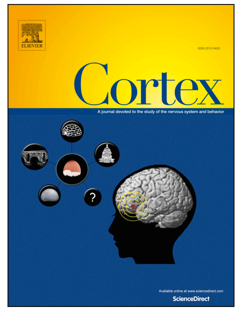

The left temporal pole is a convergence region mediating the relation between names and semantic knowledge for unique entities: Further evidence from a “recognition-from-name” study in neurological patients

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The left temporal pole is a convergence region mediating the relation between names and semantic knowledge for unique entities: Further evidence from a "recognition-from-name" study in neurological patients

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Abstract

Prior research has implicated the left temporal pole (LTP) as a critical region for naming semantically unique items, including famous faces, landmarks, and musical melodies. Most studies have used a confrontation naming paradigm, where a participant is presented with a stimulus and asked to retrieve its name. We have proposed previously that the LTP functions as a two-way, bidirectional convergence region brokering between conceptual knowledge and proper names for unique entities. Under this hypothesis, damage to the LTP should result in a "two way" impairment: (1) Defective proper name retrieval when presented with a unique stimulus (as shown in prior work); *and* (2) Defective concept retrieval when presented with a proper name. Here, we directly tested the second prediction (prediction #2) using a "recognition-from-name" paradigm. Participants were patients with LTP damage, brain-damaged comparisons with damage outside the LTP, and healthy comparisons. Participants were presented with names of famous persons (e.g., "Marilyn Monroe"), landmarks (e.g., "Leaning Tower of Pisa"), or melodies (e.g., "Rudolph the Red-Nosed Reindeer") and were asked to provide conceptual knowledge about each. We found that individuals with damage to the LTP were significantly impaired at conceptual knowledge retrieval when given names of famous people and landmarks (this finding did not hold for melodies). This outcome supports the theory that the LTP is a bidirectional convergence region for proper naming, but suggests that melody retrieval may rely on processes different from those supported by the LTP.

Keywords: anterior temporal lobe; semantic; lexical; naming; anomia

Distinct regions in the left temporal lobe have been found to be involved in the retrieval of names for categorically separate entities. For example, more posterior regions of the temporal lobe are involved in naming concrete entities such as animals and tools, while the most anterior portion of the temporal lobe at the left temporal pole (LTP) is involved in naming semantically unique items (Chao, Haxby, & Martin, 1999; H. Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996). A wide number of neuropsychological studies have illustrated such category-specific naming deficits after focal brain damage (A. Damasio, 1990; H. Damasio, Tranel, Grabowski, Adolphs, & Damasio, 2004; Drane et al., 2008; Gainotti, 2005; Kolinsky est al., 2002; Mahon & Caramazza, 2009; Warrington & Shallice, 1984).

Specifically, focal LTP damage is associated with impaired naming of visual stimuli such as landmarks (Tranel, 2006) and faces (H. Damasio et al., 1996), and auditory stimuli such as voices (Papagno, Mattavelli, Casarotti, Bello, & Gainotti, 2017; E. J. Waldron, Manzel, & Tranel, 2014) and musical melodies (Ayotte, Peretz, Rousseau, Bard, & Bojanowski, 2000; Belfi, Kasdan, & Tranel, 2017; Belfi & Tranel, 2014; J. K. Johnson et al., 2011). Similarly, findings from patients with neurodegenerative disorders have also indicated LTP involvement in naming famous persons. For example, impaired naming and recognition of famous faces have been found to be associated with atrophy of the left anterior temporal lobes in patients with primary progressive aphasia (Gefen et al., 2013). A common theme across these categories (faces, voices, landmarks, melodies) is that the items are identified by a unique, proper name. These types of items have been termed “semantically-unique” because they are associated with semantic information not associated with other, similar items – i.e., they are “one-of-a-kinds” (Gorno-Tempini & Price, 2001). It has been previously proposed that the LTP functions as a critical "convergence region" for associating a unique entity with its proper name (H. Damasio et al., 2004).

In addition to evidence from neuropsychological studies, functional neuroimaging approaches have provided further support implicating the LTP as a key region for proper naming (Gainotti, 2007; Griffith et al., 2006; Nielson et al., 2010; Ross & Olson, 2012). For example, PET and fMRI studies demonstrate increased activity in the left anterior temporal lobes when participants are naming landmarks or faces (compared to baseline tasks) (Gorno-Tempini & Price, 2001; Grabowski, Damasio, & Tranel, 2000). LTP activity for proper naming is shown across categories of unique items including faces and landmarks, suggesting further the determining factor for LTP recruitment lies in the uniqueness of the item (Tranel, 2009b). Recent research using a neurophysiological approach has provided further support for the role of the LTP in lexical retrieval for unique items (Abel et al., 2015). In this study, individuals undergoing intracranial monitoring for epilepsy performed a proper naming task. Participants saw faces and heard voices of recent U.S. Presidents and were asked to name them. Electrodes placed on the LTP showed similar responses to both face and voice naming, implicating the LTP as a heteromodal convergence region for proper naming, regardless of stimulus modality.

Most studies in this realm have used classic "confrontation naming" paradigms, requiring participants to name an entity from a picture or sound stimulus. Here, we sought to investigate the proposal that the LTP is a *bidirectional* convergence region for retrieval of lexical information (H. Damasio et al., 2004) by testing the opposite "stimulus – response" direction. That is, we aimed to test whether the LTP is a necessary region for retrieval of conceptual information when given a name. To test this, we used a "recognition-from-name" paradigm (for reviews of this method when applied to famous persons, see Blank, Wieland, & von Kriegstein, 2014; Gainotti, 2013). This task is the reverse of the tasks used in our prior work – here, participants are given the name of an entity (e.g., “Marilyn Monroe”) and are asked to provide conceptual information about that entity (e.g., “She was a famous blonde actress in the 50’s. Well known for the photograph of her standing over a vent blowing up her skirt. She died of an overdose. Married to Joe DiMaggio briefly.”).

Similar tasks have been used to study semantic knowledge in patients with neurodegenerative disorders including semantic dementia and semantic variant primary progressive aphasia. For example, patients with semantic dementia were shown pictures and names of famous persons and asked to provide identifying conceptual information about each stimulus. Patients with greater atrophy in the left hemisphere performed significantly worse at identifying (i.e., retrieving conceptual knowledge for) persons when given a name, while patients with atrophy in the right hemisphere performed significantly worse at identifying famous persons when shown a face (Snowden, Thompson, & Neary, 2004). This outcome was subsequently replicated. A similar examination of patients with semantic dementia found that those with predominantly left-hemisphere damage showed more severe deficits in conceptual retrieval from a proper name, but relatively spared conceptual retrieval when shown a picture of a famous person (Snowden, Thompson, & Neary, 2012). In both studies, patients with semantic dementia showed impairments in naming famous persons when shown a picture (Snowden et al., 2004, 2012). These results can be interpreted through the “dual-route account” for the involvement of the ATL in semantic knowledge, which suggests that the left ATL is necessary for conceptual retrieval when the input is verbal (i.e., a name), while the right ATL is necessary for conceptual retrieval when the input is non-verbal (i.e., a picture; (Hurley, Mesulam, Sridhar, Rogalski, &

Thompson, 2018). These findings provide further evidence that the LTP plays an important role in connecting lexical to semantic information for unique entities.

The goal of the present work is to identify whether the LTP functions as a "bi-directional" functional intermediary between a unique entity and its proper name. That is, based on our prior theoretical framework (H. Damasio et al., 2004), we expect that the LTP functions as a two-way relay supporting the process of word form retrieval given conceptual knowledge, and the process of conceptual knowledge retrieval given word forms, for semantically unique entities. We therefore predict that damage to the LTP should yield a two-way defect—impaired retrieval of word forms given conceptual knowledge, and impaired retrieval of conceptual knowledge given word forms. A large amount of evidence already supports the first prediction, i.e., impaired retrieval of word forms when given conceptual knowledge, in patients with LTP damage (Belfi & Tranel, 2014; H. Damasio et al., 1996, 2004; Tranel, 2006; E. Waldron, Manzel, & Tranel, 2014). Here we sought to investigate the second (reverse direction) prediction, by investigating concept retrieval when given word forms in patients with focal damage to the LTP.

While "word-to-concept" deficits have been found in patients with neurodenegerative disorders, here we focused on a population of patients with non-degenerative focal brain damage to the LTP. Also, prior work in neurodegenerative populations has indicated word-to-concept deficits for many categories of objects, including everyday objects (Mesulam et al., 2013) and persons (Gefen et al., 2013; Snowden et al., 2004, 2012). Here, we investigated further the specificity of this deficit using three categories of semantically-unique items: persons, landmarks, and musical melodies. Specifically, we predicted that individuals with LTP damage would show impairments in conceptual retrieval when given an entity's name, across all three categories, as compared to individuals with brain damage outside the left temporal pole (brain damaged comparisons) and neurologically healthy adults (normal comparisons).

Methods

Participants

Brain-damaged participants in this study were chosen from the Patient Registry of the University of Iowa Division of Neuropsychology and Cognitive Neuroscience in the Department of Neurology. Participants were categorized into the following groups on the basis of lesion location: The left temporal pole group (LTP, *n*=8) consisted of patients with damage to the LTP. The brain-damaged comparison group (BDC, *n*=17) consisted of individuals with brain damage to regions outside of the LTP. This group was included to control for the general effects of brain injury. The normal comparison group (NC, *n*=20) consisted of individuals with no history of neurological or psychiatric disorders. Lesion etiologies for the patient groups are as follows. For the BDC group, etiologies included: cerebrovascular disease (*n*=5), benign tumor resection (*n*=5), and surgical resection for epilepsy treatment (*n*=7). In the LTP group, all 8 patients had lesions from surgical resection for epilepsy treatment.

Participants were extensively characterized neuropsychologically and neuroanatomically using standard protocols from the Benton Neuropsychology Laboratory and the Laboratory of Brain Imaging and Cognitive Neuroscience (Tranel, 2009a). To be eligible for the study, brain-damaged participants had to have a strong indication of left-hemisphere language dominance (as determined from neurological, Wada, and neuropsychological testing). All left- and mixed-handed brain-damaged participants (two in the BDC group and two in the LTP group) had definitive evidence of left-handed language dominance as indicated by Wada testing. In addition, participants were screened to ensure no general intellectual impairment (as determined by the

Wechsler Adult Intelligence Scale—Third and Fourth Edition testing). Five participants in the current sample were tested using the WAIS-III (3 BDC, 2 LTP), while the remaining 20 participants were tested using the WAIS-IV; scores from the two tests have been prorated to correspond using the recommendations in the WAIS manual (Wechsler, 2008). FSIQ was estimated in NC participants using the Wechsler Test of Adult Reading (Wechsler, 2001).

Table 1 depicts demographic information for the participants. One-way ANOVAs were conducted to assess group differences in age, education, and FSIQ. These indicated no significant group differences in age [F(2,42)=0.83, p=0.44], education [F(2,42)=0.48, p=0.62], or FSIQ [F(2,39)=2.70, p=0.07]. Since there is a trend towards a significant difference in FSIQ, all analyses were conducted a second time including FSIQ as a covariate, which did not substantially change any reported results.

	NC	BDC	LTP
Sex	10 M, 10 F	8 M, 9 F	3 M, 5 F
Handedness	3 L, 17 R, 0 M	1 L, 15 R, 1 M	1 L, 7 R, 1 M
Age	58.75 (9.66)	59.23 (9.98)	53.95 (11.08)
Education	15.20 (2.19)	14.58 (2.03)	14.62 (1.59)
FSIQ	113.85 (6.01)	111.8 (11.58)	105.25 (9.48)

Table 1. Demographic data. Values are mean (SD). Sex: M=male, F=female. Handedness: L=left, R=right, M=mixed.

Neuropsychological data are presented in **Table 2**. Independent-samples t-tests were used to assess differences in neuropsychological variables between the BDC and LTP groups. While the only significant group difference was in the BNT (patients in the LTP group scored significantly lower on the BNT than participants in the BDC group), this finding is expected given the nature of this patient group, so this relative weakness is not surprising. Although the difference between groups on the BNT is statistically significant, it is important to note that the average BNT score in the LTP group is still well above the cutoff for an ‘impaired’ score on the BNT (48).

	BDC	LTP	*t*	*p*
Chronicity (years)	11.46 (7.06)	12.07 (4.88)	-0.21	0.82
WRAT – Read (SS)	103.93 (8.22)	99.42 (10.26)	1.12	0.27
WCST – Pers. Errors (raw score)	10.41(7.52)	9.12 (11.31)	0.30	0.76
CFT – 30 min recall (#/36)	20.20 (6.71)	15.75 (2.91)	1.78	0.08
BNT (#/60)	57.64 (2.64)	52.00 (7.32)	2.85	0.01
Facial Discrimination #/54)	44.73 (3.34)	46.271 (2.42)	-1.39	0.17
BDI-II (raw score)	5.82 (5.39)	5.75 (3.91)	0.03	0.97
BAI (raw score)	2.57 (4.92)	4.57 (4.15)	-0.91	0.36
TMT-A (time in sec)	24.76 (5.77)	21.00 (6.48)	1.46	0.15
TMT-B (time in sec)	55.64 (18.47)	52.25 (16.52)	0.44	0.66

Table 2. Neuropsychological data. Values are means (SDs are in parentheses). WRAT, Wide Range Achievement Test (3rd edition) scores (Read, Reading Standard Score, mean = 100, SD = 15, both group means are in the average range); WCST, Wisconsin Card Sorting Test Perseverative Errors (an index of response flexibility and punishment sensitivity; means for both groups are within normal limits; CFT, Complex Figure Test recall scores (an index of memory function at 30 min, means for both groups are within normal limits); BNT, Boston Naming Test (raw scores; scores < 48 are impaired); Facial Discrimination (a measure of visuoperceptual discrimination and matching of unfamiliar faces; raw scores; scores < 39 are impaired); BDI, Beck Depression Inventory-II (scores > 12 indicate clinically significant depression symptoms); BAI, Beck Anxiety Inventory (scores > 10 indicate clinically significant anxiety symptoms); TMT-A, Trail Making Test, Part A (an index of simple attention and psychomotor speed, time to complete in seconds, scores > 40 seconds are impaired); TMT-B, Trail Making Test, Part B (an index of complex divided attention and multitasking, time to complete in seconds, scores > 90 are impaired).

Stimuli

Three different categories of unique entities were used in the experiment: famous persons, famous landmarks, and famous melodies. Participants were exposed to 26 names of famous persons, 20 names of famous landmarks, and 16 names of melodies. All stimuli have been previously administered in naming studies performed in our lab (Belfi & Tranel, 2014; H. Damasio et al., 1996; Tranel, 2006). Landmarks consisted of both natural and man-made landmarks. Melodies consisted of both melodies with lyrics (e.g., “White Christmas”) and without lyrics (e.g., “Pomp and Circumstance”). Famous people ranged across occupations including actors, sports icons, and politicians.

Procedure

On each trial, the name of the item appeared on a computer monitor screen. After reading the name, participants rated their familiarity with the item on a six-point scale ranging from certain familiarity (a "6" on the scale) to certain unfamiliarity (a "1" on the scale). On this scale, a rating of 3 or below (closer to 1) indicates that the participant was *not* familiar with the item, whereas a rating of a 4 or above (closer to 6) indicates that the participant had at least some degree of familiarity with the item (see **Figure 1**). This type of scale has been used previously in our work on melody naming (Belfi & Tranel, 2014) and is based on scales used to identify familiarity with faces in patients with prosopagnosia (Tranel & Damasio, 1988). If the participant rated their familiarity with the item from 4 to 6, they proceeded with the following questions: The participant would then rate how well they could visualize the item on a 1-5 scale, with 1 being "not at all" to 5 being "perfectly clear and vivid" (see **Figure 1**). For melodies, the visualization rating asked participants how well they could hear the melody "in their head," while for persons and landmarks, the visualization rating asked participants how well they could "visualize" the item.

Next, participants were asked to provide information about the item. For all three categories of items, participants were asked to provide unique information about the item, specific enough that another person could guess the item from this description. In the case of melodies, in addition to providing uniquely identifying information about the item, participants could also sing, hum, or state the lyrics of the melody. There were no time limits for the participants to retrieve this information, and they were given as much time to respond as they wished. Response times were not recorded, as variability in RT in brain-damaged patients is often quite high, to the point where this may not be a valid measure in this population. If the participant struggled to retrieve information or provided very general answers the experimenter prompted for more information. If the participant provided an overly vague answer, they were prompted to be more specific until they could no longer provide additional information. For example, for the “Colosseum” a participant responded with “From ancient Rome. They held a lot of events.” and the experimenter prompted with, “Anything more specific about what it looks like?” and the participant responded with, “It’s just a great big round arena. Still standing.” For “Bill Clinton,” the participant responded: “He was President of the United States one or two Presidents ago. Kind of well known for his personality and being a smooth talker.” The experimenter prompted with “Anything notable that happened during his Presidency?” and the participant responded with: “Well there were a couple scandals. He had an affair with the intern or something.” All responses were audio recorded.

For all stimuli, regardless of familiarity rating, participants answered a final multiple-choice question. For famous persons and landmarks, participants viewed four images, one of the correct item and three foils of items with similar appearances. Melody multiple choice consisted of 3 short melody clips, one being the correct clip and two foils similar in tempo, style, and origin. For example, multiple-choice options for “White Christmas” contained two other Christmas song options, along with a clip of White Christmas. Participants were asked to select the item that corresponded to the name given at the beginning of the trial. See **Figure 1** for a depiction of the trial structure.

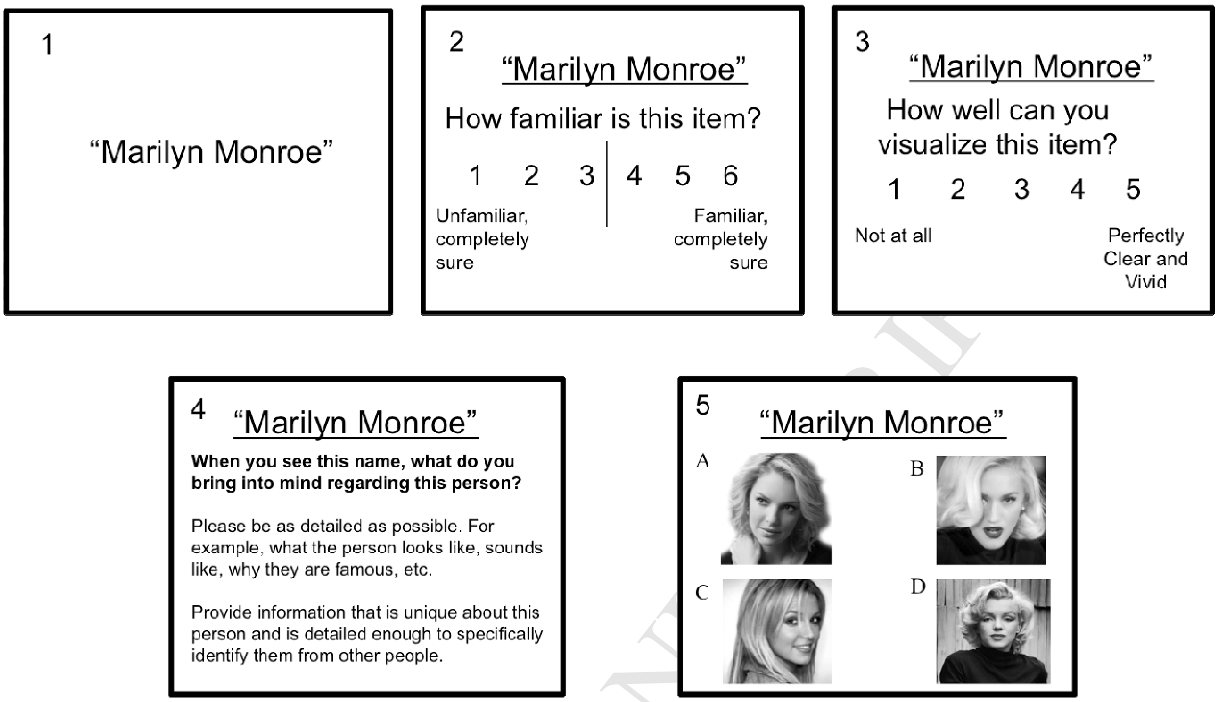

Figure 1. Trial structure in order (1-5), beginning with the stimulus proper name. If a participant rated an item as unfamiliar (a score of 1-3), visualization (3) and retrieval (4) prompts were skipped, and the participant was presented the multiple-choice options (5).

Data Quantification and Analysis

Behavioral data. Familiarity and visualization ratings were averaged across all attempted items for each participant for each category. Scores for concept retrieval were calculated in a similar manner to previous studies: First, audio recordings of the verbal descriptions were transcribed. Items were scored as 'correct' retrieval if two independent raters were able to correctly guess the name of the item (or otherwise identify the item specifically) given the description (Tranel, Logan, Frank, & Damasio, 1997). If both raters correctly guessed the item, it was scored '1' for correct; if both raters failed to identify the item, it was scored '0' for incorrect; if the raters were split (which happened infrequently), they discussed their ratings and came to a consensus. Raters were familiar with the test stimuli prior to making their ratings, which helps to ensure that raters were able to identify when information was accurate and disambiguating regarding a stimulus. While knowing the stimuli could presumably bias the raters, as they would perhaps more easily accept a definition as "definitive," such bias would most likely affect all groups, as raters were blind to group membership of the participants. Moreover, such a bias would work against our main prediction (as raters may over-rate the accuracy of conceptual knowledge retrieval in the LTP patients, who we predicted would be impaired on this measure). An example of a correct response for "Abraham Lincoln" was: "Famous President who I believe was the 16^{th} President. Shot and killed by a person. People always talk about him being tall and wearing a black hat, and he had a beard." Another example of a correct response for "Abraham Lincoln" was: "Sixteenth President of the United States, from Illinois." An example of an incorrect response for Abraham Lincoln was "He was a President of the United States and was assassinated."

We calculated overall scores for each participant on our four dependent variables, which we will refer to as: familiarity, visualization, retrieval, and multiple choice. For familiarity and visualization, overall scores were calculated as the average of each category. To obtain an overall retrieval score, the total number of correct retrievals was divided by the total number of items on which retrieval was attempted. This was to not penalize participants for items with which they were unfamiliar. For example, if a participant only rated 10 persons as "familiar" (i.e., a 4 or above on the familiarity scale) the denominator for their retrieval score would be /10 (as opposed to /26, the total number of persons). If this same participant was scored as having correct retrieval for eight persons, their overall retrieval score for persons would then be 8/10 (80%). For the multiple-choice portion, we calculated the average percent correct for each category.

Neuroanatomical data. Neuroanatomical analysis was based on data obtained during the chronic epoch of recovery. Magnetic resonance (MR) images were acquired in a 1.5-T GE Sigma scanner with 2D SPGR sequence (1.5 mm contiguous T1 weighted coronal cuts). Lesion maps were created using the MAP-3 method, in which lesion locations are visually identified on MR scans and manually transferred onto a normal reference brain (P.C. local standard space; resolution, 0.94 x 0.94 x 1.6 mm) based on the identification of anatomical landmarks (Fiez, Damasio, & Grabowski, 2000; Frank, Damasio, & Grabowski, 1997). Lesion delineation and transfer were done using Brainvox (Frank et al., 1997).

First, on the 3D image of an individual patient's brain: Sulcal boundaries are identified (e.g., sylvian fissure, superior temporal sulcus, Rolandic sulcus), which are then projected onto 2D coronal slices. The rostral, caudal, dorsal, and ventral boundaries of the lesion are then identified in these coronal slices to determine the starting and ending points of the lesion. On the atlas brain, the same sulcal boundaries are identified as used in the patient's brain. The lesioned brain is then aligned to the atlas brain. The same boundaries of the lesion are identified on the atlas brain, landmarks are identified to bind the atlas to the same regions that the lesioned brain covered. To create the lesion map, sulcal and volumetric boundaries of the lesion are visually identified both on the lesioned brain and the atlas brain. An ROI is created manually, on each slice of the atlas brain, of the anatomy that the lesion occupies (H. Damasio & Frank, 1992). This ROI is manually created by an expert technician. These 2D slices are summed into a single 3D volume, and binarized (1=lesion, 0=non-lesion).

This procedure circumvents the problems of interindividual registration encountered with lesion data and the difficulties of combining participants scanned with different imaging modalities. An additional advantage of this approach is that it preserves anatomical boundaries in mapping lesions onto the reference brain, enabling group-level analysis. After manual transfer to normal template space, the template brain was warped to the MNI152 standard 1 mm T1-

weighted atlas using a nonlinear transform (Collins, Neelin, Peters, & Evans, 1994; Evans, Dai, Collins, Neelin, & Marrett, 1991; Mazziotta et al., 2001) using BRAINSDemonWarp (H. Johnson & Zhao, 2009). This transform, from the lesion template to the MNI152 template, was applied to each of the lesion maps. The overlap of lesions in these volumes, calculated by the sum of *n* lesions overlapping at any single voxel, for the LTP and BDC groups, is color-coded in **Figure 2.**

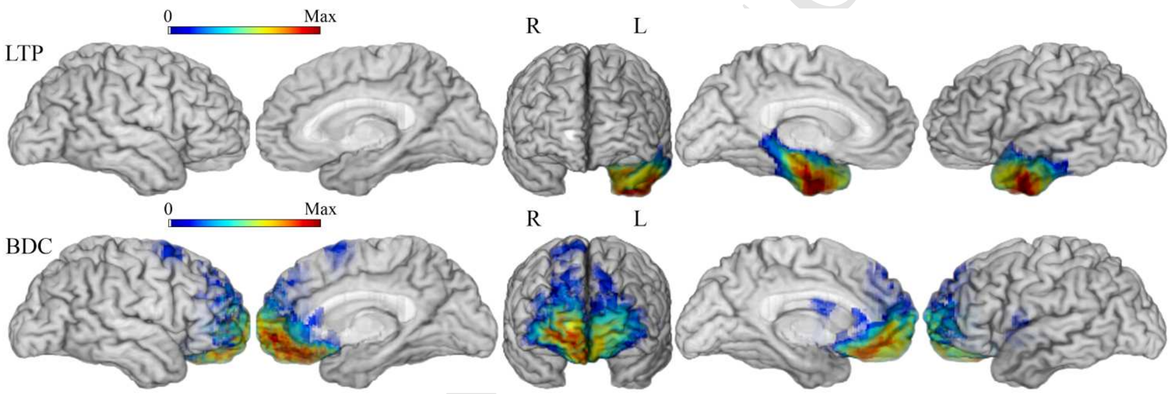

Figure 2. Lesion overlap maps for the LTP group (top row) and BDC group (bottom row). The color bar codes for maximal lesion overlap (LTP *n*=8; BDC *n*=8), with "hotter" colors representing higher numbers of overlap. The BDC map shown here includes the 8 BDC patients who do not have lesions in the right temporal pole; see **Figure 4** for an overlap map depicting the remaining nine BDC patients who fall into a right temporal pole subgroup.

Results

A 3x3 MANOVA was conducted to test the between-subjects effect of group (NC, BDC, LTP) and within-subjects effect of condition (persons, landmarks, melodies) on the four dependent variables (familiarity, visualization, retrieval, and multiple-choice). The results of this test indicated significant multivariate main effects of condition [$F(8,34)=8.04$ $p<0.01$, $\eta^2=0.65$] and group [$F(8,78)=6.24$, $p<0.001$, $\eta^2=0.39$]. In addition, there was a significant interaction between condition and group [$F(16,70)=2.03$, $p=0.02$, $\eta^2=0.31$]. We conducted follow-up univariate tests to identify which dependent measures (familiarity, visualization, retrieval, and multiple-choice) were affected by this significant interaction. These indicated a significant interaction between group and condition only for retrieval [$F(4,82)=8.80$, $p<0.001$, $\eta^2=0.28$] and multiple-choice [$F(4,82)=3.06$, $p=0.02$, $\eta^2=0.13$], but not for familiarity [$F(4,82)=1.22$, $p=0.30$, $\eta^2=0.05$] or visualization ratings [$F(4,82)=2.18$, $p=0.07$, $\eta^2=0.09$].

Post-hoc pairwise comparisons revealed that, for retrieval of conceptual information for persons, the LTP group scored significantly worse than the BDC ($p<0.001$, $d=-1.37$), and NC groups ($p<0.001$, $d=-2.13$). For retrieval in the landmarks condition, the LTP group scored significantly worse than the BDC ($p<0.001$, $d=-2.13$) and NC groups ($p<0.001$, $d=-2.13$). For retrieval in the melodies condition, there were no significant differences between any of the groups (**Figure 3A**).

For multiple choice in the persons condition, the NC group performed significantly better than both the patient groups (both *p*s<0.001, *d*s=2.00). For the landmarks condition, the LTP group performed significantly worse than the BDC ($p=0.007$, $d=-1.18$) and the NC groups ($p<0.001$, $d=-1.63$). In the melodies condition, the NC group performed significantly better than the BDC group ($p=0.02$, $d=0.72$) (**Figure 3B**).

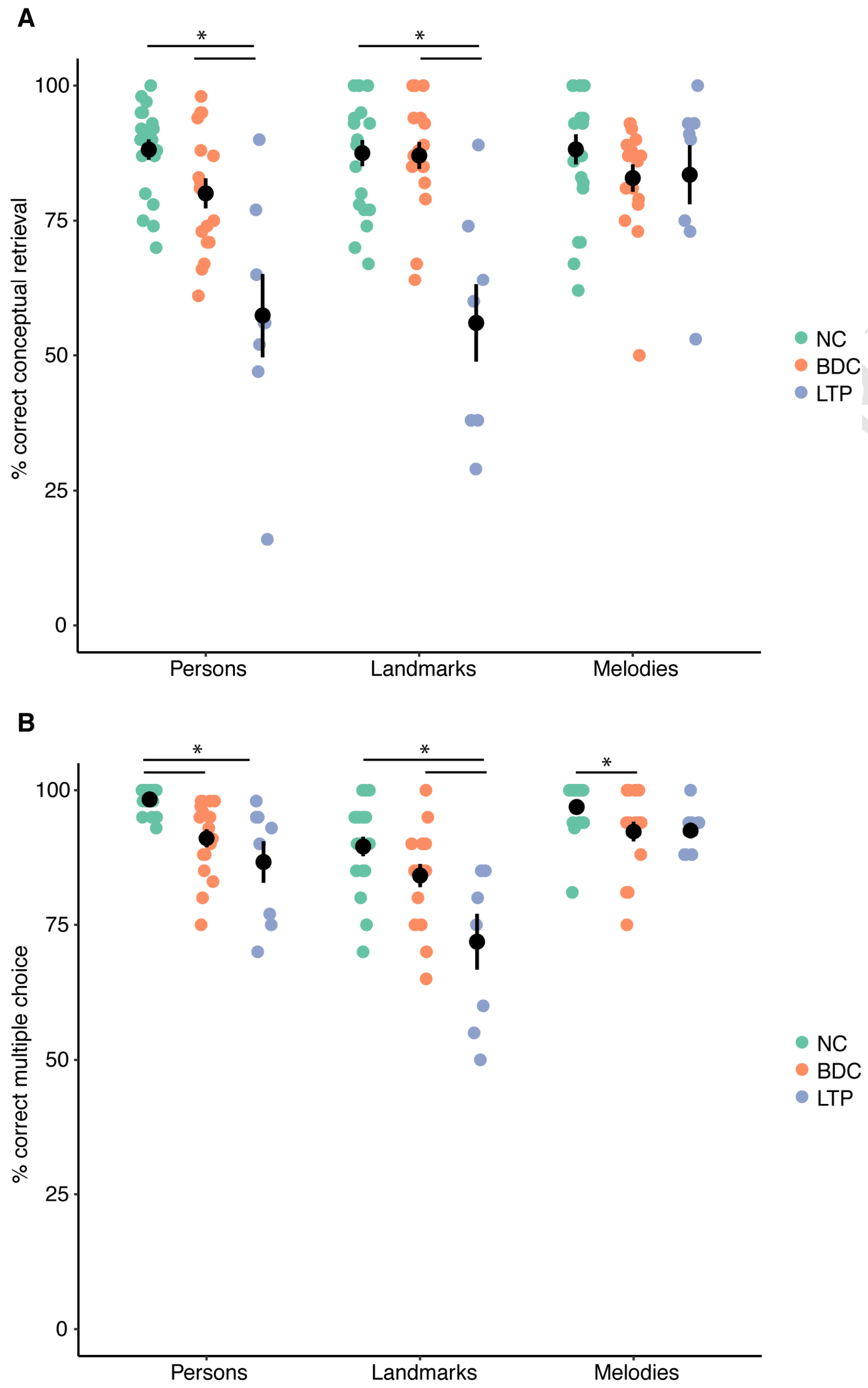

Figure 3. (**A**) Conceptual knowledge retrieval scores, in % correct. The LTP group scored significantly worse than the NC and BDC groups for persons and landmarks, but there were no group differences for music. (**B**) Multiple choice scores, in % correct. The NC group performed better than all other groups for persons; the LTP group performed worse than the two comparison groups for landmarks; the BDC group performed worse than the NC group for melodies. Each point indicates a single participant's data. Black dot indicates mean and

extending lines indicate standard error of the mean. Asterisks denote significant differences between groups.

Error Analysis

To get a fuller sense of the types of errors individuals in the LTP group made, we investigated their errors on individual items. This type of "error analysis" is typically done in standard confrontation naming paradigms, and we adapted these procedures for use in our "recognition-from-name" task. We looked at the types of errors made by the LTP participants in both categories in which they showed deficits for conceptual knowledge retrieval: persons and landmarks.

For persons, there were a total of 208 trials (8 participants in the LTP group with 26 trials per participant). Ninety-four of the 208 trials were scored as correct. Twenty-four of the 208 trials were not included in the error analysis, because the participants did not indicate familiarity with the stimulus on these trials (and so the concept retrieval portion of the trial was not conducted). For the remaining 90 trials scored as incorrect, 81 (90%) were scored as "general" errors. Errors categorized as "general" were responses that contained correct information about the item, but not specific enough to identify that item particularly. For example, a general response for Abraham Lincoln was: "He was a president of the United States. Was assassinated." While this is correct information about Abraham Lincoln, it is not specific enough to differentiate him from other famous persons fitting this description (for example, this participant could also be describing John F. Kennedy). Eight (9%) of the incorrect trials were scored as "incorrect information" errors. These were responses that contained information that was not descriptive of the correct person. For example, an incorrect response for Steve Jobs was, "The founder of Microsoft." An incorrect response for Meryl Streep was, "Female singer who won an award last year. I believe she sings country music." Finally, one trial (1%) was scored as "no response." For this type of error, the participant responded with "I don't know."

For landmarks, there were a total of 160 possible trials (20 trials per 8 LTP participants). Of these 160, 71 were scored as correct and 48 were not included (participants indicated that they were not familiar with the item). Of the 41 remaining incorrect trials, 24 (58%) were scored as "general" errors. For example, a general response for the Colosseum was, "It's in Rome, Italy. It is frequently visited by people who visit Italy." A general response for the World Trade Center was, "I think of New York City. A very large tall building surrounded by many other buildings." Thirteen of the errors (31%) were scored as "incorrect information." For example, an incorrect response for Wrigley Field was, "It's in Chicago, home of the White Sox baseball team. And often on television when the White Sox are playing at home you can see the field." An incorrect response for the Golden Gate Bridge was, "It's a bridge over the Mississippi River." Four errors (9%) were scored as "no response," where participants gave no information.

Follow-up analysis of patients with right temporal polar damage

Prior work has indicated that the right temporal pole (RTP) may be important for recognition of semantically unique items (H. Damasio et al., 2004; Drane et al., 2008; Gainotti, 2007; Rice, Ralph, & Hoffman, 2015; Tranel, Damasio, & Damasio, 1997). Given this, it is possible that damage to the RTP could also result in impairments on the current task. Nine of the 17 patients in the BDC group had damage to the RTP. Therefore, we sought to briefly investigate the performance of these individuals by pulling out their data as a subgroup (see lesion overlap map for this subgroup in **Figure 4**). This group is referred to as RTP in the analyses reported below. This RTP subgroup is well-matched to the LTP group (see Table 1 also) in terms of demographic variables [5 F, 4 M; mean age: 54.0 (SD=10.30); education: 13.88 (SD=1.96);

FSIQ: 109.14 (SD=13.95); handedness: 1 L, 7 R, 1 M], and the groups are well-matched on lesion etiology (RTP: 7 surgical resection for epilepsy treatment, 1 benign tumor resection, 1 cerebrovascular disease; LTP: 8 surgical resection for epilepsy treatment).

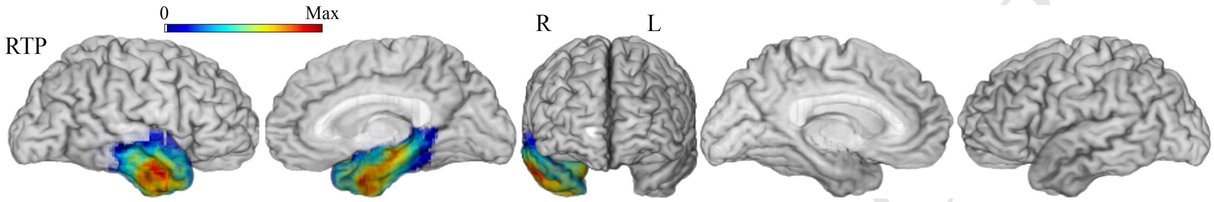

Figure 4. Lesion overlap map for RTP subgroup. The color bar codes for maximal lesion overlap (RTP *n*=9), with "hotter" colors representing higher numbers of overlap.

To investigate the potential association between RTP damage and conceptual retrieval, we conducted one follow-up test on our main variable of interest: conceptual retrieval scores. This 3x3 ANOVA (group: NC, LTP, RTP; condition: persons, landmarks, melodies) indicated a significant interaction between group and condition [F(4,68)=6.51, $p<0.001$, $\eta^2=0.27$]. Pairwise comparisons (Bonferroni corrected for multiple comparisons) indicated that, for retrieval in the persons condition, the LTP group scored significantly worse than the RTP ($p=0.005$, $d=1.37$) and NC groups ($p<0.001$, $d=2.13$). For retrieval in the landmarks condition, the LTP group scored significantly worse than the RTP ($p<0.001$, $d=1.69$) and NC groups ($p<0.001$, $d=2.02$). For retrieval in the melodies condition, there were no significant differences between any of the groups. Therefore, the RTP group did not show impairments on conceptual retrieval when given names for persons (M=78.86, SD=11.36) landmarks (M=85.54, SD=12.76) melodies (M=80.86, SD=13.15).

Discussion

Here, we tested whether the LTP functions as a bidirectional convergence zone for proper naming and conceptual knowledge retrieval for unique entities. Consistent with our prediction, patients with damage to the LTP were impaired at retrieving conceptual knowledge when given names of famous persons or landmarks. Prior work has suggested that the LTP serves as a "convergence zone," critical for mediating between conceptual and lexical knowledge about a unique entity (H. Damasio et al., 2004). A key aspect of this hypothesis is that this function of the LTP is bidirectional – the LTP mediates both name retrieval when given conceptual information, and conceptual information retrieval when given a name. This "convergence zone" framework therefore suggests that damage to the LTP would disrupt both such processes. Our present findings support this conceptual framework, illustrating that individuals with LTP damage were impaired at retrieving conceptual knowledge when given a name. Additional recent work in a single case study also supports this view: a patient with unilateral LTP damage was unable to name famous persons from a photo or provide semantic information when given a name, displaying a "two-way lexico-semantic disconnection" (Busigny & Boissezon, 2015).

When discussing the two-way nature of this deficit, it is important to note that the processes of going from a concept to a name, versus going from a name to a concept, are probably not symmetric. Retrieving a word when given a concept requires more precision than the reverse. For example, when shown a picture of a famous person, there is essentially only one correct answer for the name. Take Abraham Lincoln: when shown his picture, the only correct response would be to say "Abraham Lincoln" (or a very close variant such as "Abe Lincoln"). However, when given the name of a famous person and asked to "define" the person, many potential answers are possible and would be accurate to the extent that such answers gave uniquely identifying information about the particular person. For example, for the name "Abraham Lincoln," correct responses could range from "16th President of the United States," to "On the five dollar bill" to "President during the Civil War" to "Was assassinated at the Ford Theater by John Wilkes Booth," and so on. Nonetheless, despite this asymmetry in the two tasks, we provide evidence in the current study for a deficit in concept retrieval when given a proper name in patients with focal damage to the LTP. This fits with the theoretical framework suggesting that damage to the LTP disrupts intermediary processes, such as those required for connecting lexical and semantic information about unique entities (H. Damasio et al., 2004)

It was interesting that, unlike the deficient performance of the LTP group in concept retrieval for both famous persons and landmarks, we found no group differences for famous musical melodies. One possible explanation is that while landmarks and people require retrieving knowledge about visual items, the concept retrieval deficit may not extend to auditory stimuli. However, this would not be predicted by our model or from previous studies demonstrating impaired naming of musical melodies following LTP damage (Belfi & Tranel, 2014) or naming famous politicians from recorded speeches (E. J. Waldron et al., 2014). Additionally, prior work has indicated using direct recordings from the cortical surface that the LTP responds to both auditory and visual information about unique entities (Abel et al., 2015).

Perhaps the difference in our findings for melodies versus persons and landmarks is due not to the difference in sensory modality (i.e., auditory vs. visual) but to differences in the mechanism of knowledge retrieval. For persons and landmarks, participants verbally provided conceptual information about the entity. For example, when asked to give information about Princess Diana, a participant said, "She married into the royal family of England and had two sons. She was killed in a car accident where the paparazzi were following her." A key difference with the melodies is that when asked to illustrate conceptual knowledge, participants could hum or sing the melody, or recite the lyrics, in addition to providing any verbal information about the melody. This is perhaps taking advantage of the modularity of musical processing, allowing retrieval either directly from what has been termed the “musical lexicon” (retrieving the melody directly) or retrieving information from the phonological lexicon (information about the lyrical content of the melody; Peretz & Coltheart, 2003). This allows for multiple routes to retrieval of conceptual knowledge for melodies, compared to perhaps only a singular route to correct retrieval of conceptual knowledge for persons and landmarks.

Despite potential multiple routes to a correct response, it does not appear that melody retrieval is simply an easier task overall -- healthy comparison participants performed quite similarly across the three categories of items. It might be that additional routes to retrieval (e.g., singing or reciting lyrics) recruit additional neural regions outside the LTP, resulting in better performance in patients with damage to this region. For example, neuroimaging work has indicated that listening to highly familiar melodies recruits motor-related regions such as the pre-supplementary motor area (Jacobsen et al., 2015). This coincides with prior work suggesting that heteromodal semantic processing regions encode lower-level motor and sensory information about objects (Fernandino, Binder, et al., 2016; Fernandino, Humphries, Conant, Seidenberg, & Binder, 2016). It is possible that such sensorimotor information is more salient for musical melodies, and therefore that retrieval of melodic knowledge may rely more heavily on such sensorimotor regions. Another possible explanation for these findings is that recognition of famous melodies relies more heavily on the procedural memory system. This has also been suggested in work with patient populations: patients with severe amnesia display an ability to learn to perform new musical pieces (Cavaco, Feinstein, van Twillert, & Tranel, 2012), and memory for musical melodies is preserved in patients with Alzheimer's disease (Baird & Samson, 2009; Cuddy et al., 2012). It may also be the case that the non-verbal aspects of melody retrieval might rely more heavily on the right hemisphere, leaving this capacity preserved in patients with LTP damage. In this way, melody retrieval may be similar to "automatic" speech, such as counting and expletives, which has been shown to involve right hemisphere structures (Bookheimer, Zeffiro, Blaxton, Gaillard, & Theodore, 2000; Vanlancker-Sidtis, McIntosh, & Grafton, 2003). Conversely, damage to the LTP may disrupt connections to other left-hemisphere language structures (Geranmayeh, Leech, & Wise, 2015; Lambon Ralph, McClelland, Patterson, Galton, & Hodges, 2001). Therefore, the non-verbal and/or "rote" route to melody retrieval may account for its preservation in patients with LTP damage.

Results from the multiple choice test format showed a similar pattern to results for the open-ended conceptual knowledge retrieval format – the LTP group performed worse than the BDC and NC groups on persons and landmarks, but not melodies. However, deficits in the LTP group in this condition were less severe. The LTP group performed significantly worse than both the BDC and NC groups for landmarks, but only worse than the NC group for persons. Part of this effect could be due to the high scores in the NC group for persons (nearing a ceiling effect). It is possible that faces are more easily recognizable when given a multiple-choice recognition test than other categories of items. These data also suggest that patients in the LTP group have some preserved ability to recognize items when given several options, but show more severe deficits when asked to recall conceptual information without aids. This is similar to the discrepancy between recognition and naming in a standard confrontation naming paradigm. Despite showing impairments in conceptual knowledge retrieval when given names for persons or landmarks, patients with LTP damage showed no impairments in self-reported familiarity or ability to visualize the given entities, across all three categories (persons, landmarks, melodies). These data suggest that patients with LTP damage have preserved feelings of familiarity for semantically unique items, but when pressed for specific identifying conceptual knowledge, are impaired.

While our data indicate that patients with LTP damage are impaired at conceptual retrieval for unique entities when given a name, we also conducted follow-up analyses to investigate the role of the RTP. Prior lesion and neuroimaging work has implicated the RTP in recognition of unique entities (H. Damasio et al., 2004; Drane et al., 2008; Gainotti, 2007; Rice et al., 2015; Tranel, Damasio, et al., 1997). For example, patients with RTP damage have been shown to have deficits in recognition of famous faces, displayed by an inability to retrieve unique knowledge about the persons (Tranel, Damasio, et al., 1997). In addition, rTMS applied to the RTP disrupts familiarity for famous faces, but rTMS applied to the LTP does not (Ranieri et al., 2015). However, this work has typically used the conventional approach to the task, whereby participants are presented with an entity (e.g., a picture of a famous person) and asked to retrieve either lexical or semantic information about that entity. Here, we found no deficits for patients with RTP damage. It may be that, as in the present study, "recognition-from-name" relies on different processes and structures outside the RTP.

This work is not without limitations. We have a relatively small sample size, although it is not atypical for studies of this target patient population (Belfi & Tranel, 2014; Drane et al., 2008). We did not collect response time data during the conceptual retrieval portion of the task, and such data could potentially shed further light on the differences between groups that we found (although RT data are often quite noisy in patients with brain damage). We did not attempt to test both the standard picture (or melody) naming *and* recognition-from-name paradigm in this study; however, patients with lesions similar to those in the present groups have been shown to be deficient at the standard naming tasks (H. Damasio et al., 1996; Tranel, 2006). Some of the same patients presented here were used in previous studies of the “face-to-name” direction. Four of the LTP patients in the present study displayed deficits in that direction for persons (mean percentage correct naming: 66.75, SD=4.34, as compared to scores from 55 normal comparisons: mean naming=85.00, SD=11.10). This provides further support for the two-way nature of the impairments described here.

One possible limitation to the interpretation of a “two-way” deficit is that the retrieval of conceptual knowledge for unique entities may rely on retrieval of unique names for related concepts – for example, correct conceptual knowledge retrieval for a movie star could include retrieving the names of specific films in which the actor has starred. While this is certainly the case, and many correct descriptions include these types of “proper name” information for related concepts, it is also the case that successful conceptual retrieval can be completed without any additional “proper name” information. For example, drawing on examples in the current study, correct concept retrieval for Bill Clinton that contained very little “proper name” information was: “Former president, Democrat. His wife is running for President now. Unfaithful to his wife.” Correct concept retrieval for Michael Jackson that contained no “proper name” information was: “A historic musician for pop. He was part of a family group, I think in the 70s, and then he branched out and did his own thing. He was big in the 80s. A singer, songwriter, dancer, musician. Black, but then he lightened up as he got older. I thought he married, what’s his name, big rock singer from the 50s. He married his daughter. He was the king of pop and her dad was the king of rock.” Such descriptions illustrate correct concept retrieval for unique entities without additional “proper name” information about related entities. Still, it could certainly be the case that impaired proper name retrieval could hinder one's ability to define concrete entities when given a name. An interesting avenue for future exploration would be to have healthy participants "define" unique entities from names (as done here) without using any additional proper names in their definitions. This would provide a way to more precisely identify the influence of additional proper name information on the ability to correctly define semantically unique items.

In sum, the present findings lend support to the proposal that the LTP functions as a bidirectional convergence region for proper naming, as patients with damage to the LTP showed impairments in retrieving semantic information about unique entities when given a proper name. This pattern obtained for the categories of persons and landmarks; however, patients with LTP damage showed relatively preserved ability to retrieve musical knowledge (from melody names), suggesting that melody retrieval relies on different neural structures outside the LTP. Furthermore, damage to the RTP was not associated with any defects in retrieving conceptual knowledge given a name. This work illustrates that the LTP serves as a *bidirectional* convergence region for proper naming, suggesting a critical role for the LTP in the association between lexical and semantic information for unique entities.

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