the above FN400 analyses, we used typical *a priori* ROIs. We dropped the trial count threshold slightly to a minimum of 14 trials for the categories of familiar source correct, familiar source incorrect, and correct rejections to include more participants in these analyses ($n=17$; for trial counts, see Table 1) and those for the following experiments. Due to noisy ERPs because of low numbers of trials and participants, we also used a slightly different electrode ROI based on the maximal difference between all correctly identified old items (regardless of source accuracy) and new items in the participant sample from the previous ERP analyses, essentially the standard old/new effect. In this and subsequently reported experiments, the old/new difference centered on electrode FCz (see Fig. 6, source correct vs. correct rejection contrast for an approximation) and so a frontocentral ROI was used which is in between our *a priori* ROIs (dotted outline in Fig. 2) and is very near electrodes used for previous analyses of the FN400 (e.g., Addante et al., in press; Ecker, Zimmer, & Groh-Bordin, 2007b; Peters & Daum, 2009; Wolk et al., 2006; Woroch & Gonsalves, 2010).

ERPs were averaged over 300–500 ms at the frontocentral ROI (Fig. 7), and a one-way ANOVA revealed differences between conditions [$F(1.94,31.02)=4.39$, $MSE=0.89$, $p<0.05$]. Pairwise comparisons revealed that familiar source correct trials ($M=-3.02\ \mu V$) were significantly more positive than familiar source incorrect trials ($M=-3.96\ \mu V$) [$t(16)=$, $p<0.05$] and were marginally more positive than correct rejections ($M=-3.60\ \mu V$) [$t(16)=1.95$, $p=0.069$]. The latter did not differ [$p=0.29$]. This is essentially the same pattern

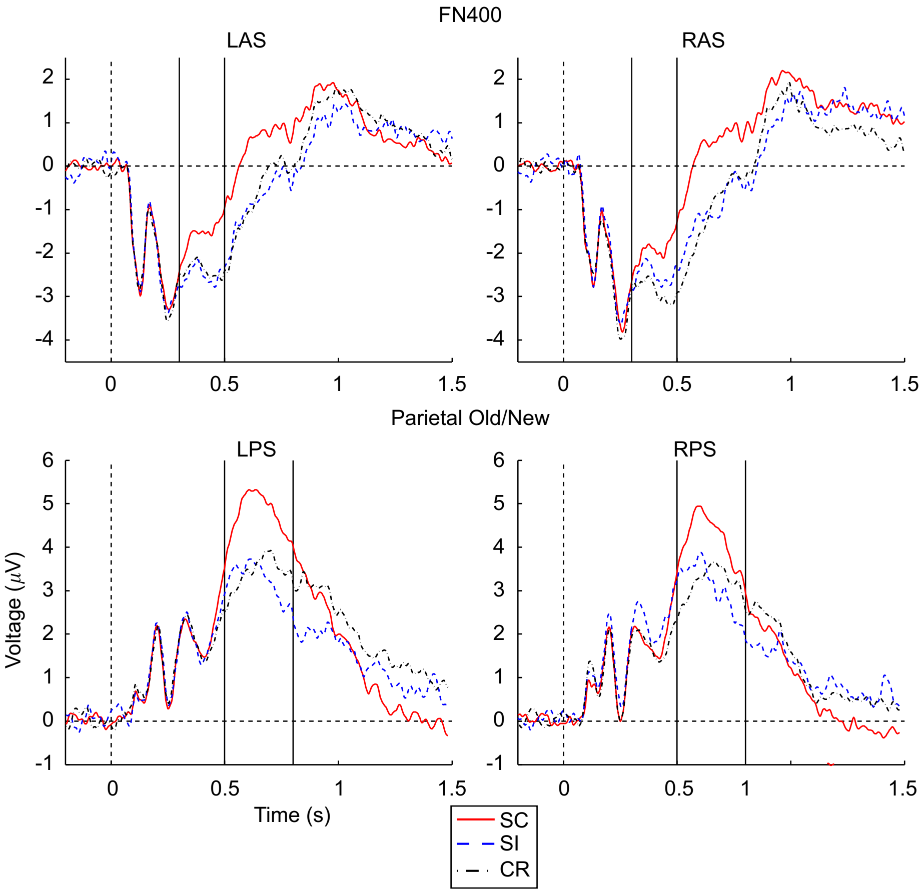

Fig. 4. Experiment 1: ERP waveforms for the three main trial conditions for the left and right anterior- and posterior-superior ROIs. Source correct trials (SC) are solid red, incorrect source trials (SI) are dashed blue, and correct rejections (CR) are dash-dotted black. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

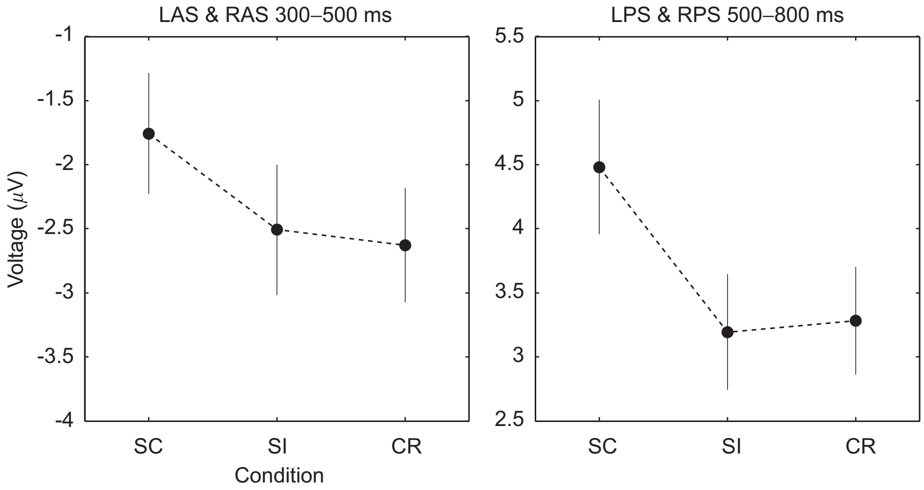

Fig. 5. Experiment 1: ERP voltages for the three main trial conditions averaged across the left and right anterior-superior and the left and right posterior-superior ROIs; error bars are standard errors. *Notes: SC, source correct; SI, source incorrect; CR, correct rejections.*

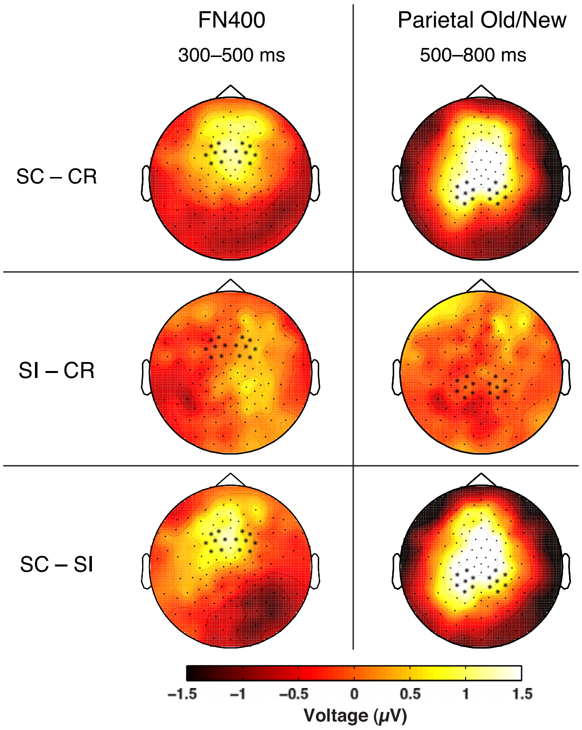

Fig. 6. Experiment 1: Topographic contrast plots showing the broader distributions of EEG activity as differences between the trial conditions named in the left column. The middle and right columns separate the temporal regions for the effects of interested, and the electrodes in the corresponding ROIs are marked with larger asterisks. *Notes: SC, source correct; SI, source incorrect; CR, correct rejections.*

seen in the earlier FN400 analyses when collapsing across all RK responses.

1.3. Discussion

Experiment 1 tested recognition memory for spatial source information and showed both behavioral and electrophysiological accuracy effects related to familiarity contributing to accurate source recognition. The important behavioral result is that source accuracy for "familiar" responses was above chance. The pattern of the FN400 ERP effects across the frontal ROIs also corroborates the tested hypothesis in that it showed a source accuracy effect for all RK responses and only the "familiar" trials: the amplitude of source correct trials was more positive than that of source incorrect trials.[1] Neither of these patterns of results would be expected if a familiarity process only differentiates between old and new items, and instead they suggest that familiarity can contribute to successful source monitoring of spatial information, which has been considered extrinsic.

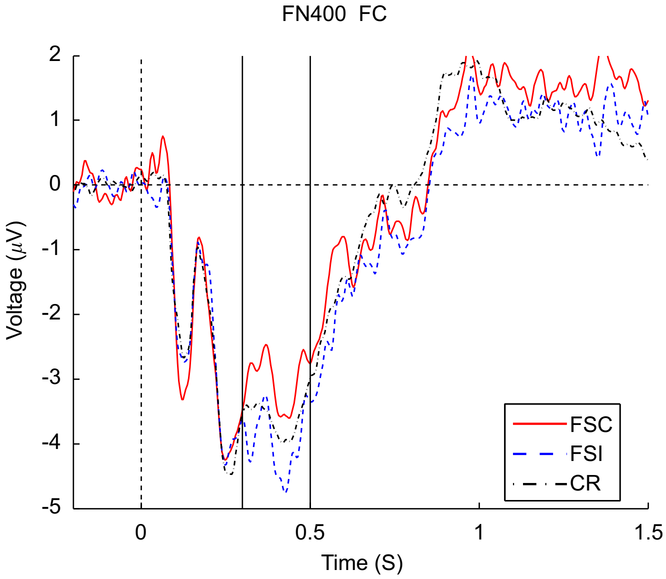

Fig. 7. Experiment 1: ERP waveforms for the "familiar" trial conditions for the frontocentral ROI. Familiar source correct trials (FSC) are solid red, familiar incorrect source trials (FSI) are dashed blue, and correct rejections (CR) are dash-dotted black. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

2. Experiment 2

Experiment 1's results differed from those of Ecker et al. (2007b), who did not find FN400 differences between correct and incorrect source recognition when the source involved an

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[1] The FN400 ERP effect for spatial source accuracy was replicated in two unpublished experiments using similar study and test block procedures.

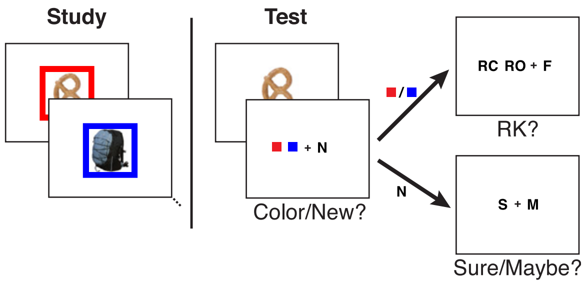

Fig. 8. An illustration of the study and test tasks used in Experiment 2. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

extrinsic color manipulation. The primary differences between our experiments is that the present Experiment 1 used two spatial locations as sources, whereas Ecker et al. used six different colored frames surrounding the target stimuli as sources. Thus, our different results could reflect differences between spatial and color sources, or they could reflect differences between two and six possible sources.

In Experiment 2, source information was defined by the color of the frame surrounding each object (see Fig. 8). Each item was presented in the middle of the screen, and participants were told to remember the color of the frame with which each item was paired. The presence of two and six possible source colors was manipulated within subjects. At test, centered items without the colored frame were shown, and participants were asked to either recognize the paired color from the study period for old items or respond “new” to new items. The response procedure was the same as in Experiment 1 except with color source information instead of spatial location. We predicted that if familiarity is able to distinguish between a small number of sources, there should be a difference between source correct and incorrect trials in the two-color condition but not in the six-color condition. However, if the type of source information is important for determining familiarity’s involvement in source memory, then familiarity should not be able to accurately distinguish extrinsic color sources regardless of the number of possible sources, while it can still distinguish extrinsic spatial sources.

2.1. *Material and methods*

2.1.1. *Participants*

Thirty University of Colorado undergraduates participated in the experiment for either course credit or payment of $15 per hour (ages 18–27, M=21.2; 17 male, 13 female). All participants were right-handed native-English speakers and had normal or corrected-to-normal vision. Informed consent was obtained from each participant, and the study conformed to the Human Research Committee guidelines.

2.1.2. *Materials*

The stimuli used were the same as in Experiment 1, and each item was surrounded by a 48-pixel colored frame. There were eight possible frame colors: purple, green, blue, pink, red, orange, yellow, brown.

2.1.3. *Design*

The design of Experiment 2 was essentially the same as Experiment 1. Two of the four study lists used six frame colors, while the other two study lists used the remaining two colors, and the lists were presented with an A–B–A–B design. Half of the participants started with two colors while the other half started with six. The order of studied items was randomized after assigning the colors as evenly as possible across the items, and the colors used for the two- and six-color groups were randomly chosen for each participant.

2.1.4. *Procedure*

An electrode net was applied to each participant’s head, and the participants then completed two practice lists, one for each color set, to familiarize them with the study and test procedures (16 studied and 22 tested items).

During each study list, participants fixated the centered cross and observed the items that appeared at that point on the screen. They were instructed to remember the frame color with which each item was presented. Again, frame color was chosen randomly, but evenly, from the available colors for that list (either two or six colors). Each item and frame remained on the screen for 1500 ms, followed by a 625 ± 125 ms inter-stimulus interval. The same visual Gaussian noise method was used to prevent after-image effects that could be induced by an item or its frame. The area containing the studied stimuli subtended a visual angle of 5.6° wide × 5.6° high.

This experiment’s test procedure followed Experiment 1, except it used color choices instead of location choices. Each test list was presented immediately after its corresponding study list. A centered fixation cross was visible at all times except when a test probe image was presented, and participants were instructed to keep their eyes focused on the center of the screen. While the fixation cross was on the screen immediately preceding each test probe, participants also saw a 750 ms “preview” of the two colors that they would have to choose between following the probe; the preview appeared to one side of the cross. For old items, one of these colors was always the correct source color (presented with that particular probe during study) and the other was a lure color; target and lure location was counterbalanced within each participant. Only two possible source responses were given in the six-color condition to equate the testing conditions between the two- and six-color conditions, as well as to be more comparable to Experiment 1.

After the preview, each centered probe was then presented for 750 ms. Following a 1500 ms pause with fixation only, participants saw □ □ + N (for Color 1, Color 2, fixation cross, New, where the squares were solid colors; see Fig. 8 for an example). These options lined up with their three response keys to indicate

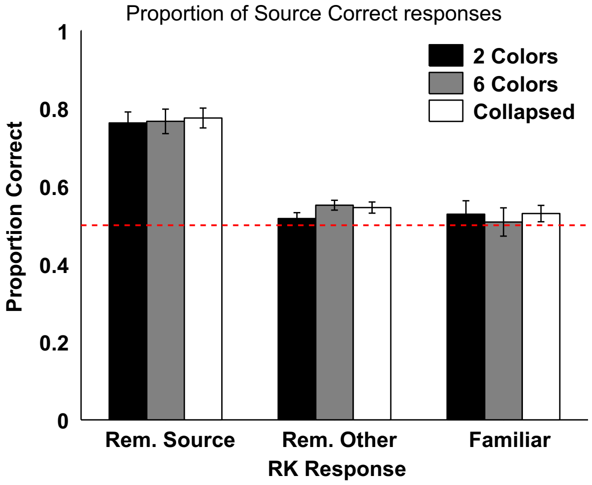

Fig. 9. Experiment 2: Source accuracy within each remember–know response type for the two- and six-color conditions separated (n=22) and collapsed (n=28); error bars are standard errors. The horizontal red line indicates chance-level performance. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

the source information from the study period for each item. If the answer was not “new”, participants then used three-option RK judgments: on the screen they saw `RC RO+F` (for Remember Color, Remember Other, fixation cross, Familiar). If the participant answered “new”, they saw `Maybe+Sure`, to indicate how confident they were about it being a new item. An inter-stimulus interval of 625 ± 125 ms followed each response. The visual angle of each test probe image was 4.3° wide × 4.3° high. The same pseudo-random response key and mapping method from Experiment 1 was used, but only with the constraint that both colors were always to one side of the fixation cross and the `N` was on the other side.

2.1.5. *Electrophysiological recordings and processing*

The procedure for recording and processing electrophysiological data in Experiment 2 was the same as in Experiment 1. Grand average ERPs are presented in Figs. 10 and 13, voltages for the recognition memory effects are summarized in Fig. 11, and the topographic contrasts between conditions for each effect are plotted in Fig. 12.

2.2. *Results*

Two participants were excluded from all analyses because of low accuracy (source hit rates were more than three standard deviations below the mean). As detailed below, we first analyzed behavioral and ERP results broken down by the two- vs. six-color source conditions. These analyses excluded six additional participants because of low trials counts (<15) in one condition (included $n=22$). Because our initial analyses did not find meaningful differences between the two- and six-color conditions, subsequent analyses collapsed over this variable so that the six participants with lower trial counts could be included to increase power (included $n=28$). Behavioral analyses included all trials, while ERP analyses included only artifact-free trials. Average trial counts for ERP analyses are in Table 1.

2.2.1. *Behavioral results*

Item and source accuracy rates for the two- vs. six-color conditions are summarized in Table 2 (collapsing across RK and Sure/Maybe ratings for “old” and “new” responses). These rates were calculated in a similar way to Experiment 1, but source accuracy rates used the preview colors described in the current methods section to denote the target and lure distributions. The conditions did not significantly differ on any of the item or source memory measures in Table 2. Only the hit rate differences approached significance as being marginally higher for two colors than six colors [$t(21)=1.94$, $p=0.066$]. Additionally, item response biases (c) for both colors separately and collapsed across colors were significantly liberal (negative) [$ps<0.01$], indicating a tendency to label new items as “old” (using a source response regardless of accuracy). Dividing the data into RK response types also showed no differences between the two- and six-color source conditions (Fig. 9), with only the RO differences approaching

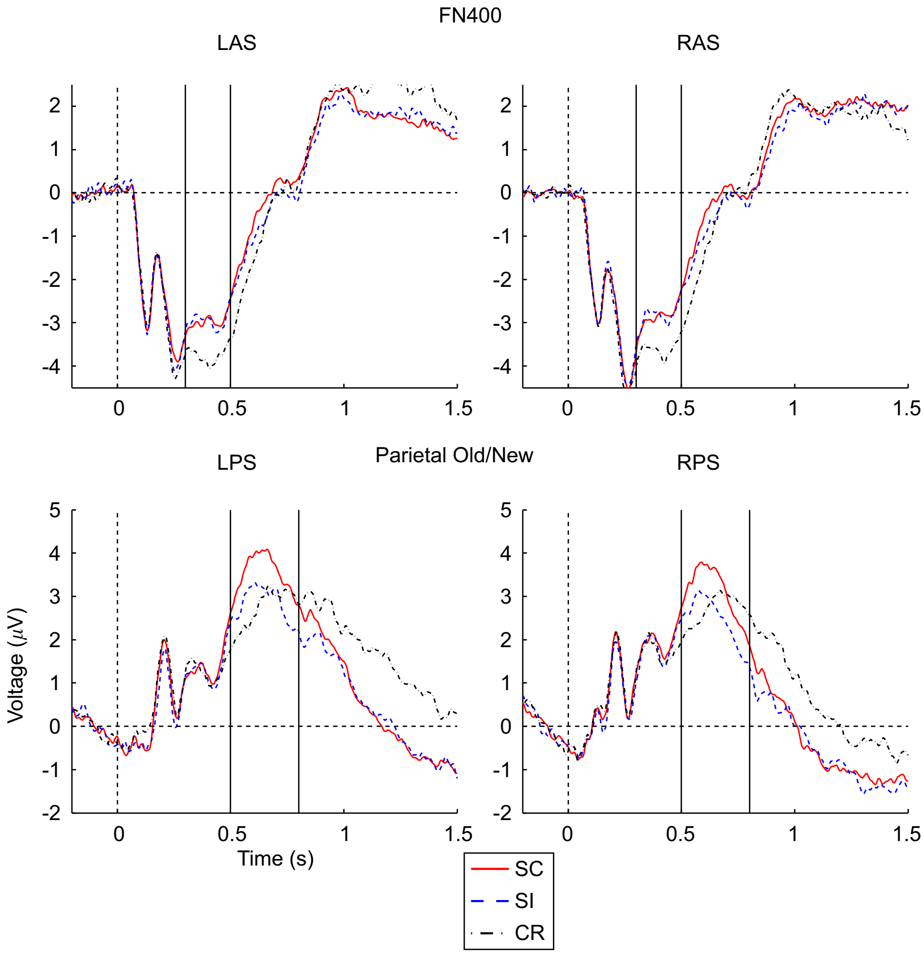

Fig. 10. Experiment 2: ERP waveforms for the three main trial conditions for the left and right anterior- and posterior-superior ROIs collapsed across the two- and six-color conditions ($n=28$). Source correct trials (SC) are solid red, source incorrect trials (SI) are dashed blue, and correct rejections (CR) are dash-dotted black. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

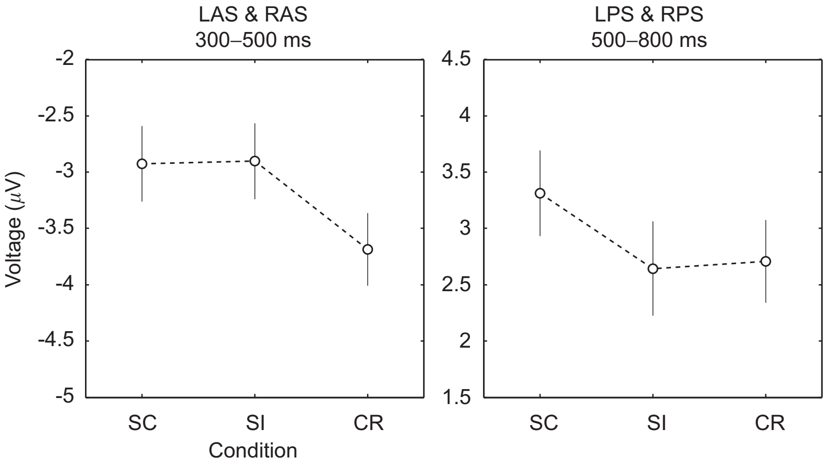

Fig. 11. Experiment 2: ERP voltages for the three main trial conditions averaged across the left and right anterior-superior and the left and right posterior-superior ROIs collapsed across the two- and six-color conditions ($n=28$); error bars are standard errors. *Notes: SC, source correct; SI, source incorrect; CR, correct rejections.*

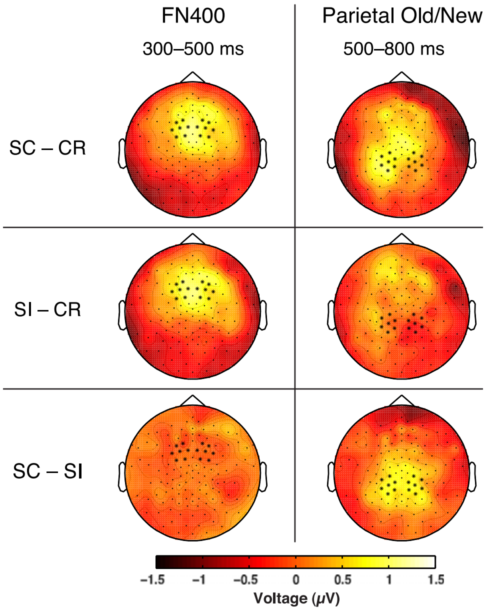

Fig. 12. Experiment 2: Topographic contrast plots showing the broader distributions of EEG activity as differences between the trial conditions named in the left column. The middle and right columns separate the temporal regions for the effects of interested, and the electrodes in the corresponding ROIs are marked with larger asterisks. *Notes: SC, source correct; SI, source incorrect; CR, correct rejections.*

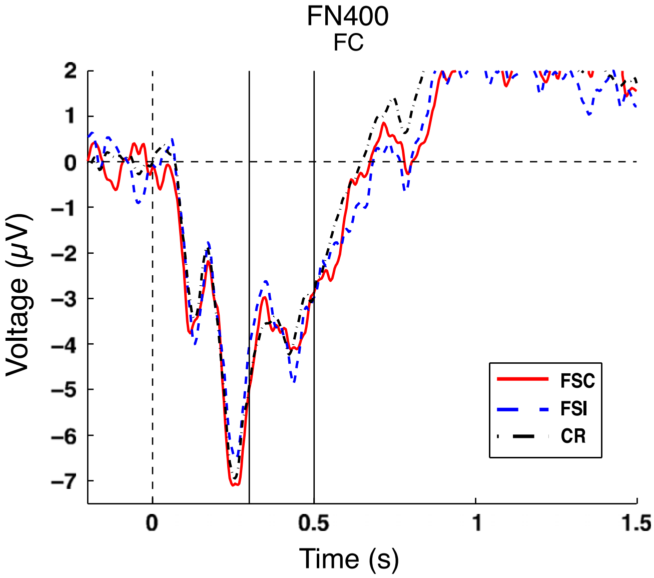

Fig. 13. Experiment 2: ERP waveforms for the "familiar" trial conditions for the frontocentral ROI. Familiar source correct trials (FSC) are solid red, familiar incorrect source trials (FSI) are dashed blue, and correct rejections (CR) are dash-dotted black. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

significance [$t(21)=1.99$, $p=0.06$]. Compared to chance-level performance, RO response accuracy was only greater than chance in the six-color condition (two: [$M=0.52$, $t(21)=1.13$, $p=0.27$]; six: [$M=0.55$, $t(21)=4.08$, $p<0.001$]) and when collapsing across conditions [$M=0.55$, $t(27)=3.42$, $p<0.01$]. Importantly, source accuracy for "familiar" responses was not different from chance in either condition (two: [$M=0.53$, $t(21)=0.82$, $p=0.42$]; six: [$M=0.51$, $t(21)=0.23$, $p=0.82$]); this held when collapsing across source conditions [$M=0.53$, $t(27)=1.42$, $p=0.17$].

Source responses were faster in the two- than the six-color condition for both correct [$t(21)=5.31$, $p<0.0001$] and incorrect [$t(21)=4.06$, $p<0.001$] source responses (Table 3), but were no different for correctly rejecting new items [$t(21)=1.36$, $p=0.19$]. This makes sense because the color choices for non-new responses were fixed in the two-color condition, but varied in the six-color condition, thereby leading to slower responses. Additionally, in both conditions correct source responses were faster than incorrect source responses [$ps<0.05$] and correct rejections were faster than both correct and incorrect source responses [$ps<0.001$].

2.2.2. *Electrophysiological results*

Before ruling out any differences between the two- and six-color conditions in the ERP domain, we conducted two three-way repeated measures ANOVAs to examine the FN400 and parietal old/new effects ($n=22$). These statistical results are reported below for completeness, but all tables and figures show the ERP results from the larger sample ($n=28$) because the two source conditions did not differ. All the statistical results reported below were not qualitatively different when the larger collapsed sample was analyzed.

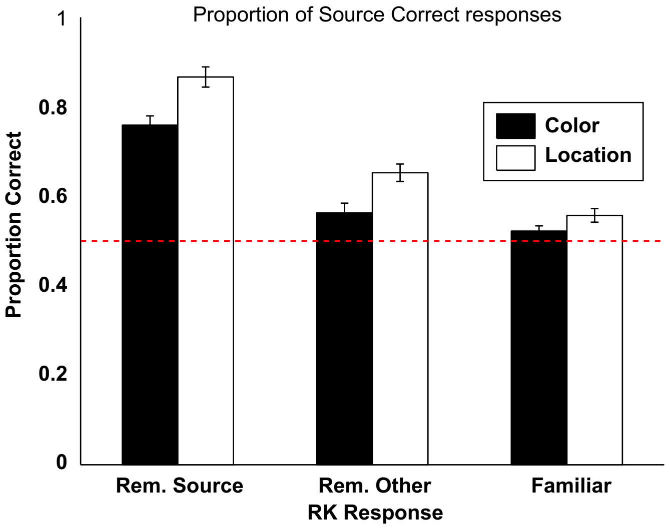

Fig. 14. Experiment 3: Source accuracy within each remember-know response type for the color and location conditions; error bars are standard errors. The horizontal red line indicates chance-level performance. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

For the FN400 effect, the ANOVA had factors of hemisphere (left and right anterior-superior regions, see Fig. 2), source condition (two and six colors), and trial condition (source correct, source incorrect, and correct rejections). The dependent measure was amplitude averaged over 300–500 ms. There was a main effect of trial condition $[F(1.82,38.32) = 13.01$, $MSE = 1.43$, $p < 0.0001]$, but not hemisphere or source condition $[F(1,21)\ s < 1]$. Pairwise comparisons revealed that, collapsing over hemisphere and source condition, correct rejections were more negative ($M = -3.59\ \mu V$) than both source correct ($M = -2.80\ \mu V$) $[t(21) = 5.06$, $p < 0.0001]$ and source incorrect trials ($M = -2.86\ \mu V$) $[t(21) = 3.7$, $p < 0.01]$, while the source accuracy conditions were no different from each other $[t(21) = 0.39]$. These results demonstrate a standard old/new effect.

For the parietal old/new effect ERPs were averaged over 500–800 ms within the left and right posterior-superior regions. There was a main effect of both trial condition $[F(1.99,41.82) = 9.23$, $MSE = 1.52$, $p < 0.001]$ and source condition $[F(1,21) = 11.66$, $MSE = 2.59$, $p < 0.01]$, but not for hemisphere $[F(1,21) < 1]$. Pairwise comparisons revealed that the main effect of source was due to the voltages in the two-color condition ($M = 3.32\ \mu V$) being higher overall compared to the six-color condition ($M = 2.65\ \mu V$) $[t(21) = 3.41$, $p < 0.01]$. Because source condition did not interact with trial condition, the main effect of source condition was not considered meaningful. Investigating the main effect of trial condition showed that source correct trials were more positive ($M = 3.41\ \mu V$) than both source incorrect ($M = 2.61\ \mu V$) $[t(21) = 4.4$, $p < 0.001]$ and correct rejections ($M = 2.94\ \mu V$) $[t(21) = 2.52$, $p < 0.05]$, and the latter did not differ from each other $[t(21) = 1.72$, $p = 0.1]$.

2.2.3. Familiar ERPs

The same comparisons of "familiar" trial ERPs were made as in Experiment 1, collapsing across color conditions and averaging voltage across 300–500 ms in the frontocentral ROI. Trial counts were lower overall in these conditions (see Table 1), and using a trial count threshold of 14 only nine participants remained; the threshold would have needed to drop too low to get the participant count up (only 13 had ≥ 10 trials), and so only those nine participants were used. There were no differences between conditions $[F(1.59,12.75) = 0.04$, $MSE = 1.77$, $p = 0.94]$.

2.2.4. Comparisons between Experiments 1 and 2

Source accuracy for "familiar" judgments was above chance in Experiment 1 (location, 56%) but not in Experiment 2 (color, 53%), so we directly compared these accuracies between experiments using an independent-samples *t*-test assuming equal variances. Source accuracy was not significantly different between the two experiments $[t(52) = 1.26$, $p = 0.21$, two-tailed$]$.

FN400 amplitudes differed between correct and incorrect source judgments in Experiment 1 but not in Experiment 2, so we directly compared these effects by conducting a mixed three-way repeated measures ANOVA with factors of experiment (1 [location] and 2 [color]; between-subjects), hemisphere (left and right anterior-superior; within-subjects), and trial condition (source correct, source incorrect, and correct rejections; within-subjects). There was a main effect of trial condition $[F(1.77,91.90) = 21.74$, $MSE = 0.941$, $p < 0.00000001]$, but not for experiment $[F(1,52) = 2.47$, $p = 0.12]$ or hemisphere $[F(1,52) = 0.21$, $p = 0.65]$. There was, however, a significant interaction between experiment and trial condition $[F(1.77,91.90) = 5.66$, $MSE = 0.941$, $p < 0.01]$. Pairwise comparisons collapsing across hemisphere revealed that the difference between source correct and source incorrect trials was larger for location (Experiment 1; $M = 0.75\ \mu V$) than color (Experiment 2; $M = 0.02\ \mu V$) $[t(52) = 3.25$, $p < 0.01]$, and the difference between source incorrect and correct rejections was smaller for location (Experiment 1; $M = 0.12\ \mu V$) than color (Experiment 2 $M = 0.78\ \mu V$) $[t(52) = 2.30$, $p < 0.05]$.

To more directly examine the important contrast between source correct and incorrect trials, an additional three-way ANOVA was run with these two trials conditions in the third factor. Critically, testing the significant experiment by trial condition interaction confirmed that the difference between source correct and source incorrect trials was larger for location (Experiment 1; $M = 0.75\ \mu V$) than color (Experiment 2; $M = -0.02\ \mu V$) $[F(1,52) = 10.53$, $MSE = 0.764$, $p < 0.01]$.

A similar two-way ANOVA was performed using FN400 voltages at the frontocentral for the "familiar" trials, with factors of experiment (1 [location] and 2 [color]; between-subjects) and trial condition (familiar source correct, familiar source incorrect, and correct rejections; within-subjects). No main effects or interactions were found $[Fs < 1.7$, $ps > 0.2]$. However, in an ANOVA using only familiar source correct and incorrect trials in the second factor, a marginal interaction emerged between experiment and trial condition $[F(1,24) = 3.96$, $MSE = 0.879$, $p = 0.058]$, which shows that the difference between familiar source correct and incorrect trials was marginally larger in for location (Experiment 1; $M = 0.94\ \mu V$) than color (Experiment 2; $M = -0.15\ \mu V$).

2.3. Discussion

Experiment 2 tested recognition memory for extrinsic color source information and did not show any meaningful effects related to the number of sources that were encoded. This experiment also failed to show any effects related to familiarity contributing to accurate source discrimination, as might be expected based on prior results in the literature (Ecker et al., 2007b). Behavioral accuracy clearly indicated the advantage of a subjective feeling of source recollection for accurate source monitoring, though "remember other" responses were slightly above chance. Nonetheless, "familiar" responses were at chance-level performance for source memory. The FN400 ERP results followed this pattern, showing only a standard old/new effect while not being influenced by source accuracy. The same went for when only analyzing trials deemed "familiar", though it should be noted that these tests were likely severely underpowered. When comparing Experiments 1 and 2 directly, there was no behavioral source accuracy difference for "familiar" responses. However, the FN400 interaction between experiment and trial condition reveals that there was an accuracy-dependent voltage difference reflected in the familiarity signal modulated by the type of source information being remembered. This voltage difference was also marginally present when comparing only the "familiar" source correct and incorrect trials. These results lead us to believe that familiarity's contribution to source recognition depends on the type of information being processed.

3. Experiment 3

Experiment 3 was a within-subjects version of Experiments 1 and 2 combined together, and took measures to make the study and test methods as similar as possible for the color and spatial location conditions. In each of the two sessions participants studied spatial source for two lists (as in Experiment 1) and extrinsic color source for two lists (as in Experiment 2, but only two colors were used in Experiment 3). The test phase that followed each study list was the same as in the previous experiments: old and new items were presented without source information, and participants made a source judgment followed by a RK judgment. We expected to find the same behavioral and ERP patterns seen in the prior experiments.

3.1. Method

3.1.1. Participants

Thirty-eight University of Colorado undergraduates participated in the experiment for either course credit or payment of $15 per hour (ages 18–29, $M=20.6$; 21 male, 17 female). All participants were right-handed native-English speakers and had normal or corrected-to-normal vision. Informed consent was obtained from each participant, and the study conformed to the Human Research Committee guidelines.

3.1.2. Materials

The stimuli were the same as in the previous experiments. The color source study blocks used two frame colors, blue and yellow, to equate the number of color and spatial location sources across all trials.

3.1.3. Design

In each of two sessions, occurring on separate days, four lists were studied and tested where two lists were presented with color source information and two lists were presented with spatial source information. The order of source modality alternated within a session (A–B–A–B), and the second session used the opposite order from the first (B–A–B–A). Ordering was counterbalanced across participants such that half started with color and half started with spatial location.

3.1.4. Procedure

An electrode cap was applied to each participant's head, and the participants then completed two practice lists, one for each source condition, to familiarize them with the study and test procedures (14 studied and 20 tested items in each practice). The study procedure was slightly modified from Experiments 1 and 2 in an attempt to raise color source accuracy. For both source conditions, a source indicator frame appeared by itself (on top of the visual Gaussian noise image) for 500 ms prior to the presentation of the stimulus image; this served to alert the participant of either the color or spatial location to be paired with the upcoming stimulus. For the color condition the indicator was a blue or yellow frame, and for the spatial condition it was a white frame on either the left or right side of the screen. The stimulus image then appeared for 2000 ms within the source indicator frame. The study phase inter-stimulus interval was increased to 1125 ± 125 ms. Test list timing was the same as in Experiments 1 and 2. The procedures were also the same except for two changes: (1) both source responses were assigned to one hand while the new response was assigned to the other (response key counterbalancing used the same method as the prior experiments); (2) to make the test periods more similar for the two conditions, there was no color preview (as in Experiment 2), and letters were used as the source cues (L and R for the spatial location condition and B and Y for the color condition).

3.1.5. Electrophysiological recordings and processing

The procedure for recording and processing electrophysiological data was the same as in the prior experiments except the recording sampling rate was 500 Hz and the amp used only a 100 Hz low-pass hardware filter. About 0.1 Hz high-pass and 40 Hz low-pass filters were applied when preprocessing the data. ERPs for the conditions of interest are shown in Figs. 15 and 18, while voltages are summarized in Fig. 16 and topographic contrasts are presented in Fig. 17.

3.2. Results

Twelve participants were excluded from analyses because they either did not complete the second session ($n=5$), made no "familiar" responses ($n=4$), or had fewer than 15 trials in the main analyzed ERP conditions ($n=3$), The remaining 26 participants were included in all behavioral and ERP analyses, and trials were collapsed across sessions. Behavioral analyses included all trials while trials with EEG artifacts were excluded from ERP analyses. Average trial counts for ERP analyses are included in Table 1.

3.2.1. Behavioral results

Accuracy rates for both color and spatial location source conditions remained similar to Experiments 1 and 2 (see Table 2). Item d' was higher for the color trials [$t(25)=2.88$, $p<0.01$], while source d' was higher for the location trials [$t(25)=7.31$, $p<0.000001$]. Item response bias (c) was slightly liberal, with a significant bias for color [$t(25)=2.32$, $p<0.05$] and a marginally significant bias for location [$t(25)=1.99$, $p=0.058$], indicating a slight tendency to give a source response regardless of accuracy. Source c did not differ from zero in any conditions [ps >0.29]. Item and source response biases did not differ between the two conditions [ps >0.12]. Dividing responses into the three RK options (Fig. 14) revealed that source accuracy for items subsequent judged with RS (0.79 for color, 0.87 for spatial location) and RO (0.56 for color, 0.65 for spatial location) responses were above chance [ps <0.01]. F-response source accuracy for spatial source was above chance [$M=0.56$, $t(25)=3.78$, $p<0.001$] and that of color source was at (or marginally above) chance [$M=0.52$, $t(25)=1.86$, $p=0.08$]. Importantly, F accuracy for spatial source was significantly higher than F accuracy for color source [$t(25)=2.63$, $p<0.05$].

Reaction times are listed in Table 3. In the color condition, reaction times for both source correct and correct rejections were faster than those of source incorrect [$t(25)$ s >2.40, ps <0.05]. Correct rejections were also faster than source correct responses [$t(25)=4.60$, $p<0.001$]. In the location condition, reaction times for both source correct and correct rejections were faster than

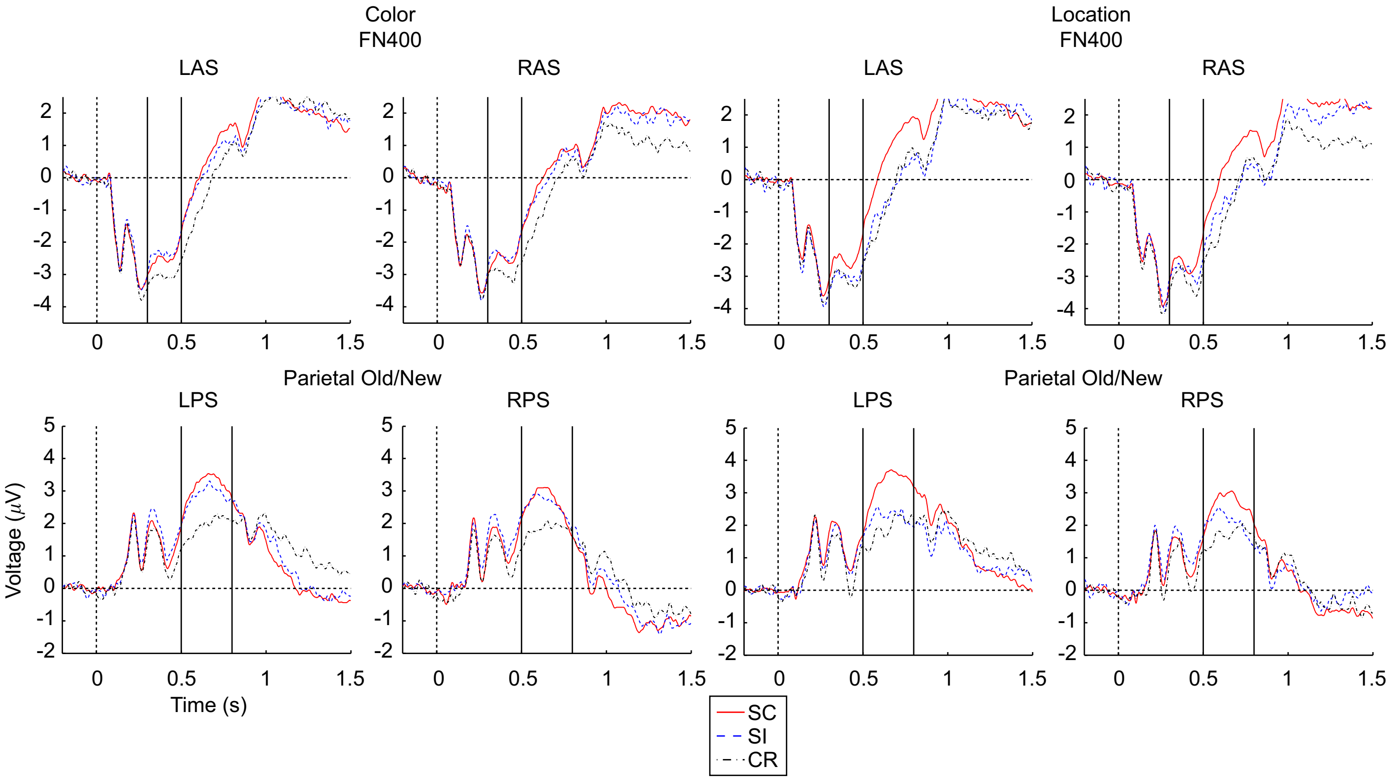

Fig. 15. Experiment 3: ERP waveforms for the three main trial conditions for the left and right anterior- and posterior-superior ROIs for the color and location source conditions. Source correct trials (SC) are solid red, source incorrect trials (SI) are dashed blue, and correct rejections (CR) are dash-dotted black. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

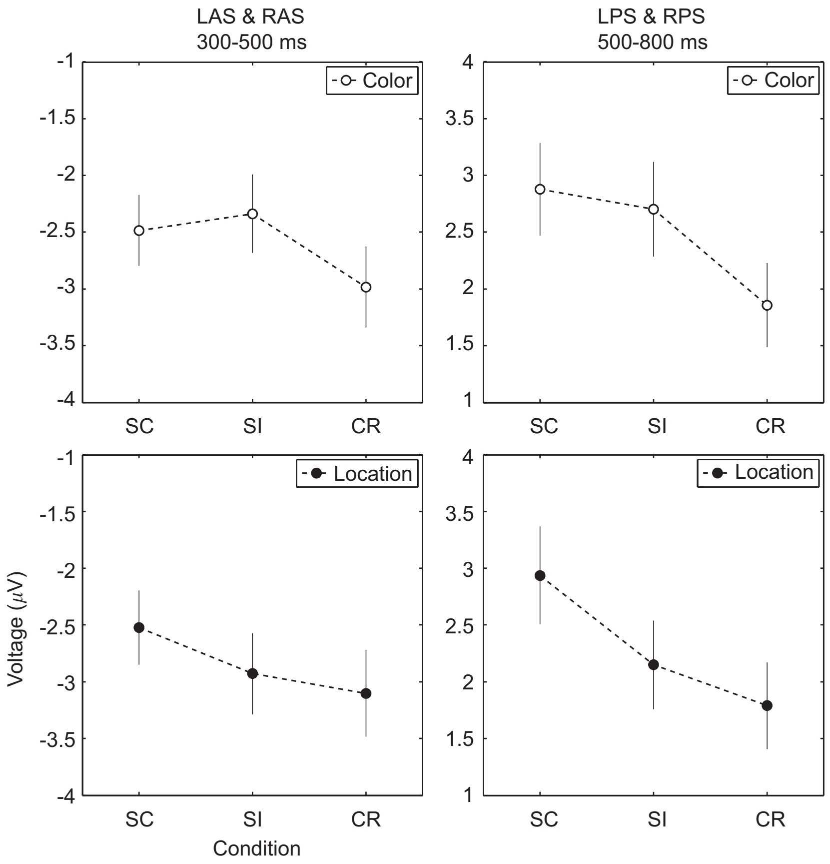

Fig. 16. Experiment 3: ERP voltages for the three main trial conditions averaged across the left and right anterior-superior and the left and right posterior-superior ROIs for the color and location source conditions; error bars are standard errors. *Notes: SC, source correct; SI, source incorrect; CR, correct rejections.*

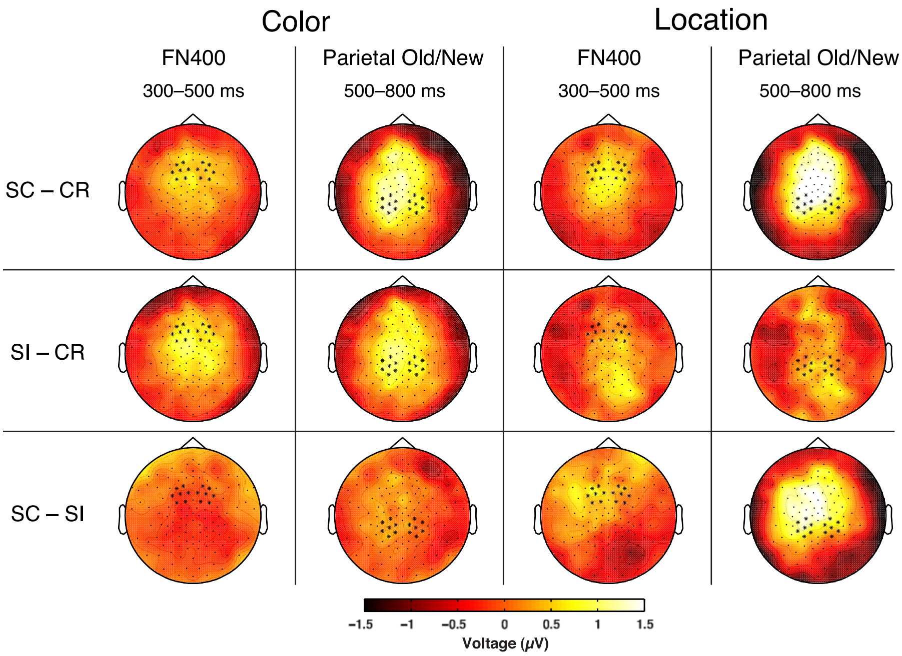

Fig. 17. Experiment 3: Topographic contrast plots showing the broader distributions of EEG activity as differences between the trial conditions named in the left column. The middle and right columns separate the temporal regions for the effects of interested, and the electrodes in the corresponding ROIs are marked with larger asterisks. *Notes: SC, source correct; SI, source incorrect; CR, correct rejections.*

those of source incorrect [$t(25)$ s > 5.90, *ps* < 0.00001]; the former did not differ from each other [$t(25) = 1.64$, $p = 0.11$].

3.2.2. Electrophysiological results

We conducted three-way repeated measures ANOVAs to examine the FN400 (300–500 ms) and parietal old/new (500–800 ms) effects with factors of hemisphere (left and right anterior- or posterior-superior regions for the respective effects, see Fig. 2), source condition (color and spatial location), and trial condition (source correct, source incorrect, and correct rejections).

For the FN400 effect, there were significant main effects of both source condition [$F(1,25) = 8.72$, $MSE = 0.55$, $p < 0.01$] and trial condition [$F(1.77,44.26) = 11.60$, $MSE = 0.80$, $p < 0.001$], but not hemisphere [$F(1,25) = 0.006$]. There was also a significant source condition by trial condition interaction [$F(1.79,44.79) = 5.69$, $MSE = 0.46$, $p < 0.01$]. Collapsing over hemisphere, pairwise comparisons revealed that in the color condition, voltage for correct rejections ($M = -2.98$ μV) was more negative than for both source correct ($M = -2.49$ μV) [$t(25) = 4.17$, $p < 0.001$] and source incorrect ($M = -2.34$ μV) responses [$t(25) = 5.04$, $p < 0.0001$], and that there was no effect of source accuracy [$t(25) = 1.12$, $p = 0.27$]. These results match those of Experiment 2. In the location condition, voltage for correct rejections ($M = -3.10$ μV) and source incorrect responses ($M = -2.93$ μV) was the same [$t(25) = 0.91$, $p = 0.37$], but both conditions were more negative than source correct responses ($M = -2.52$ μV) [CR: $t(25) = 4.79$, $p < 0.0001$; SI: $t(25) = 2.36$, $p < 0.05$]. These results match those of Experiment 1. Overall, source incorrect responses were more negative in the location condition compared to the color condition [$t(25) = 3.68$, $p < 0.01$], with no differences between the other trial conditions [*ts* < 1.0].

We also ran a three-way ANOVA with a more direct comparison of source correct and incorrect trials in the third factor. There was a main effect of source condition [$F(1,25) = 11.98$, $MSE = 0.428$, $p < 0.01$], but no effects of hemisphere or trial conditions [$F(1,25)$ s < 1.2]. However, there was a significant source condition by trial condition interaction [$F(1,25) = 7.99$, $MSE = 0.498$, $p < 0.01$], and pairwise tests showed the same pattern as above: collapsing over hemisphere, source correct trials were more positive than source incorrect trials in the location condition [$t(25) = 2.36$, $p < 0.05$] but not in the color condition [$t(25) = 1.12$, $p = 0.27$].

For the parietal old/new effect, there was only a main effect of trial condition [$F(1.58,39.57) = 44.45$, $MSE = 0.87$, $p < 0.0001$], with an interaction between trial condition and hemisphere [$F(1.81,45.34) = 4.98$, $MSE = 0.28$, $p < 1 \times 10^{-11}$]. Pairwise tests showed that the pattern of significance was the same for both hemispheres, but effects were stronger over the left posterior-superior region compared to the right. Over the left hemisphere, in the color condition source correct responses ($M = 3.13$ μV) were more positive than correct rejections ($M = 1.90$ μV) [$t(25) = 7.10$, $p < 0.000001$] and were marginally more positive than source incorrect responses ($M = 2.85$ μV) [$t(25) = 1.83$, $p = 0.079$]. The location condition showed a more positive voltage for source correct ($M = 3.24$ μV) compared to source incorrect ($M = 2.22$ μV) [$t(25) = 4.36$, $p < 0.001$] and correct rejections ($M = 1.89$ μV) [$t(25) = 5.96$, $p < 0.00001$]. The latter did not differ from each other [$t(25) = 1.75$, $p = 0.092$].

3.2.3. Familiar ERPs

The comparisons of "familiar" trial ERPs were also made for Experiment 3, averaging voltage across 300–500 ms in the frontocentral ROI. Using a trial count threshold of 14, 13 participants remained (Table 1). A two-way ANOVA was run with factors of source condition (color and location) and trial condition (familiar source correct, familiar source incorrect, and correct rejections). There was a marginal main effect of source condition [$F(1,12) = 3.93$, $MSE = 0.43$, $p = 0.071$], no effect of trial condition [$F(1.43,17.17) = 1.28$, $MSE = 1.14$, $p = 0.29$], and an interaction that approached significance [$F(1.49,17.82) = 3.81$, $MSE = 0.64$, $p = 0.053$]. To more directly test the important contrast, a similar two-way ANOVA was run with only familiar source correct and incorrect trials in the second factor. This revealed no significant main effects [$ps > 0.13$], but the interaction was significant [$F(1,12) = 5.72$, $MSE = 0.62$, $p < 0.05$], again confirming that the source accuracy effect was larger for location than color.

Pairwise comparisons showed the same patterns as were found for Experiments 1 and 2, albeit with significant instead of marginal results for the location condition. For the location condition, familiar source correct trials ($M = -2.24\ \mu V$) were significantly more positive than both familiar source incorrect ($M = -3.12\ \mu V$) [$t(12) =$, $p < 0.05$] and correct rejections ($M = -2.79\ \mu V$) [$t(12) =$, $p < 0.05$]. The latter did not differ [$p = 0.39$]. No differences were found in the color condition [$ps > 0.42$].

3.3. Discussion

Implementing a within-subjects manipulation of Experiments 1 and 2 essentially replicated the important behavioral and ERP results, including showing differences between "familiar" source correct and incorrect trials in the location condition but not the color condition. It also showed that "familiar" source accuracy for spatial location was significantly greater than that of extrinsic color associations.

It should be mentioned that the parietal old/new ERP effect between source incorrect and correct rejections in the color condition is not a typical recollection effect. Typically, these trial conditions show no significant differences and are both more negative than source correct trials, indicating a difference for when episodic details are remembered (reviewed by Rugg & Curran, 2007). However, it has been demonstrated that the voltage of the parietal old/new effect varies with the amount of information recollected (Vilberg et al., 2006; Wilding, 2000), so perhaps something other than accurate source information was recollected for these items (i.e., non-criterial recollection; Yonelinas & Jacoby, 1996). In this context, non-criterial recollection might include simply remembering seeing the item during the study list, remembering what one was thinking or doing during that item's presentation at study, or how seeing the item evoked some external association. That non-source information might be remembered here seems possible because item recognition accuracy was higher in the color condition than the location condition while source accuracy showed the opposite pattern.

4. General discussion

The present experiments examined whether familiarity, as indexed by both behavioral responses and the FN400 ERP old/new effect, is able to differentiate certain kinds of extrinsic perceptual/sensory features encoded as source information (spatial and color associations). The novel finding is that familiarity is sensitive to spatial source information and not to extrinsic color source information. We specifically used source information that was extrinsic to the encoded items to examine how familiarity contributes to remembering different types of source features. In Experiment 1, pictures of objects were encoded as they were presented on one side of a computer display, a spatial source context. The FN400 differed between old items with their source correctly recognized compared to those with it incorrectly recognized for both trials given any RK response and only those classified as feeling "familiar". However, when the encoded source information was an extrinsic color association (Experiment 2), ERP evidence for accurate familiarity-based source recognition was not present. Experiment 3 replicated these results in a within-subjects comparison of spatial and color source judgments. Additionally, behavioral familiarity-based source accuracy was higher for spatial source than color source. In sum the experiments showed that, in addition to the typical recollection process, familiarity can accurately discriminate some kinds of extrinsic source information as demonstrated here with spatial location.

It is possible that spatial location is actually an intrinsic feature and therefore familiarity could assist in recognizing this information when cued at test, whereas this would not happen for the extrinsic color condition. However, this seems to unlikely especially when spatial location has been considered extrinsic in the past (Ecker et al., 2007a). Examining spatial source information with an example, imagine you are walking back to your red Corvette after seeing a movie. You can see across the open air parking lot from the theater, and there are two red Corvettes, one on each side of the lot. From a source memory perspective, your Corvette has an associated spatial location, but location is not an intrinsic property of your car: you could have parked it on either side of the lot and it would still be your car. If you also spotted a blue Corvette on the left side of the lot, you could be sure that it does not belong to you based on its color (an intrinsic property). Whether spatial information is actually intrinsic cannot be definitively resolved by a simple example, and it even seems that strict operational definitions of intrinsic and extrinsic properties might be difficult to produce.

A second alternative is that spatial location is able to be unitized with the item at the time of encoding (regardless of whether it is intrinsic or extrinsic). It has been shown that the unitization of item and source information may be sufficient for familiarity to contribute to source recognition (e.g., Diana et al., 2008; Mayes et al., 2004; Quamme et al., 2007; Rhodes & Donaldson, 2007; Yonelinas et al., 1999). Though it does not seem any more likely for an item and its spatial location to unitize than it does for an item and an extrinsic color association, this is unfortunately not a dimension that we can examine with the current data. However, it should be noted that encoding instructions were simple and straightforward ("remember the side on which each item appears" and "remember the color with which each item appears"), and were neither designed to promote unitization nor do they seem to promote unitization under *post hoc* examination. Of course, it is also not possible to resolve the question of unitization status without strictly defined criteria, which have not been resolved (Mayes et al., 2004); (Mayes, Montaldi, & Migo, 2007; Montaldi & Mayes, 2010).

Diana et al. (2011) examined the influence of unitization on ERP voltage using a recognition memory task. Though the authors did not find the typical FN400 and parietal old/new recognition memory effects, they did find later effects modulated by the level of unitization that occurred during encoding. Specifically, comparing the high- and low-unitization conditions for "familiar" trials (based on confidence judgments) to incorrect source responses, only high-unitization differed from incorrect responses during a late (750–1000 ms) time window. This shows that there was an accuracy effect for familiar trials only when the item and source were highly unitized. Though we did not analyze ERP voltages other than those of the FN400 and parietal old/new effects, our "familiar" ERPs (Figs. 7, 13, and 18) show that, qualitatively, there are some later differences in the frontocentral ROI between familiar source correct and incorrect trials in the location condition in Experiment 3, but not in Experiment 1 or 2. Thus, our results neither support nor challenge the idea that later ERP effects depend on unitization, as was discussed by Diana et al. (2011). More experimentation is needed to test for unitization in the spatial condition, perhaps using a design similar to that of Diana et al. (2011) with spatial source information. Regarding research connecting the FN400 to conceptual priming (Lucas et al., 2010; Paller et al., 2007; Yovel & Paller, 2004), it seems

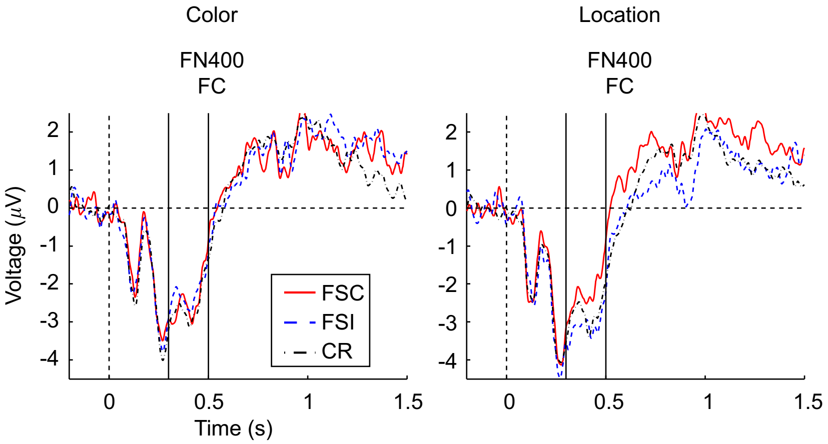

Fig. 18. Experiment 3: ERP waveforms for the "familiar" trial conditions for the frontocentral ROI in each source condition. Familiar source correct trials (FSC) are solid red, familiar incorrect source trials (FSI) are dashed blue, and correct rejections (CR) are dash-dotted black. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

unlikely that there would be conceptual differences between source correct and incorrect trials in the location conditions and thus the present results do not support this view.

Mayes et al. (2004, 2007) have indicated that it is still an open issue regarding whether familiarity can contribute to remembering associations between different domains of information (e.g., item–location associations, as opposed to item–item associations). Regardless of whether unitization occurred in the location condition, we have shown that familiarity can support associations between items and locations (different kinds of information) and that there is a difference between processing location- and color-based source information. Though these familiarity effects are not necessarily limited to spatial information, our results provide additional clues regarding the conditions under which familiarity can and cannot contribute to source recognition. In an investigation of how recognition memory processes are involved in associative memory, Montaldi and Mayes (2010) used results from previous lesion, anatomical, and functional imaging studies to constrain which theories are reasonable regarding how the MTL and surrounding cortices are involved in recognition memory. They reviewed how different MTL structures process and store different kinds of information and thus lead to differences in performance during a recognition memory task. Additionally, they discussed how the complex connectivity within and between MTL and non-MTL structures influence how these differences manifest in behavior, including familiarity's involvement in recognizing contextual details. That memory for spatial location may operate somewhat differently than that of other extrinsic source attributes is an interesting avenue to explore.

Despite the fact that it is difficult to hypothesize about underlying neural substrates using scalp-recorded ERPs, it is important to think about what structures might be involved in remembering different types of source information. It is thought that the MTL cortices, specifically the perirhinal cortex (PRC) and the parahippocampal cortex (PHC), contribute to familiarity-based recognition (Diana et al., 2007; Montaldi & Mayes, 2010; Norman & O'Reilly, 2003), especially the PRC (Mayes et al., 2007; Sadeh et al., 2012). Although FN400 effects are more likely to be generated by prefrontal rather than MTL cortices (reviewed by Rugg & Curran, 2007), it is possible that FN400 effects are dependent on earlier familiarity-sensitive processes within the PRC and PHC. Another possibility concerns the hippocampus, which is highly sensitive to spatial information (Ross & Slotnick, 2008). Although some evidence suggests that selective hippocampal damage does not diminish FN400 effects (Düzel, Vargha-Khadem, Heinze, & Mishkin, 2001), its potential role in familiarity still merits consideration due to other results (e.g., Mayes et al., 2004; Vargha-Khadem et al., 1997). Wixted and Squire (2011) proposed that instead of dividing the MTL and surrounding cortices by the psychological distinctions of recollection and familiarity, a material- and experience-specific division should be used. Perhaps, as these authors promote, the hippocampus is also involved in some familiarity judgments, not as a generator of the FN400 because the structure is thought to be a closed electrical loop but rather in modulating information that contributes to the familiarity process. In this capacity it could contribute to the familiarity signal when remembering spatial information as in Experiments 1 and 3 (but see Montaldi & Mayes, 2011). Slotnick (2010) showed other evidence to support this view: rather than being the seat of episodic recollection, the hippocampus instead supports binding (e.g., between different kinds of information).

Regarding the MTL cortices, during visual processing the PRC receives input from the ventral visual pathway ("what" information), while the PHC receives input from the dorsal visual processing stream ("where" and "how" information) (Eichenbaum, 2006; Suzuki & Amaral, 2004). In a basic item recognition paradigm, the PRC would contribute to an old/new familiarity judgment because it can rely purely on "what" information. In a source memory procedure, when source is intrinsic to or unitized with the item the PRC is able to contribute to source recognition because the source information was encoded as part of the item. In the case of extrinsic sources, such as in the present experiments, source information is encoded separately from item information and if unitization did not occur then the PRC would not be able to activate the source details. However, since the dorsal stream (PHC) processes "where" information, perhaps this provides a viable mechanism to retrieve spatial information along with the PRC's item information resulting in a familiarity signal that can make accurate spatial source judgments. This would allow a familiarity process to accurately recognize extrinsic information processed by the PHC; this is similar to a theory discussed by Montaldi and Mayes (2010). Additionally, it is interesting to consider how this relates to a class of recognition memory models called global matching models, which essentially operate using a single familiarity process (reviewed by Clark & Gronlund, 1996). Here, a stronger familiarity signal would result when both item and source context are recognized compared to only recognizing item information, which again could be supported by our behavioral and ERP data.

Although we have thus far interpreted our results as suggesting that familiarity is more likely to contribute to the recognition of location compared to color source information, it should be acknowledged that differences between these conditions could be influenced by overall accuracy differences which may in turn have induced different strategies. Item discrimination was consistently higher for the color conditions whereas source discrimination was consistently higher for the location conditions. In accordance with our accuracy results, Uncapher and Rugg (2009) performed an experiment with picture stimuli and had participants focus on one dimension of concurrent extrinsic color and spatial location source information during an item judgment task. They found that source accuracy for spatial location was higher than that of color. It is possible, for example, that differences between conditions reflected an attentional tradeoff between item and source information. From a global matching perspective, familiarity is driven by the match between encoded information and the retrieval cues that are used to probe memory at test (e.g., Clark & Gronlund, 1996; Ratcliff et al., 1995). Familiarity can influence source judgments insofar as source information is encoded at study and is used as a retrieval cue at test. Thus, the item/source discrimination differences between the color and location conditions could have been driven by differential attention to item vs. source information in the two conditions. This may indicate that the location source was more salient than the color source (at study or test, or both) and that results similar to those of the present experiments could be achieved through an attentional manipulation rather than a manipulation of source type.

The foregoing hypothesis about attentional tradeoffs may also shed some light on an unexpected aspect of the FN400 results in the location conditions. Differences between source incorrect and correct rejection trials in the main ERP analyses were significant in the color conditions of Experiments 2 and 3, marginally significant in the location condition of Experiment 1, and non-significant in the location condition of Experiment 3. The pattern shown in the color condition makes more sense from the perspective that even the items in the source incorrect condition should be more familiar than completely new items. However, it has been shown that the extent to which the FN400 discriminates between conditions depends on retrieval orientation at test (Ecker & Zimmer, 2009). In this experiment, when test pictures were either the same as studied pictures or different exemplars from the same categories, the FN400 discriminated between same and different conditions only when participants were given retrieval instructions that encouraged them to attend to the exemplar-level differences. Similarly, if participants in the present experiments attended more to source information in the location than color conditions (and vice versa for item information), the FN400 would differentiate based more on source properties in the location conditions and on item properties in the color conditions.

In conclusion, the present results suggest that familiarity is sensitive to location information that was not explicitly unitized with associated items, which adds to the existing literature regarding familiarity's involvement in source memory (e.g., Diana et al., 2008; Ecker et al., 2007a, 2007b; Mayes et al., 2004; Yonelinas et al., 1999), and provides evidence against the view that item–location associations cannot be recognized on the basis of familiarity (Montaldi & Mayes, 2010). The present experiments showed that the familiarity process, as indexed behaviorally ("familiar" judgments above chance) and electrophysiologically (FN400 source accuracy effect) in Experiments 1 and 3, can support recognition of spatial source information. Clearly, the research concerning the contribution of familiarity and recollection to source memory must continue. As was promoted by Aly et al. (2010), these results provide a challenge to the material-general view of recognition memory processes (that familiarity memory is sensitive to items and recollection is sensitive to episodic details), and support the idea that recognition memory processes are influenced by the nature of the contents of memory (Wixted & Squire, 2011).

Acknowledgments

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