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Cognitive Brain Research 22 (2005) 153–164

COGNITIVE BRAIN RESEARCH

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Research report

Electrophysiological correlates of forming memories for faces, names, and face–name associations

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Accepted 11 August 2004
Available online 7 October 2004

Abstract

The ability to put a name to a face is a vital aspect of human interaction, but many people find this extremely difficult, especially after being introduced to someone for the first time. Creating enduring associations between arbitrary stimuli in this manner is also a prime example of what patients with amnesia find most difficult. To help develop a better understanding of this type of memory, we sought to obtain measures of the neural events responsible for successfully forming a new face–name association. We used event-related potentials (ERPs) extracted from high-density scalp EEG recordings in order to compare (1) memory for faces, (2) memory for names, and (3) memory for face–name associations. Each visual face appeared simultaneously with a unique spoken name. Signals observed 200–800 ms after the onset of face–name pairs predicted subsequent memory for faces, names, or face–name associations. Difference potentials observed as a function of subsequent memory performance were not identical for these three memory tests, nor were potentials predicting associative memory equivalent to the sum of potentials predicting item memory, suggesting that different neural events at the time of encoding are relevant for these distinct aspects of remembering people.

Keywords: Encoding; Faces; Names; Item memory; Associative memory; ERPs; Dm

1. Introduction

One way to investigate the neural substrates of memory formation is to monitor brain activity produced in response to to-be-remembered events (for review, see [20,31]). Neural correlates of memory formation have been identified in this manner using a variety of methods, included event-related potential (ERP) recordings and functional magnetic resonance imaging (fMRI). In many experiments, ERPs elicited by stimuli that were subsequently remembered were compared to ERPs elicited by stimuli that were subsequently forgotten. These neurophysiological *d*ifferences based on later *m*emory performance (sometimes referred to generically as *Dm*) provide a way to measure neural events at the time of encoding that are predictive of successful memory performance at some later time.

One generalization from ERP experiments of this sort is that Dm effects arise because some stimuli receive superior perceptual analysis or elaborative processing resulting in facilitated retrieval on a subsequent memory test [18,21,23,31,32]. Episodic encoding is not uniform and inflexible, but rather can vary according to the type of processing engaged, given that electrophysiological correlates of memory encoding vary systematically with the nature of the study task [16,21]. Although scalp ERP recordings have not pinpointed the brain regions responsible for episodic encoding, intracranial ERP recordings have revealed Dm effects for words in the hippocampus and in nearby medial temporal cortex [9,10], and at the same time, neural synchrony between these two regions at about 40 Hz

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0926-6410/$ - see front matter
doi:10.1016/j.cogbrainres.2004.08.009

was associated with memory formation [8]. Responses of single neurons in the medial temporal lobe were also shown to be predictive of later memory performance with word pairs [2].

In a few recent studies, memory testing allowed separate Dm analyses according to whether stimuli were recognized on the basis of recollection or familiarity. In a study with facial stimuli, ERP correlates of memory formation differed for faces later recognized with concurrent retrieval of episodic details from the time of learning compared to faces later recognized with familiarity in the absence of episodic recollection [34]. In a study with verbal stimuli, young and older subjects showed a Dm for recollection, whereas only older subjects showed a Dm for familiarity [11]. In a study with pictures of objects, Dm for familiarity exhibited a left frontal topography, whereas Dm for recollection was right lateralized for the initial 150 ms and then bilateral [6]. Dm findings may tend to be more robust when memory testing is based on recollection, and are generally more consistent with recall testing than with recognition testing (e.g., Ref. [22]). On the whole, Dm findings require (1) a memory test that allows trials to be subdivided into distinct remembered and forgotten conditions, with enough trials in each condition to yield high signal-to-noise ratios for ERP analyses, (2) strong memory for a subset of the items such that remembered and forgotten items reflect differential encoding, and (3) processing relevant for memory formation associated with electrical activity that is well time-locked to stimulus presentation in the study phase rather than displaced in time [18].

Based on neuropsychological evidence (e.g., Refs. [3,19,28]), we presume that remembering novel associations between faces and names is likely to depend on many brain regions. Remembering faces differs from remembering names because of reliance on different sensory systems (visual and auditory, respectively). Remembering novel associations between faces and names is thus likely to require the combination of activity within multiple neocortical regions and the medial temporal lobe.

Insights into episodic memory formation have also been derived from recent fMRI investigations (e.g., Refs. [1,17,24,30]), and results are generally consistent with the notion that hippocampal and adjacent structures in the medial temporal lobe are critically involved in face–name memory. Findings reported by Sperling et al. [26,27] implicated anterior hippocampus bilaterally, right entorhinal cortex, and left inferior prefrontal cortex in the formation of associations between a face and a name (presented concurrently in the visual modality). These results, along with functional connectivity analyses [27] and high-resolution fMRI findings in a block-design study [35] suggest that these brain regions are part of a network subserving associative memory for names and faces. In a related study, Small et al. [24] showed that viewing faces and hearing names resulted in distinct activation patterns in the hippocampus subdivided along the long axis, and that face–name pairs produced activation that was not merely the summation of activation patterns for faces and names in isolation.

Here we investigated neural events associated with successful memory formation for three different aspects of face–name memory: remembering faces, remembering names, and remembering face–name associations. Multiple memory tests were used so that direct comparisons could be made among these three types of memory. Our goal was to determine whether electrical measures would implicate different neural activity responsible for memory formation in the case of face–name associations compared to either faces or names alone. Indeed, our findings suggest that memory formation does differ for these different aspects of face–name memory.

Subjects in our experiments viewed 140 novel faces, each presented simultaneously with a unique spoken name, while ERPs were recorded from 59 scalp locations. Names were gender-matched but were otherwise randomly assigned to faces. All three types of memory were tested for each face–name pair. In Experiment 1, the three tests were given after all stimuli were viewed in a single study phase. In Experiment 2, the memory test for face–name associations and a free recall test for names were both given after subjects studied 10 face–name pairs at a time. Face and name recognition tests were then given after 14 study-test blocks. As noted above, signal-to-noise considerations for ERP analyses require that performance be neither too good (yielding too few forgotten trials) nor too poor (yielding too few remembered trials). Accordingly, the use of different retention delays in the two experiments was intended to provide the opportunity to obtain a sufficient number of trials for examining Dm effects with each memory test.

2. Experiment 1

2.1. Methods

2.1.1. Subjects

Fifteen right-handed students (six male and nine female) participated in the experiment and received monetary compensation. The mean age was 22.5 years (range=18–28 years).

2.1.2. Stimuli

Visual stimuli consisted of a set of 210 photographs scanned from a 1994 high school yearbook. Each picture was presented in color within a rectangular area of 12.5 by 16 cm centered on a computer screen. Auditory stimuli consisted of a set of 210 names spoken in a female voice and delivered through a speaker directly behind the subject's head.

2.1.3. Procedure

Each subject was tested individually following set-up for EEG recordings. Faces and names were presented in the study phase, and then three paper-and-pencil tests of recognition were given in the test phase. The three tests were always given in the same order.

In the study phase (Fig. 1), face–name pairs were presented in seven blocks of 20 (140 pairs in total). Subjects were instructed to press a button with their right hand as quickly as possible after the onset of each pair. Although this task response was easy, it ensured that attention was directed at the stimuli. Subjects were told in advance that memory for face–name pairs would be tested later. Face and name onset in the study phase were synchronized. Faces were presented for 1000 ms with random interstimulus intervals ranging from 3000 to 7000 ms (mean=5000 ms). A fixation cross was presented during each interstimulus interval. Each face subtended a visual angle of 5.9° by 7.6°. Name duration ranged from 350 to 850 ms (mean=556 ms). A break of at least 15 s was given after each block.

In the test phase, the first of three memory tests was a *face memory test*, given using nine pages of color face images, including all 140 faces from the study phase and 70 faces not viewed previously, in random order. No information was given about the relative proportion of old and new items on this test. Recognition confidence was assessed using a 4-point scale. Subjects were instructed to mark each face that they were certain did not appear in the study phase with an 'X', and to mark all other faces with a number from 1 to 4 to reflect recognition confidence (1=Very Confident, 2=Confident, 3=Fairly Confident, 4=Not Very Confident). These recognition confidence ratings allowed us to categorize confidently remembered trials separately, a common practice in Dm analyses. Responses 1 and 2 were considered high-confidence memory responses. Given that low confidence is tantamount to a guess, we classified response 4 and X together as not remembered, as described below.

The second test was a *name memory test*, which was identical to the face memory test except that it was given using five pages listing all 140 names spoken during the study phase and 70 new names, in random order.

The third test was an *association memory test*, which was given using seven pages with all 140 face/name pairs from the study phase (a name printed below each face). These faces and names were paired as they had been presented during the study phase, but subjects were led to believe that half of the face/name pairings were correct and that half were incorrect. This subterfuge was used to prevent this test from taking an inordinately long time to complete and from being too difficult. Subjects attempted to mark each correct pairing using the same set of confidence ratings used on the previous two tests, and to not mark any of the incorrect pairings. On debriefing it appeared that none of the subjects knew that there were no incorrect pairings on the association memory test.

2.1.4. ERP Recordings

Electroencephalographic recordings were made from 59 scalp sites using tin electrodes embedded in an elastic cap at locations designed to provide fairly even coverage across the scalp [33]. Three channels were used for monitoring horizontal and vertical eye movements. Trials contaminated by electro-ocular artifacts were excluded from ERP analyses. Impedance was less than 5 kΩ. EEG signals were filtered with a band-pass of 0.10–100 Hz and sampled at a rate of 500 Hz. Each averaging epoch lasted 1100 ms, including 100 ms prior to stimulus onset. The online reference (right mastoid) was converted offline to an average mastoid reference. ERP measurements were evaluated using repeated measures analysis of variance (ANOVA) with Geisser–Greenhouse correction when necessary.

2.2. Results and discussion

2.2.1. Behavioral measures

We assessed memory performance for faces and names by comparing test-phase responses for old versus new items. In an initial analysis, the percent of items endorsed for each of the five response categories was computed (Fig. 2A). To further quantify memory performance for studied items, scores were collapsed to yield two categories: *remembered* items were taken as those endorsed as old with high confidence (levels 1 and 2); *forgotten* items were taken as those endorsed as old with low confidence (level 4, which were taken to be guesses) or as new. Intermediate confidence items (level 3) were excluded. This strategy allowed us to compute ERPs separately for these two categories of trials.

Responses to new items provided estimates of guessing rates. Accordingly, corrected memory scores were computed

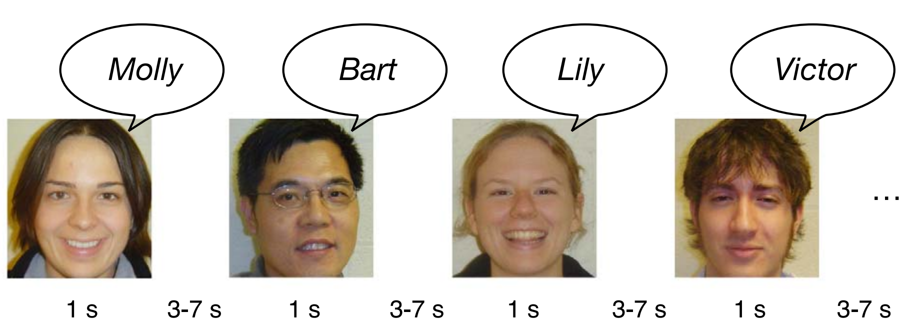

Fig. 1. Schematic representation of the study phase.

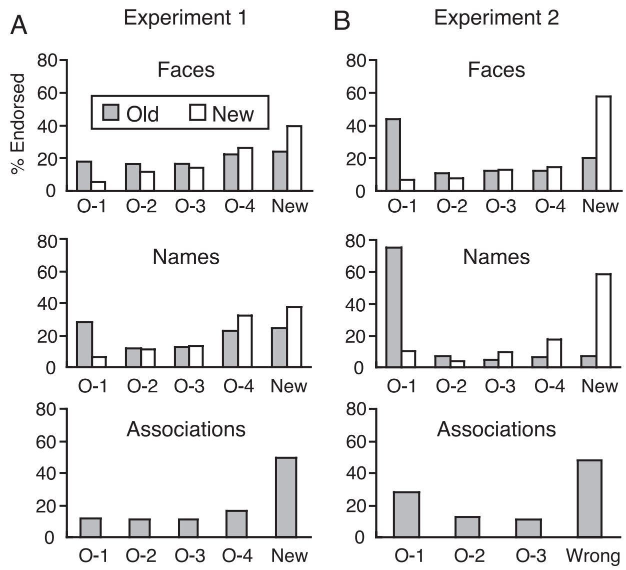

Fig. 2. Recognition results from Experiment 1 (A) and Experiment 2 (B). The percent of items endorsed for each response category is shown: O-1=very confident old; O-2=confident old; O-3=fairly confident old; O-4=not very confident old; N=new. In the association memory test in Experiment 2, only three levels of confidence were used.

using these two collapsed categories of remembered and forgotten as follows. First, a hits-minus-false-alarms measure was computed by subtracting the remembered endorsement rate for new items from that for old items (high confidence items only). This measure indicates percentage points above a guessing baseline for accurately remembered items. Second, a correct-rejections-minus-misses measure was computed by subtracting the forgotten endorsement rate for old items from that for new items. This measure indicates percentage points above baseline for correctly rejected new items. These two scores were not identical because items with confidence level 3 were excluded (the percentage of level 3 responses ranged from 4 to 34 for face memory and 1 to 31 for name memory). In the absence of veridical memory, these two measures would be near zero. To provide a single measure of memory performance for each individual for each test, these two measures were averaged to yield a *corrected memory score*.

For the face recognition test, the mean corrected memory score was 17.48 (S.E.=2.89). For the name recognition test, the mean corrected memory score was 21.87 (S.E.=2.84). This trend for name memory to be better than face memory was not statistically significant [$t(13)=1.46$, $p=0.17$]. There was no corrected memory score in the association test because there were no new items.

Given that three memory tests were used for each item, the results would be less informative to the extent that memory for items and associations were highly correlated. In the extreme, if each item either was remembered on all three tests or was forgotten on all three tests, Dm would appear identical for all three tests. However, results from an item analysis showed that memory for face–name associations was not perfectly correlated with memory for faces or names. That is, correct performance on one test did not guarantee correct performance on the other. Rather, there were many face–name pairs for which the face was remembered and the association forgotten, or vice versa, and likewise for names and associations, and for faces and names, as shown in Table 1.

2.2.2. ERP measures

ERPs elicited by face–name pairs in the study phase were computed on the basis of subsequent performance on each memory test. As described above, the classification of "remembered" included only those trials with a correct recognition response and a high confidence level (1 or 2). The classification of "forgotten" included all trials without correct recognition and those with correct recognition at the lowest confidence level (level 4). Corresponding ERPs from four midline scalp locations, averaged across all subjects, are shown in Fig. 3. Topographic analyses were also conducted (see below), and inspection of results from all other scalp locations showed that a good overview of the results was provided by this midline analysis.

Clear differences as a function of subsequent memory were observed at several latencies. For example, beginning about 300 ms after stimulus onset, ERPs were more positive when a face was subsequently remembered compared to when it was forgotten. This ERP difference is termed *Dm-faces*. In contrast, ERPs were more negative when a name was subsequently remembered compared to when it was forgotten. This ERP difference is termed *Dm-names*. ERPs were highly similar when an association was subsequently remembered compared to when it was forgotten, although there were trends for some differences, termed *Dm-*

Table 1
Average number of trials per subject for conditions with the same outcome (remembered or forgotten) on two memory tests (consistent performance) or with a different outcome on two memory tests (inconsistent performance)

	Consistent performance		Inconsistent performance	
Term	*A*+, *F*+	*A*−, *F*−	*A*+, *F*−	*A*−, *F*+
Experiment 1	26.4	40.5	18.9	18.6
Experiment 2	48.0	27.6	22.9	41.6
Term	*A*+, *N*+	*A*−, *N*−	*A*+, *N*−	*A*−, *N*+
Experiment 1	31.4	43.2	15.6	17.0
Experiment 2	59.1	13.9	11.7	55.2
Term	*F*+, *N*+	*F*−, *N*−	*F*+, *N*−	*F*−, *N*+
Experiment 1	26.1	36.2	20.1	21.7
Experiment 2	35.9	37.6	35.0	31.6

A+=association remembered; A−=association not remembered; F+=face remembered, F−=face not remembered; N+=name remembered, N−=name not remembered (name recognition in Experiment 1, name free recall in Experiment 2). Correlational analyses showed similar findings. In Experiment 1 face and association memory were correlated ($r=0.61$, $p<0.05$), as were name and association memory ($r=0.73$, $p<0.01$). In Experiment 2, face and association memory were not correlated ($r=-0.30$, $p>0.05$), nor were name and association memory ($r=0.05$, $p>0.05$). The significant correlations in Experiment 1 may reflect the close temporal proximity of the three tests, but in any event there were enough inconsistent trials to yield different Dm findings for the three tests.

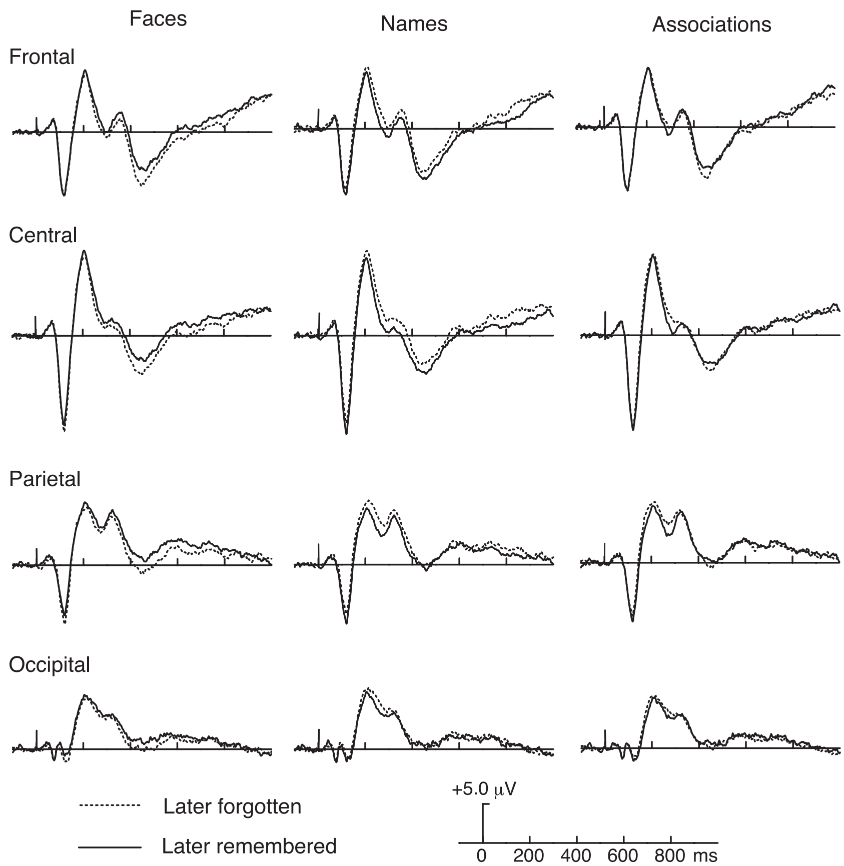

Fig. 3. ERPs from the study phase in Experiment 1. Recordings are shown for subsequently remembered and forgotten items from four midline scalp locations (approximately situated at Fz, Cz, Pz, and Oz).

associations. At approximately 300 ms ERPs appeared slightly more positive for remembered associations, and at approximately 500 ms less positive for remembered associations.

Subsequent memory effects can also be viewed as difference waves computed by subtracting ERPs for subsequently forgotten trials from ERPs for subsequently remembered trials. For example, Dm-faces was evident as a prolonged positivity over much of the epoch beginning at about 200 ms (Fig. 4A). Dm-names, in contrast, was evident as a relative negativity large at early latencies, decreasing by 600 ms, and then increasing again.

Subsequent memory effects were quantified by measuring mean amplitudes in three contiguous latency intervals (200–400, 400–600, and 600–800 ms) relative to the mean amplitude of the prestimulus baseline (−100–0 ms, set to 0 μV in figures). Similar intervals have been used in prior studies of related subsequent memory phenomena [12,18]. Although initial analyses focused on four midline locations, subsequent analyses confirmed that important effects at other locations were not missed in this initial analysis. These measurements were submitted to a four-way repeated-measures analysis of variance (ANOVA); the four factors were subsequent memory (remembered and forgotten), test (face, name, and association), interval (200–400, 400–600, and 600–800 ms), and location (Fz, Cz, Pz, and Oz). There were two significant interactions involving subsequent memory. A significant interaction between subsequent memory and test [$F(2,28)=6.1$, $p=0.007$] indicated that ERP differences between remembered and forgotten varied with test. A significant interaction between subsequent memory and interval [$F(2,28)=4.45$, $p=0.022$] indicated that Dm varied with latency. Accordingly, we analyzed results for each test separately to determine which subsequent memory effects were reliable. Dm across the three time intervals and the four midline electrodes was significant in the face memory test [$F(1,14)=10.0$, $p=0.007$], and in the name memory test [$F(1,14)=6.87$, $p=0.02$], but not in the association memory test. Additional analyses showed how these effects varied with time interval. Dm-faces was marginal for the 200–400 ms interval [$F(1,14)=4.45$, $p=0.053$] and significant for the 400–600 and 600–800 ms intervals [$F(1,14)=10.05$, $p=0.007$; $F(1,14)=6.14$, $p=0.027$]. Dm-names was significant for the 200–400 ms interval [$F(1,14)=17.14$, $p=0.001$], and showed a marginal interaction with location for the 400–600 ms interval [$F(3,42)=3.28$, $p=0.061$], due to significant differences at frontal and central locations [$F(1,14)=10.08$, $p=0.007$, and $F(1,14)=4.72$, $p=0.047$, respectively]. The different topography and time course of Dm-faces and Dm-names can be observed in the topographic maps shown in Fig. 4B.

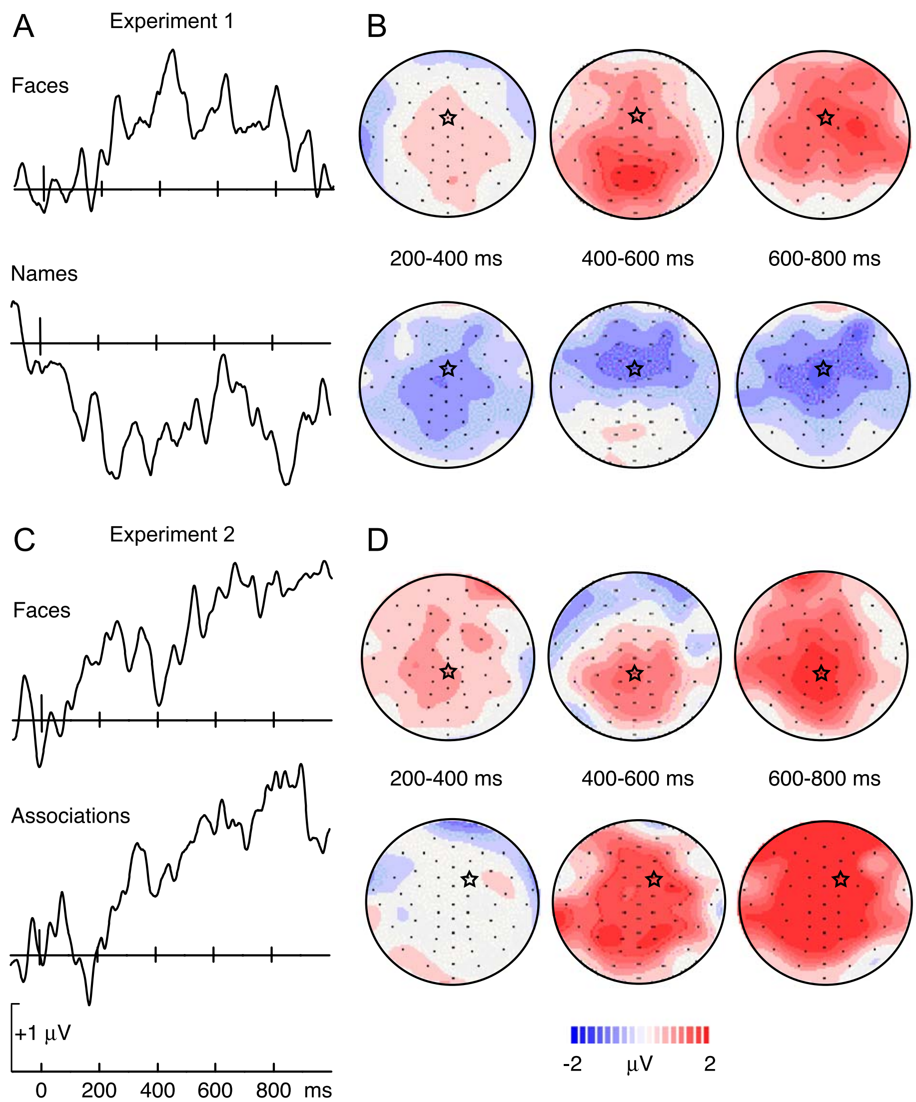

Fig. 4. ERP difference waves in Experiment 1 were computed by subtracting ERPs to forgotten items from ERPs to remembered items (A). Recordings shown were from the location with the largest Dm, as shown by corresponding stars in (B), which shows topographic maps for each difference wave computed for three intervals, 200–400, 400–600, and 600–800 ms. Topographic maps show amplitudes on the head as if viewed from above, and were computed using a spherical spline interpolation. Difference waves (C) and topographic maps (D) are shown in an analogous fashion for data from Experiment 2.

Across-subject correlations were also computed between the corrected memory scores and Dm amplitude for the three different tests. None of these correlations reached significance.

Whereas Dm-faces in the present experiment was similar to that observed in prior experiments [25,34], Dm-names showed a negative polarity that is fairly uncommon in the Dm literature. Interestingly, a negative Dm based on subsequent recognition was also reported in one study conducted with auditory stimuli [4]. This ERP effect was observed for subjects who were instructed to intentionally memorize novel environmental sounds, but not in subjects who heard the sounds under incidental learning conditions, suggesting that the Dm findings reflected some active encoding process that might have been similar to the process engaged for subjects in the present experiment listening to auditory names.

The results from Experiment 1 demonstrated clear subsequent memory effects for face recognition and name recognition. Strikingly, these two effects were opposite in polarity. The third effect, Dm-associations, was small in amplitude and generally nonsignificant, although there was an early trend resembling Dm-names and a later trend resembling Dm-faces. One possibility is thus that Dm-associations reflected a conjunction of processing associated with effective face encoding and with effective name encoding, essentially averaging Dm-faces and Dm-names together so that they largely cancelled each other out. Alternatively, reduced amplitudes for Dm-associations could have resulted from poor memory performance on this test and, consequently, minimal substantive encoding differences between the categories of remembered and forgotten pairs. Indeed, a very low proportion of high-confidence old responses were observed on this test. The associative memory test was given after the face and name recognition tests because performance on these other two memory tests would have been strongly affected by the faces and names presented in the associative test if that test had been given earlier, and we wanted to be able to make valid observations of Dm-faces and Dm-names. The downside of this design was that the retention delay may have been too long and the number of trials too great to yield strong memory for these new associations. Therefore, Experiment 2 was designed so that Dm-associations could be analyzed on the basis of stronger memory for face–name pairs, assessed after each set of 10 face–name pairs rather than after all 140 pairs and after two tests for item memory.

3. Experiment 2

3.1. Methods

Stimuli and ERP recording methods were the same as in Experiment 1, except that the recording band-pass was 0.05–200 Hz with a sampling rate of 1000 Hz. Digital filtering with the same filter settings as in Experiment 1 (0.10–100 Hz) showed negligible differences in ERP waveforms as a function of filtering.

3.1.1. Subjects

Fifteen right-handed students (five male and ten female) participated in the experiment and received monetary compensation. The mean age was 21.1 years (range=18–25 years). One additional subject was excluded due to poor memory performance such that less than 25 trials remained for ERP averages.

3.1.2. Procedure

Ten face–name pairs were presented in each of 14 blocks (140 pairs in total, as in Experiment 1). Gender was alternated across block such that each block included either all males or all females. A distraction task and two memory tests followed each set of 10 face–name pairs. The distraction task lasted 20 s, during which the subject counted backwards aloud by threes from a three-digit number shown on the screen. The subject then attempted to recall names from the preceding study list, which were spoken aloud by the subject and recorded by the experimenter. This was the *free recall test for names*. Next, the *matching-style association memory test* was given. The 10 faces and names from the preceding study list were shown together on the screen (faces in two rows, with names near the bottom of the screen, in random order). Subjects attempted to select the correct pairings by filling in 10 boxes on a sheet of paper that corresponded to the 10 faces on the screen, and using the numbers 1–10 that were shown adjacent to each name. Confidence was assessed using three levels ('++'=high confidence or level 1; '+'=mild confidence or level 2; blank=low confidence or level 3). Following the final study-test block, subjects performed a face memory test and a name memory test identical to those used in Experiment 1. The four tests were always given in the same order.

3.2. Results and discussion

3.2.1. Behavioral measures

In the free recall test, names were recalled on 48.2% of the trials. Associations were remembered correctly on 41.1% of the trials. Memory performance on these two tests was quite good, considering that guessing would yield very low accuracy. Patterns of recognition performance for faces and names (Fig. 2B) were somewhat similar to those found in Experiment 1. For the face recognition test, the mean corrected memory score was 39.64 (S.E.=6.05). For the name recognition test, the mean corrected memory score was 64.81 (S.E.=3.68). Name memory was significantly better than face memory [$t(14)=4.218$, $p=0.001$]. Moreover, name recognition was so accurate that there were too few trials for a Dm computation, so results from the three other memory tests were emphasized instead. Stimulus presentation in the association memory test as well as the generation of names in the free recall test probably functioned to provide additional study opportunity, leading to higher memory scores in the face and name recognition test compared to corresponding scores in Experiment 1.

As in Experiment 1, we conducted an item analysis to determine whether memory performance on one test could be predicted by memory performance on another test. Results showed that memory performance in the three tests was somewhat independent (see Table 1).

3.2.2. ERP measures

Trials were classified as remembered in the face memory test when there was correct recognition with high confidence (level 1 or 2). Forgotten trials included those when the face was not recognized and when it was recognized with low confidence (level 3 or 4). For names, free recall results were used to classify trials (name recognition performance yielded too few forgotten names to allow for a sufficient signal-to-noise ratio, see Fig. 2B). Trials were classified as remembered in the association memory test if the face–name match was correct with high confidence (level 1 or 2) and as forgotten if the face–name match was incorrect.

ERPs elicited by face–name pairs in the study phase were computed according to subsequent performance on the face memory test, the name recall test, and the association memory test, as shown in Fig. 5. Dm-faces was similar to that in Experiment 1, in that there was a more positive-going ERP for subsequently remembered faces than for forgotten faces. Dm-names (based on the name free recall test) was apparent at approximately 300 ms, when ERPs for remembered names at the midline parietal location were

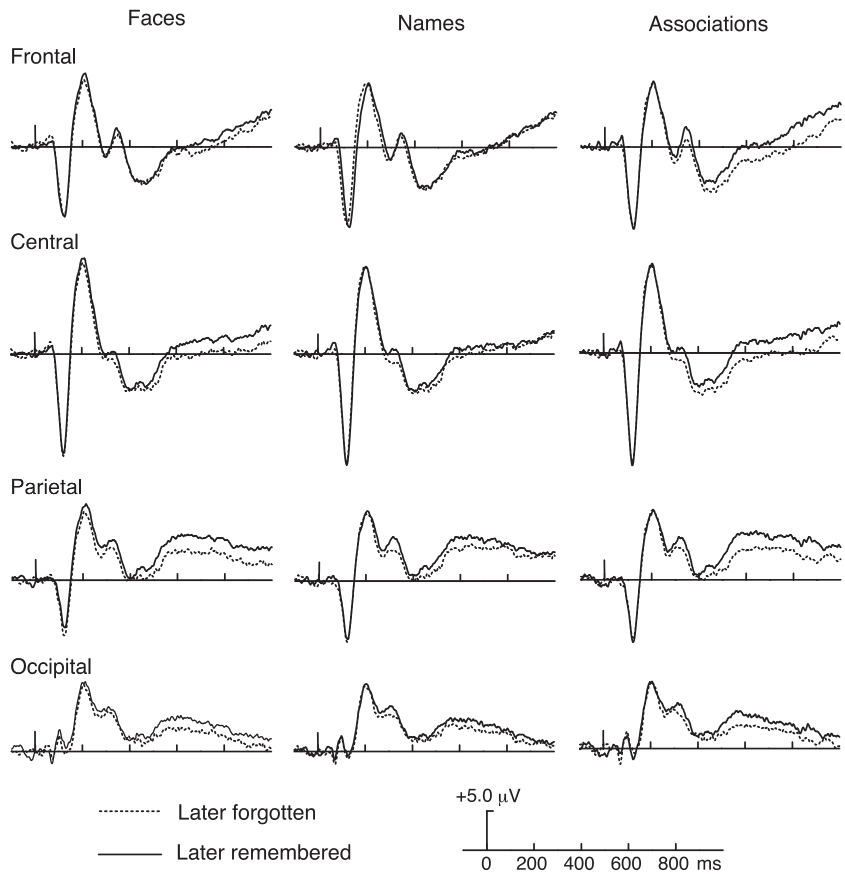

Fig. 5. ERPs from the study phase of Experiment 2. Recordings are shown for subsequently remembered and forgotten items from four midline scalp locations (approximately situated at Fz, Cz, Pz, and Oz).

more positive than ERPs for forgotten names. The largest differences were observed for associations. Dm-associations took the form of a prolonged positivity relatively greater for subsequently remembered associations than for forgotten associations. These effects can be viewed as difference waves computed between remembered and forgotten conditions (Fig. 4C) and as topographic maps (Fig. 4D).

Subsequent memory effects were again quantified by measuring mean amplitudes in three intervals and measurements were submitted to a four-way repeated-measures ANOVA. Factors were subsequent memory (remembered and forgotten), test (face, name, and association), interval (200–400, 400–600, and 600–800 ms), and location (Fz, Cz, Pz, and Oz). The main effect of subsequent memory was significant [$F(1,14)=15.57$, $p=0.001$], but differed across midline electrodes [subsequent memory by location interaction, $F(3,42)=3.44$, $p=0.039$].

To analyze the time course of subsequent memory effects, a repeated-measures ANOVA with factors subsequent memory (remembered and forgotten) and location (Fz, Cz, Pz, and Oz) was run for each test and each interval. Dm-faces was significant for two of the three intervals [$F(1,14)=5.00$, $p=0.042$; $F(1,14)=2.23$, $p=0.16$; $F(1,14)=6.51$, $p=0.023$, respectively, for 200–400, 400–600, and 600–800 ms]. Dm-associations was significant in all three intervals [$F(1,14)=5.98$, $p=0.028$; $F(1,14)=19.04$, $p=0.001$; $F(1,14)=15.59$, $p=0.001$]. In some ways, Dm-faces and Dm-associations were similar.

One possible explanation for this outcome could be that faces presented in the association test provided additional study opportunity that may have been more effective for those faces for which the face–name pairing was remembered correctly. However, the similarity between Dm-faces across the two experiments, as well as apparent topographic divergence, casts some doubt on this possibility (see Fig. 4) and instead suggests that Dm-faces and Dm-associations reflect nonidentical encoding processes. However, a topographic analysis failed to reveal a significant difference between Dm-faces and Dm-associations [amplitude normalized values measured from 200–800 ms from 59 channels were submitted to a two-way ANOVA and yielded a nonsignificant interaction between test (face or association recognition) and electrode, $F(58,812)=0.4$, $p=0.76$].

Dm-names was not significant in any interval [$F(1,14)=3.83$, $p=0.071$; $F(1,14)=3.37$, $p=0.088$; $F(1,14)=1.94$, $p=0.185$]. The marginal nature of Dm-names may reflect the short retention delay prior to the free recall test. The names produced by subjects in this test may have come to mind partly from working memory processes that bridged the distraction task, and may not correspond to the long-term memory formation as operative in Experiment 1. Also, the initially recalled names may have provided interference that acted to prevent other names from being recalled, in which case the recalled/non-recalled contrast would not truly reflect processing differences at the time of encoding.

4. General discussion

When we meet new people in our daily experiences, there are multiple aspects of perceptual information processing that can be important for subsequent memory. For example, we may need to recall the name when we see the face again, we may need to recall the name without seeing the face, we may need to recognize the name among many names, we may need to recognize the face among many faces either with or without being prompted by the name, or we may need to be able to match the appropriate name to a given face. Which specific aspects of memory encoding and storage support memory performance in these different circumstances? To begin to address this question, it would be helpful to determine whether or not such varied instances of memory for people rely on identical memory storage mechanisms put into play when a face and name are first encountered. Indeed, our results showed that neural events at the time of encoding that are predictive of subsequent memory differed according to the type of memory test given.

Our approach to comparing memory formation for faces, names, and face–name associations was to test memory with multiple tests for every face–name pair presented in the study phase. This approach had the advantage of allowing comparisons across the same subjects and the same study-phase EEG responses. Two disadvantages, however, were that retention delay was not the same for each test, and that in some cases performance on one test was influenced by intervening events due to another memory test. We decided that these disadvantages were outweighed by the possible benefit of making comparisons based on the same data collected in response to face–name pairs in the study phase. If the different tests were instead employed in different subjects, or for different face–name pairs within subjects, interpretations would possibly be limited by differences in the way encoding occurred across pairs (although this approach is still worthy of future investigation). Accordingly, interpretive limitations in the present experiment include differing retention delays and intervening test experiences across the two experiments. Nevertheless, results from the two experiments taken together provided new information about these different aspects of face–name learning.

Interestingly, our behavioral data showed that people could remember a face or a name but still fail to remember the corresponding face–name association (Table 1). This finding suggests that there was a degree of independence between memory for items versus memory for associations in these circumstances. People generally found the association tests to be the most difficult, and they produced fewer high-confidence memory responses for associations. Our data was insufficient for determining whether forming memory for items and associations relies on systematically different brain regions, although we hypothesize that this would be the case.

This substantial degree of memory independence made it possible for us to assess memory in different ways for the same face–name pairs. Table 2 provides a summary of the different memory tests and Dm findings from this experiment and from another recent experiment [32] in which we obtained Dm effects for face–word pairings. In Experiment 1, we observed very different findings for Dm-faces versus Dm-names. Specifically, a more positive ERP was observed for faces that were subsequently remembered than for those subsequently forgotten, and a more negative ERP was observed for names that were subsequently remembered than for those subsequently forgotten. The opposite polarity of these effects does not imply opposite sorts of neural processing. Rather, a different orientation and location of generators may have been active in the two circumstances, even if cognitively similar information transactions were involved. In fact, a reasonable a priori speculation would be that visual cortex would be relatively more involved for face encoding and auditory cortex for spoken name encoding.

Table 2
Summary of results for subsequent memory analyses for face–name pairs in Experiment 1 and Experiment 2 or face–occupation pairs in the experiment of Yovel and Paller [34]

Memory test	Dm effect
Experiment 1	
Name recognition after 140 pairs	Negative polarity, significant from 200–600 ms, broad symmetric central topography shifting to frontal–central
Face recognition after 140 pairs	Positive polarity, significant from 400–800 ms (marginal from 200–400 ms) broad symmetric central–posterior topography
Association recognition after 140 pairs	No Dm—memory presumably too weak
Experiment 2	
Name recall after 10 pairs	No Dm—recall may have reflected rehearsal in working memory
Name recognition after 140 pairs	No Dm—memory too strong
Face recognition after 140 pairs	Positive polarity, significant from 200–400 and 600–800 ms, broad symmetric central–parietal topography
Association recognition after 10 pairs	Positive polarity, significant from 200–800 ms, broad symmetric frontal–central topography
Yovel and Paller [34]	
Occupation recall after 24 pairs	Positive polarity, significant from 400–800 ms, broad symmetric topography, shifting from anterior to posterior
Face familiarity after 24 pairs	Positive polarity, significant from 600–800 ms with a focal right posterior topography

Tests given either after each block (10 or 24 pairs) or after all blocks (140 pairs).

Interestingly, Dm with a negative polarity was also found with environmental sounds [4]. In any event, our results suggest that different neural events were responsible for the effective storage that supported recognizing a face seen once versus recognizing a name heard once.

One limitation in interpreting these differences between Dm-names and Dm-faces is that the retention delay was not identical for these two tests. Based on pilot work, we opted to administer the tests in the same order to each subject in order to maximize the chances of having a sufficient number of trials in each condition. Further research is now required to show that these differences between memory for names and faces are not contaminated by effects of retention delays and that they generalize to different testing situations.

Although previous studies of face–name learning did not use multiple subsequent memory analyses for faces, names, and associations, some related findings have been obtained. Small et al. [24] studied brain activation patterns for items and associations with respect to faces and names. Viewing faces alone resulted in greatest activation in posterior hippocampus, whereas hearing names alone resulted in greatest activation in anterior hippocampus. Furthermore, hearing a name presented with a face produced a pattern of hippocampal activity that was not identical to the sum of that elicited by the single-item presentations. Results from our two experiments provide additional evidence that associative memory for such stimuli is qualitatively different from item memory, and also suggest that these differences involve neocortex in addition to hippocampus. Although precise relationships between these fMRI findings and scalp ERP findings are presently unclear, an important goal for future work will be to build such connections by combining ERP and fMRI methodologies.

Memory for face–name associations was suitably robust only in Experiment 2. ERPs were more positive from at least 200–800 ms for subsequently remembered associations compared to forgotten associations. Dm-faces was also observed in Experiment 2, albeit on the basis of a face recognition test given after extra study opportunity due to the intervening association memory test. Nevertheless, Dm-faces was observed as a relative positivity that was somewhat similar to Dm-faces in Experiment 1. Taken together with prior Dm findings using facial stimuli [25,34], the formation of a face memory that endures for 30–60 min seems to reliably engage brain activity reflected by ERP positivity at the scalp. Conceivably, these electrical measures reflect encoding activity involved in representing multiple aspects of the episode when the face was presented, rather than only the facial information per se.

Yet, some differences in timing and topography were apparent between Dm-faces and Dm-associations, as shown in Fig. 4C,D. This outcome suggests that memory storage may indeed differ for items (faces in this case) as opposed to associations (face–name pairings), but further research will be necessary to show more specifically how memory storage in these two cases differs. One possible way to obtain relevant evidence might be to include manipulations that differentially promote effective memory storage for faces, names, and face–name associations.

Yovel and Paller [34] also studied ERPs elicited by combination stimuli composed of a visual face and auditory speech. Each face was associated with a unique occupation instead of a unique name as in the present study. Strong Dm effects were observed by contrasting ERPs to faces that were recognized as having been presented before and for which the occupation could be recalled versus ERPs to faces that were not recognized. This Dm for occupation recall took the form of a bilateral posterior positivity and was interpreted as a reflection of encoding that supported recollection of the study episode. In contrast, a smaller right-sided positivity was observed for Dm for familiarity; this right posterior positivity was greater for faces that were recognized as having been presented before, but for which the occupation could not be recalled and for which no other details of the study episode could be recalled, versus unrecognized faces. Given that the Dm findings in the present experiment did not show this right-lateralized topography, we infer that our memory results reflect recollective aspects of item and associative memory and not pure familiarity experiences.

Table 2 also highlights that these Dm analyses included many different memory tests and retention delays. In order to develop a more complete understanding of the electrophysiology of face–name and face-occupation encoding, and of forming memories for people generally, it will be necessary to sample a much wider portion of the space defined by stimulus factors, test factors, and retention delay. Indeed, retention delay is highly relevant as it pertains not only to the passing of time but also to the number of to-be-remembered items (or memory load) and to interference from other processing. We included just a few memory test circumstances here. Future work should continue to explore multiple ways to test memory for people and multiple retention delays.

Forming memories of the people we meet requires that multiple brain regions work together in a coordinated fashion, and understanding this neurocognitive processing will require a combination of methodologies. Prior neuroimaging studies have identified brain activations that occur during face–name learning [13,24,26,35], and some of these regions have been specifically associated with successful as opposed to unsuccessful encoding using item-by-item Dm analyses [27]. Many neuroimaging studies have also attempted to differentiate between memory for items and memory for associations using verbal stimuli (e.g., Ref. [5]). Our findings have attempted to directly compare memory formation for face–name associations to that for the component items. Although this direct comparison has not been made in any prior study, Sperling et al. [27] argued that their hippocampal activation for associative encoding was more anterior than previously reported hippocampal activations for item encoding [1,14,30]. At any rate, a common generalization is that stronger associative binding depends more heavily on hippocampal processing and on neocortical–hippocampal connections. This idea is consistent with functional connectivity between hippocampal and frontal regions [27], and perhaps also with the ERP findings we observed for Dm-associations. Moreover, the time course of Dm-associations suggests that the relevant brain events take place over an extended period of time. Additional functional connectivity analyses, perhaps including time–frequency analyses of electromagnetic data (e.g., Refs. [7,15,29]), may be useful for further illuminating the brain events responsible for our ability to link a name to a face.

Acknowledgements

This research was supported by the United States National Institutes of Health (grant NS34639). Chunyan Guo was a Visiting Professor at Northwestern University and supported by the National Pandeng Project (95-Special Project-09), the National Natural Science Foundation of China (No.30170322), and the Ministry of Science and Technology of China (2002CCA01000).

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