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Anomia for musical entities

Amy M. Belfi [a], Anna Kasdan[a] and Daniel Tranel[b,c]

[a]Department of Psychology, New York University, New York, NY, USA; [b]Department of Neurology, University of Iowa Carver College of Medicine, Iowa City, Iowa, USA; [c]Department of Psychological and Brain Sciences, University of Iowa, Iowa City, Iowa, USA

ABSTRACT

Background: Previous work has investigated extensively the neuroanatomical correlates of lexical retrieval of words for concrete entities. Musical entities, such as musical instruments, are often included in studies of category-specific naming deficits but have rarely been the focus of such work.

Aims: This article reviews a program of research investigating the neuroanatomical basis for lexical retrieval of words for unique (i.e., melodies) and nonunique (i.e., musical instruments) musical entities.

Main Contribution: We begin by reporting findings on the retrieval of words for unique musical entities, including musical melodies. We then consider work focusing on retrieval of words for nonunique musical entities, specifically musical instruments. We highlight similarities between the two lines of work and then report results from new analyses including direct comparisons between the two. These comparisons suggest that impairments in naming musical melodies and in naming musical instruments are both associated with damage to the left temporal pole (LTP). However, musical instrument naming appears to rely on a more distributed set of brain regions, possibly including those relating to sensorimotor interactions with such instruments, whereas melody naming relies more exclusively on the LTP.

Conclusions: Retrieval of names for musical melodies appears to rely on similar neuroanatomical correlates as for other proper nouns, namely the LTP. Musical instrument naming seems to rely on a broader network of regions, including the LTP and sensorimotor areas. Overall, melody naming seems to coincide with naming of other proper nouns, while musical instrument naming appears distinct from other categories of nonunique items.

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Aphasia; anomia; music; naming; lesion

Deficits in name retrieval are a frequent consequence of neurological damage. Typically, damage to the left hemisphere is associated with the most severe naming deficits. Certain locations within the left hemisphere, when damaged, tend to result in a selective deficit for a particular category of items. Studies of such category-specific naming deficits often include various categories, representing both unique (e.g., people, places) and nonunique

CONTACT Amy M. Belfi amybelfi@mst.edu Department of Psychological Science, Missouri University of Science and Technology, 136 Humanities and Social Sciences, 500 W. 14th St., Rolla, MO, USA
Present affiliation for Amy M. Belfi is "Department of Psychological Science, Missouri University of Science and Technology, Rolla, MO, USA".

(e.g., animals, tools, fruits, and vegetables) items. Unique (or "semantically unique") entities are those that hold semantic associations not tied to other similar items (Gorno-Tempini & Price, 2001). This concept has been used to describe the apparent functional specialization for famous faces – while all faces share similar perceptual features, famous faces are easily distinguished and identified at a unique level, presumably based on their unique semantic associations. Additionally, semantically unique items typically are denoted by a proper name. By contrast, nonunique items are manifold and are typically denoted by a common noun. For example, the dog "Lassie" would be considered a semantically unique item, while a generic "dog" would be considered nonunique. Naming deficits for semantically unique items, such as people or places, have been associated with damage to the left temporal pole (LTP); deficits for nonunique entities, including animals and tools, are associated with more posterior temporal lobe damage, in a category-related manner (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996). This and other prior work suggests a distinction in the neural correlates associated with naming unique compared to nonunique items and in naming different categories of nonunique items (Gorno-Tempini & Price, 2001; Ross & Olson, 2012).

Music provides an interesting opportunity to study such distinctions between naming of unique and nonunique items within a single higher level category. In this case, the higher level category of "musical entities" includes the subordinate categories of musical *melodies* and musical *instruments*. Musical instruments are frequently included in studies of naming deficits for nonunique items, while musical melodies have occasionally been studied as an example of unique entities, similar to faces or places. An additional compelling aspect of music with regards to individuals with brain damage is that musical abilities are often preserved in persons with aphasia (Tzortzis, Goldblum, Dang, Forette, & Boller, 2000) and music-related therapies for aphasia are efficacious in helping patients regain language capabilities (Schlaug, Marchina, & Norton, 2009; Wan, Zheng, Marchina, Norton, & Schlaug, 2014). Despite this evidence of preserved musical abilities (such as singing) in patients with aphasia, naming deficits for musical entities are often the most severe (Barbarotto, Capitani, & Laiacona, 2001).

The current article focuses on the retrieval of names for musical entities, including melodies and instruments. Naming of musical entities can be disrupted by damage to various brain regions, as well as by neurodegenerative disorders (Hsieh, Hornberger, Piguet, & Hodges, 2011; Omar, Hailstone, & Warren, 2012) and even healthy aging (Coppens & Frisinger, 2005). We focus here on directly comparing the neural correlates for naming deficits in melodies, musical instruments, and other categories of items. Given that musical entities are frequently studied as a category in individuals with naming deficits, but are seldom the focus of such accounts, the present review aims to outline prior research on this topic. In the following sections, we present prior work from our laboratory regarding the retrieval of names for musical entities, both unique (melodies) and nonunique (instruments). In addition to reviewing this prior work, we include further analyses to directly compare performance on melody and instrument naming, as well as other categories of items. Our findings are situated in the context of work from other laboratories that have converged on similar conclusions, and we briefly outline a theoretical framework to account for these findings.

Anomia for melodies

When hearing a famous melody, such as Scott Joplin's "The Entertainer," one might recognize the melody without being able to recall its name (Kostic & Cleary, 2009). Early case studies of patients with focal brain damage indicated that bilateral lesions to the superior temporal lobes resulted in a selective inability to recognize melodies (Peretz, 1996; Peretz et al., 1994). Melody recognition has also been found to be impaired in patients with damage to either the left or right anterior temporal lobes (Zatorre, 1985). Other studies suggest that medial temporal lobe (MTL) structures may *not* be critical for the ability to recognize melodies. For example, patients with MTL damage due to Alzheimer's disease are able to differentiate between familiar and unfamiliar musical melodies (Cuddy et al., 2012). One case study found preserved melody recognition (the ability to distinguish between familiar and non-familiar melodies) in a patient with severe amnesia due to herpes simplex encephalitis (Finke, Esfahani, & Ploner, 2012). Similar work in patients with focal brain damage has confirmed that MTL structures are not necessary for feelings of familiarity: patients with unilateral MTL lesions are as fast and as accurate at judging short musical excerpts as familiar, compared to individuals without neurological damage (Huijgen et al., 2015).

Neuroimaging work in healthy adults suggests that the anterior temporal lobes might be most critical for melody recognition. For example, the left anterior temporal lobe has been shown to be involved when making familiarity judgments of musical melodies (Groussard et al., 2009; Platel, Baron, Desgranges, Bernard, & Eustache, 2003). In these studies, participants typically have to distinguish a melody as "familiar" or "unfamiliar" or differentiate between two given melodies. While this provides a measure of melody *recognition*, it does not provide insight into the processes underlying name retrieval. For the present purposes, it is important to distinguish between recognition, which requires retrieving semantic information that confers "knowing," and naming, which requires retrieval of a specific lexical entity. This distinction between recognition and naming for melodies has been identified in patients with both semantic dementia and Alzheimer's disease: these individuals were severely impaired in naming melodies, while recognition was relatively spared (Omar, Hailstone, Warren, Crutch, & Warren, 2010).

This dissociation between recognition and naming suggests that music processing occurs in a "modular" fashion (Omar et al., 2010; Peretz & Coltheart, 2003). In relation to the proposed model of Peretz and Coltheart (2003), we suggest that "feelings of familiarity" or *recognition* of a melody could unfold successfully solely by engagement of the "musical lexicon" module. In this framework, the musical lexicon is a representation of all melodic structures one has been exposed to over their lifetime, independent of language or name-related information. In contrast, melody *naming* would require reciprocal connections between the "musical lexicon," "associative memories," and "phonological lexicon" modules. We suggest that in order to successfully name a melody, one needs to associate melodic information (i.e., the "musical lexicon") with unique identifying semantic information, stored in the "associative memories" module, and with verbal/lexical information stored in the "phonological lexicon," which would result in retrieval of a name.

As also suggested in the model of Peretz and Coltheart (2003), this conceptual modularity (or separability) between recognition and naming may correspond with a neuroanatomical modularity: Damage to the right temporal pole (RTP) has been more frequently associated with recognition deficits (Drane et al., 2008; Gainotti, 2007; Rice, Ralph, & Hoffman, 2015; Tranel, Damasio, & Damasio, 1997), while damage to the LTP is more frequently associated with naming deficits for various categories of items. A long history of research implicates the LTP as a critical structure for naming unique entities (Tranel, 2009). Patients with damage to the LTP are impaired at naming unique entities including famous landmarks (Tranel, 2006) and famous people (both from faces: Busigny & Boissezon, 2015; Damasio et al., 1996; Drane et al., 2013; and voices: Papagno, Mattavelli, Casarotti, Bello, & Gainotti, 2017; Waldron, Manzel, & Tranel, 2014). Functional imaging research further implicates the LTP in naming semantically unique items (Gorno-Tempini et al., 1998; Grabowski, Damasio, & Tranel, 2000; Ross & Olson, 2012). This has also been corroborated with evidence from direct physiological recordings of the LTP, which have indicated LTP involvement in proper naming irrespective of sensory modality (Abel et al., 2015). Collectively, this work supports the theory that the LTP serves as a heteromodal convergence zone, critical for binding an item's name with knowledge about that item.

We have proposed that musical melodies are similar to other categories of semantically unique entities in that the LTP is critical for name retrieval. While there are few studies directly investigating melody naming, one early study indicated that left-hemisphere damage is associated with melody naming impairments (Ayotte, Peretz, Rousseau, Bard, & Bojanowski, 2000). Patients with left hemisphere, right hemisphere or bilateral lesions, and healthy comparisons, named a series of famous melodies. Both the left hemisphere and bilateral patient groups were significantly impaired at naming, but not judging the familiarity of the melodies. This suggests that structures in the left hemisphere are particularly important for melody naming, as opposed to recognition. Similarly, patients with LTP damage due to primary progressive aphasia were impaired at pairing melodies to related semantic concepts (Macoir et al., 2016). Patients with Alzheimer's disease, frontotemporal dementia, and semantic dementia have all been found to have impaired melody naming performance, which is correlated with gray matter volume in the LTP (Johnson et al., 2011). This work suggests that the LTP is a critical structure for the ability to name melodies. Later, we detail our initial study directly testing the prediction that focal damage to the LTP would be associated with impaired naming of musical melodies. In addition, we provide additional data to directly compare between melody naming and naming for other categories of unique items.

Melody naming

Our initial study on anomia for musical entities was conducted in a target group of patients with focal damage to the LTP (Belfi & Tranel, 2014). Prior work has indicated that damage to the LTP is associated with anomia for two other categories of semantically unique items – famous faces and landmarks. We predicted that if musical melodies could be considered semantically unique items, anomia for melodies would also result from focal LTP damage.

Participants

Participants included 10 patients with damage to the LTP, 10 brain-damaged comparison (BDC) participants with damage outside the LTP, and 10 normal comparisons (NC) with no history of neurological or psychiatric disorders. All groups were matched on age, education, sex, and handedness. All brain-damaged patients had left-hemisphere language dominance (as determined by neurological, neuropsychological, and Wada testing) and did not have general intellectual impairment (as determined by Wechsler Adult Intelligence scale – Third or Fourth Edition (Wechsler, 2008)).

Task and procedure

The task consisted of listening to 52 famous melodies (see Appendix A for a full list). All melodies were one-line melodies (i.e., no harmonic accompaniment, no lyrics) in a MIDI piano timbre. Stimuli consisted of the first two lines of each melody. Consequently, melodies ranged from 8 to 15 s in duration.

After hearing each melody, participants rated their familiarity with the melody on a 6-point scale ranging from certain familiarity (a 6 on the scale) to certain unfamiliarity (a 1 on the scale) (Tranel & Damasio, 1988). Scores below a rating of three indicated that the participant was not familiar with the melody, while scores of three or above indicated that the participant had some degree of familiarity with it. After rating their familiarity, participants were asked to identify the melody by name. If participants could not provide the name of the melody, they were asked to state the lyrics, continue humming/singing the melody, or provide any other identifying information about the melody.

Scoring

For each of the 52 melodies, if the participant gave the correct name, naming was scored as correct. If the participant did not give a name or gave an incorrect name, naming was scored as incorrect. Occasionally, participants would provide the name of the composer (e.g., "Beethoven" for "Fur Elise") or the name of a different melody with a similar topic (e.g., "America" for "This Land is Your Land"), or a more general theme (e.g., "Christmas Song" for "White Christmas"); these were scored as incorrect naming. Items with a correct naming score were also given a correct recognition score, on the assumption that correct naming indicates correct recognition, as in prior work. For items that were not named correctly, we judged the additional information the participant provided. If the participant correctly hummed the tune or gave correct lyrics, recognition was scored as correct. If participants did not hum or give lyrics, their ratings of familiarity were used to judge recognition. A five or six on the familiarity scale was taken to indicate the participant was highly familiar with the melody. If a participant gave this rating, their recognition score was also scored as correct. For each participant, their overall naming score was calculated by taking the number of items correctly named and dividing by the number of items correctly recognized. This was to not penalize participants for failing to recognize items.

Neuroanatomical analysis

Neuroanatomical analysis was based on MRI data obtained in a 1.5-T scanner. Using Brainvox (Frank, Damasio, & Grabowski, 1997), each patient's lesion was reconstructed in three dimensions. The lesion contour for each patient was manually warped into a normal template brain using the MAP-3 method (Fiez, Damasio, & Grabowski, 2000). The overlap of lesions in these volumes, calculated by the sum of *n* lesions overlapping at any single voxel, is color-coded in Figure 1(A).

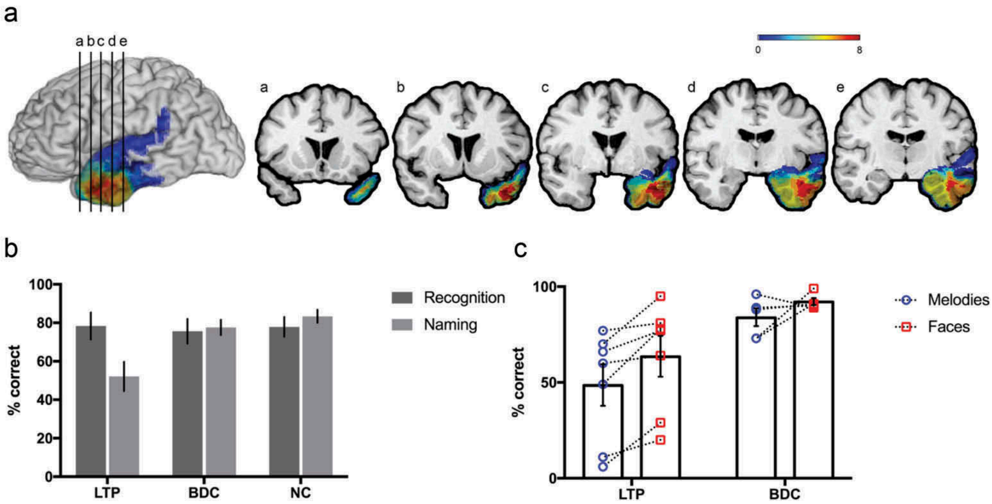

Figure 1. (A) Lesion overlap map of participants in Belfi and Tranel (2014). Color bar codes for maximal lesion overlap, with "hotter" colors depicting areas of higher overlap. Images are shown in radiological convention (left hemisphere on the right), with coronal slices going from more anterior to most posterior (a–e). (B) Results from Belfi and Tranel (2014). The LTP group scored significantly poorer than the BDC and NC groups in naming, but not recognizing, famous melodies. Error bars depict standard error of the mean. (C) Data from both famous melodies and famous faces naming tasks, in the LTP and BDC groups. Circles illustrate a single subject's data from melodies, and squares illustrate a single subject's data from faces. Error bars depict standard error of the mean. Data from a single participant are connected by a dotted line. The naming performance of the LTP group was below that of the BDC group for both melodies and faces.

From "Impaired naming of famous musical melodies is associated with left temporal polar damage" by A. M. Belfi and D. Tranel, 2014, Neuropsychology, 28(3), 429-435, published by APA. Reprinted with permission.

Results

In our original article, we reported that the LTP group showed significantly impaired naming compared to the BDC and NC groups [$F(2,27) = 10.2$, $p < 0.001$, $\eta_p^2 = 0.43$], but no impairments in recognition (see Figure 1(B)).

Here, we sought to examine further the specificity of this naming deficit for melodies by directly comparing these data to previously acquired data on retrieval of names for famous faces. To do this, we compared only the naming scores between BDC and LTP patients who completed both tasks (no NCs completed both the famous melodies and famous faces naming tasks). Data on famous face naming were acquired in connection with patients' enrollment in a program of research in our laboratory studying the neural correlates of knowledge retrieval (see Damasio, Tranel, Grabowski, Adolphs, & Damasio, 2004), and some of these data have been reported in previous articles (e.g., Damasio et al., 1996, 2004; Tranel, 2006). Five individuals in the BDC group and seven in the LTP group completed both famous melodies and famous faces naming tasks (see Appendix B for a full list of faces). A 2 × 2 mixed ANOVA (group: LTP, BDC; category: faces, melodies) revealed a significant main effect of category [$F(1,10) = 11.40$, $p = 0.007$, $\eta_p^2 = 0.53$] and a significant main effect of group [$F(1,10) = 6.27$, $p = 0.03$, $\eta_p^2 = 0.38$], but no interaction between group and condition.

Further investigating the main effect of category, *post-hoc* tests indicate higher naming scores for faces (M = 77.71, 95% CI [63.36, 92.06]) than for melodies (M = 66.11, 95% CI [51.02, 81.20]) across both groups. Investigating the main effect of group, the LTP group scored significantly lower (M = 55.92, 95% CI [37.57, 74.28]) than the BDC group (M = 87.90, 95% CI [66.18, 109.61]) across both categories. See Figure 1(C) for a graphical depiction of these results.

Melody naming summary

From this and related work, it appears that the LTP is a critical region for naming musical melodies. However, when directly comparing data on melody naming to face naming, it is clear that this naming deficit for melodies is not specific to this category. Instead, it appears that melody naming is similar to other categories of unique entities: impairment in naming these entities is associated with damage to the LTP. This is consistent with the theory that the LTP is a convergence region critical for naming unique entities irrespective of category.

It also appears that, in general, melody naming may be more difficult than face naming. While this has not been investigated systematically on a large scale, the data included here indicate that even comparison groups show poorer performance on melody naming. This coincides with other work illustrating that faces are more frequently associated with autobiographical memories than music (Belfi, Karlan, & Tranel, 2016). It is possible that famous people are more "familiar" than famous melodies (e.g., have more and stronger semantic associations), which may lead to better naming performance. It is also possible that individuals have less exposure to melodies than to famous people or that melody names are often longer than names of persons, which may increase the difficulty of retrieval. Despite this apparent difference in difficulty between melodies and faces, across both categories LTP patients performed worse than BDC patients, suggesting the LTP as a critical region for naming unique entities more generally.

Another possible explanation is that musical experience influences melody naming. For example, it could be the case that individuals perform more poorly on melody than face naming because they have less background or training in music. To investigate this, we looked at musical experience data collected as part of a separate experiment. These data included years of formal musical training and scores on the Barcelona Music Reward Questionnaire (BMRQ; Mas-Herrero, Marco-Pallares, Lorenzo-Seva, Zatorre, & Rodriguez-Fornells, 2013) for 10 of the 20 brain-damaged participants (6 LTP, 4 BDC). The BMRQ is a measure of an individual's overall emotional responsiveness to music, with higher scores representing stronger emotional connections to music. While this is distinct from musical training, emotional responsiveness to music may be considered another type of musical expertise and therefore may potentially be related to melody naming. With these admittedly fairly small *N*s, we correlated melody naming scores with years of formal musical training ($r = -0.28$, $p = 0.43$) and overall BMRQ scores ($r = -0.02$, $p = 0.93$). Overall, these data suggest that formal musical training and emotional responsiveness to music are not strongly tied to melody naming ability. It is important to mention, however, that there are many measures of musical ability, expertise, and engagement. For example, a commonly used measure of musical "sophistication" includes musical training and emotional responses to music as well as perceptual abilities, singing abilities, and active engagement with music (Müllensiefen, Gingras, Musil, & Stewart, 2014). Therefore, future work could more systematically investigate the relationships between the various aspects of musical experience and melody naming.

Anomia for musical instruments

Previous work has focused on naming nonunique categories of items, such as tools, animals, and vegetables (Capitani, Laiacona, Mahon, & Caramazza, 2003; Crutch & Warrington, 2003; Gainotti, 2005; Hillis & Caramazza, 1991; Martin, Wiggs, Ungerleider, & Haxby, 1996; Rumiati & Foroni, 2016). This work sometimes indicates a living/nonliving distinction such that individuals who cannot name living entities are spared at naming nonliving entities (Capitani, Laiacona, Barbarotto, & Trivelli, 1994; Capitani et al., 2003; Gainotti, 2005). A prior systematic review identified that damage to the ventral visual stream tends to be associated with naming impairments for living items, while damage more dorsally tends to be associated with naming impairments for nonliving items (Gainotti, 2005). This living/nonliving distinction has even been identified in naming deficits in healthy older adults with no history of neurological damage such that naming of nonliving items is preserved while naming of living items decreases with age (Coppens & Frisinger, 2005).

Musical instruments as a category seem to be anomalous in that they do not often follow this living/nonliving distinction: Prior work has identified individuals for whom musical instrument naming is impaired while naming for other nonliving categories is spared (Dixon, Piskopos, & Schweizer, 2000; Masullo et al., 2012; Warrington & Shallice, 1984). For example, one patient showed naming impairments for living entities (animals, fruits, vegetables) *and* musical instruments, but no impairments for other nonliving entities (tools, transportation devices, furniture; Masullo et al., 2012). This suggests that musical instruments may have some similarities to living items. One suggested explanation for this finding is that musical instruments are not recognized based on their function (as are other nonliving items such as tools) but based on their different shapes and acoustic characteristics (Barbarotto et al., 2001).

At the same time, other studies have identified cases in which musical instrument naming *does* follow the living/nonliving distinction. Several cases report patients with impaired naming of living items but intact musical instrument naming (De Renzi & Lucchelli, 1994; Hanley, Young, & Pearson, 1989; Kolinsky et al., 2002; Tzortzis et al., 2000). One such case illustrates a professional musician who showed selective sparing of musical instrument naming (Tzortzis et al., 2000). This patient was impaired at naming other categories of items, both living (animals) and nonliving (everyday objects), but had preserved naming ability for musical instruments. The authors suggest this preservation of naming for musical instruments was due to his extensive musical background and training, although the influence of musical experience on instrument naming is unclear.

Also ambiguous is the frequency and degree of impairments for musical instrument naming. While as earlier, certain individuals show remarkable sparing of musical instrument naming, other work indicates that musical instrument naming tends to be more severely impaired than other categories of items (Barbarotto et al., 2001; Basso, Capitani, & Laiacona, 1998; Dixon et al., 2000; Gainotti, 1996; Gale, Done, & Frank, 2001; Stewart, Parkin, & Hunkin, 1992; Warrington & Shallice, 1984). One suggested explanation for this is that musical instrument knowledge tends to be acquired later in life, and musical instruments are encountered less frequently than other categories of items (Barbarotto et al., 2001). Perhaps because of these seeming inconsistencies, the category of musical instruments has often been omitted from studies of object naming (Capitani et al., 1994; Coppens & Frisinger, 2005; Garrard et al., 2001; Garrard, Patterson, Watson, & Hodges, 1998; Laws, 1999).

Despite the particular idiosyncrasies of musical instruments as a category, prior work has provided hints as to the specific lesion locations associated with anomia for musical instruments. An initial large-scale study investigated the neural correlates of naming deficits for tools, animals, people, fruits/vegetables, and musical instruments. Impaired naming of musical instruments was associated with the LTP, insula, and inferior pre- and post-central gyri (Damasio et al., 2004). In a later study, we further expanded on this by focusing specifically on naming of musical instruments. Later, we describe these prior works and provide additional analyses to directly compare naming for musical instruments with musical melodies and other categories of items.

Musical instrument naming

Prior work has illustrated a double dissociation between naming unique and nonunique items for various categories of items. For example, patients with left-hemisphere anterior temporal lobe lesions due to epilepsy resection were significantly impaired at naming famous faces and animals, but not man-made objects (Drane et al., 2008). However, it is unclear whether such a distinction exists between unique and nonunique items of the same higher level category, such as musical entities. That is, we do not know whether impairments in naming melodies (unique) and instruments (nonunique) can be dissociated. Below, we outline our prior experiment on musical instrument naming. In addition to this summary, we directly compare the performance of patients who completed both the melody naming (Belfi & Tranel, 2014) and instrument naming (Belfi et al., 2016) tasks to assess this question.

Participants

Participants consisted of 298 individuals with focal brain damage, 128 of whom were reported on in a prior study of item naming (H. Damasio et al., 2004). Lesions were located in the left hemisphere (n = 172), right hemisphere (n = 93), or bilaterally (n = 33). Etiologies for the patients are as follows: cerebrovascular disease (n = 212), herpes simplex encephalitis (n = 10), head trauma with focal contusion (n = 5), benign tumor resection (n = 19), or resection for medically intractable epilepsy (n = 51).

Task and procedure

Stimuli consisted of 16 visual images of musical instruments, 10 of which were black-and-white line drawings and six black-and-white photographs (Damasio et al., 2004; Snodgrass & Vanderwart, 1980). See Figure 2(A) for stimuli examples. Musical instrument stimuli were

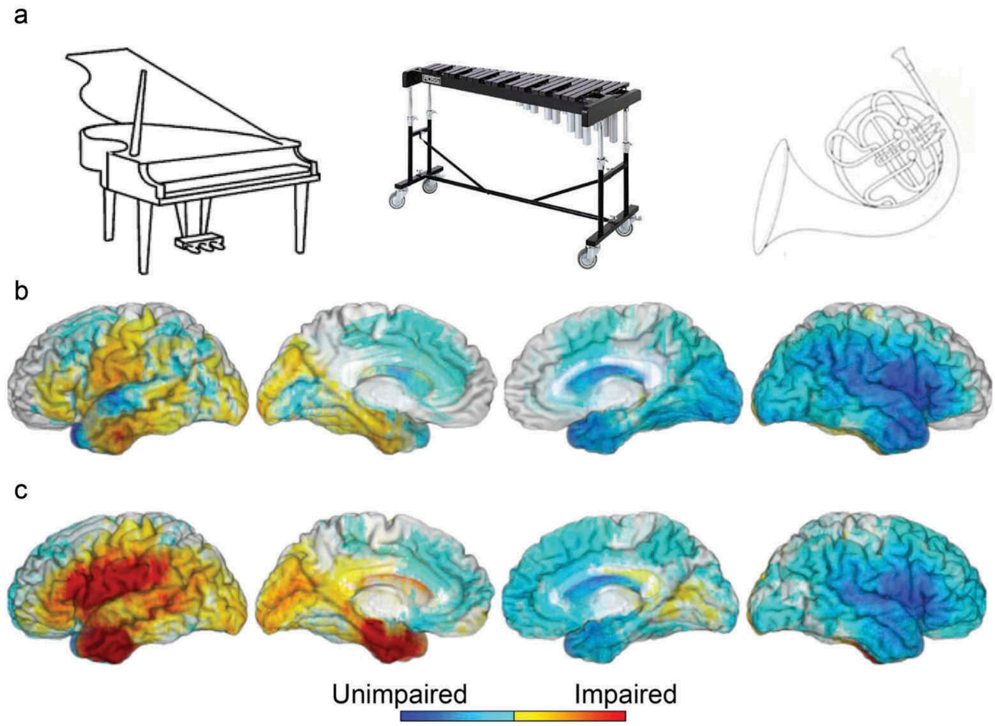

Figure 2. (A) Examples of musical instrument stimuli used in Belfi, Bruss, et al. (2016) and Damasio et al. (2004). (B) Subtraction map depicting impairments on musical instrument naming from Damasio et al. (2004). This subtraction map was created using the original MAP-3 method that was used in Damasio et al. (2004). In this method, lesion overlap maps are created for impaired and unimpaired groups, and the overlap volume for the unimpaired group is subtracted from the overlap volume for the impaired group, on a voxel-by-voxel basis. (c) Subtraction map depicting impairments on musical instrument naming from Belfi, Bruss et al. (2016). This map was created using the proportional MAP-3 (PM3) method described in the text (see the "Neuroanatomical analysis" section, page 11). For both b and c, hotter colors depict regions associated with impaired naming, while cooler colors depict regions associated with unimpaired naming.

presented in a mixed fashion with other categories of items including persons (n = 77), animals (n = 16), tools and utensils (n = 104), and fruits and vegetables (n = 67). Participants were presented stimuli visually. For each stimulus, participants were instructed to identify the item. If the participant gave a vague response, the experimenter provided a general prompt requesting a more specific name. If participants could not name the item, they were asked to provide specific information about the item.

Scoring

Scores were calculated in a similar manner to those in the melody-naming task described earlier. Items named correctly were scored as having correct naming and recognition. If an item was not named correctly, two independent raters read the participant's description of the item. If both raters were able to name the item given this description, it was scored as correct recognition. The overall naming score for each participant was calculated by adding together the number of correctly named items and dividing this by the number of correctly recognized items.

Neuroanatomical analysis

Neuroanatomical analysis was based on data obtained during the chronic epoch of recovery. MRIs were acquired in a 1.5-T GE Signa scanner (General Electric, Milwaukee, WI) with a two-dimensional spoiled gradient recalled echo sequence (1.5 mm contiguous T1 weighted coronal cuts). If participants were unable to undergo MRI scanning (n = 30), computerized axial tomography data were collected. To create voxelwise lesion proportion difference maps, we used what we have called the "proportional MAP-3" (PM3) method (Rudrauf et al., 2008). PM3 expresses, for every voxel, the proportion of individuals whose lesion includes the voxel and who have a deficit (NLD) relative to the total number of individuals with a deficit (ND), minus the proportion of individuals with a lesion at the voxel and no deficit (NLnD) relative to the total number of individuals with no deficit (NnD). The formula can be expressed with the equation Prob ($L|D$) – Prob ($L|$nD), the conditional probability of a lesion (L) given a deficit (D) minus the conditional probability of a lesion given no deficit (nD). This analysis effectively takes into account the four bins of true positives, true negatives, false positives, and false negatives.

Results

We identified 78 participants who were impaired in musical instrument naming (214 were unimpaired) and calculated the difference in lesion locations between these two groups using the PM3 method described earlier (Figure 2(C)). Replicating the previous study (Damasio et al., 2004), impairments in musical instrument naming were associated with damage to the LTP and the left pre- and post-central gyrus (see Figure 2(B,C) for a comparison of the results of both studies). However, as can be seen in Figure 2(C), the regions associated with impaired naming were more broadly distributed in the replication study.

In light of the present focus on anomia for both types of musical entities, we sought to directly compare performance on melody and instrument naming. To do this, we compared naming scores between BDC and LTP patients who completed both tasks (no NCs completed both the famous melodies and instrument naming tasks). Fourteen patients completed both melody and instrument naming tasks, nine with damage to the LTP and five with damage to other regions (BDC). A 2 × 2 mixed ANOVA (group: LTP, BDC; category: instruments, melodies) revealed a significant main effect of category [$F(1,11) = 13.60$, $p = 0.004$, $\eta_p^2 = 0.55$] and a significant main effect of group [$F(1,11) = 7.25$, $p = 0.02$, $\eta_p^2 = 0.39$] but no interaction between category and group. Investigating the main effect of category indicated that scores were higher for instruments (M = 88.65, 95% CI [75.15, 102.15]) than for melodies (M = 67.58, 95% CI [53.86, 81.31]) across both groups. Investigating the main effect of group, the LTP group scored significantly lower (M = 63.34, 95% CI [48.36, 78.32]) than the BDC group (M = 92.90, 95% CI [73.95, 111.85]) across both categories. See Figure 3(A) for a graphical depiction of this effect.

In visually inspecting individual participants' data, we noticed an interesting dissociation in one particular participant: This individual appeared to have relatively spared

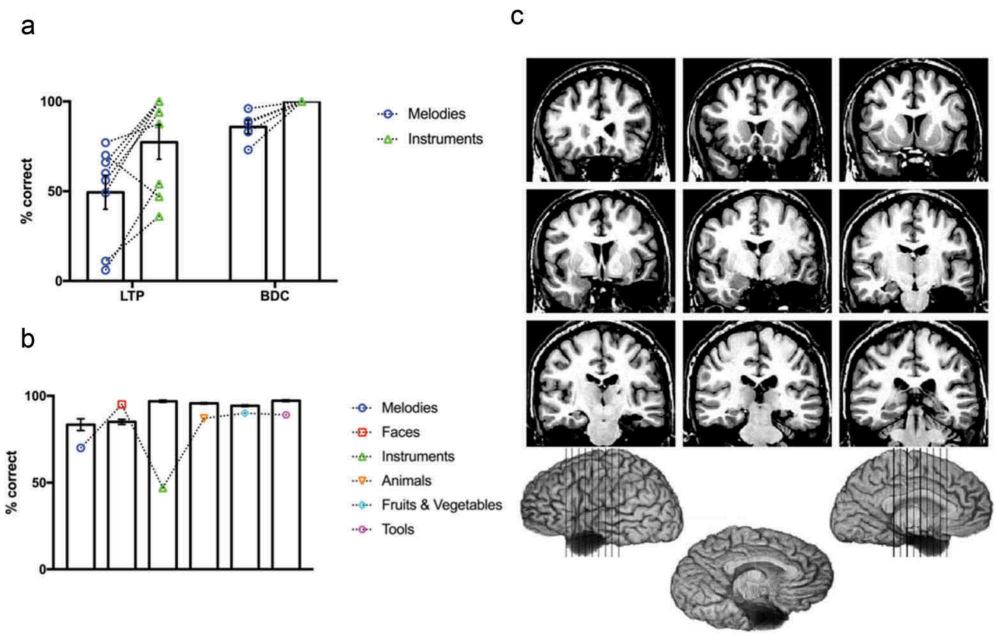

Figure 3. (A) Comparison between melody and instrument naming tasks for LTP and BDC groups. Overall, the BDC group performed significantly better than the LTP group, and both groups performed better on the instrument naming task. Error bars depict standard error of the mean. (B) Data for one patient who showed a selective impairment on musical instruments. Data are superimposed over mean data from normal comparison participants (n = 10 for melodies, n = 55 for all other categories). Error bars depict standard error of the mean for these comparison participants. (C) Lesion image for case study patient. Lesion is localized to the LTP and etiology is due to a temporal lobectomy for medically intractable epilepsy.

performance on melody naming, but substantial impairment in instrument naming. To expand on this, we investigated this individual's naming performance on all categories tested: melodies, instruments, faces, animals, fruits and vegetables, and tools. Data for this patient are superimposed on data from a group of NC participants in Figure 3(B), and an image illustrating the patient's lesion location is shown in Figure 3(C).

It is interesting to note that this is the only individual (out of the 14 patients who completed both melody and instrument naming) who was more impaired on instrument than melody naming. Across the board, performance was much higher for instrument naming (and, in fact, was perfect in the BDC group reported here). When looking at this participant's scores across all tested categories, it appears that this individual may have a selective impairment for musical entities in general. Her performance was normal on faces and slightly below normal for animals, fruits/vegetables, and tools; she is somewhat impaired on melodies and substantially impaired on instruments. This coincides with prior work illustrating that, in some cases, musical instruments are the most frequently and severely impaired category of items (Barbarotto et al., 2001; Damasio et al., 2004).

It is possible this patient has impaired music perception, although her performance on the melody naming task is not as severely impaired as many other patients. We have not tested her musical perceptual abilities, so it is unknown whether music perception influenced her naming impairments. This patient has completed the BMRQ (Mas-Herrero et al., 2013), which indicates an individual's level of reward in response to music. Her scores on this were not significantly impaired compared to a large set of patients with focal brain damage, suggesting she has normal emotional responses to music (Belfi, Evans, Heskje, Bruss, & Tranel, 2017). A final thought relates to prior work indicating that musical experience may influence instrument naming. This patient reported having 2–3 years of piano lessons during her early teenage years, and no other formal or informal musical training. This is not different from other participants included in the present study, so a lack of musical training cannot entirely explain the seemingly selective deficit in naming for musical entities.

In considering the relationship between musical training and instrument naming, we sought to investigate this within our entire group of participants. We looked at years of formal musical experience (obtained for 48 of the patients in the instrument naming study) and BMRQ scores (Mas-Herrero et al., 2013), a measure of an individual's level of emotional responsiveness to music (obtained for 45 patients). Correlations between instrument naming scores and years of musical training ($r = -0.16$, $p = 0.25$) and BMRQ scores ($r = 0.01$, $p = 0.94$) both revealed nonsignificant relationships. These results suggest that formal musical training and emotional responsiveness to music are not particularly associated with naming the musical instruments used here.

General discussion

Here, we have outlined a program of research focusing on naming impairments for musical entities. Taken together, this work suggests the LTP as a region important for naming both musical melodies and instruments. For melodies, this finding coincides with prior work indicating the LTP as a critical region for naming unique entities, including faces and landmarks. We have previously proposed a theoretical framework positing that the LTP serves as a "convergence zone" which brokers between conceptual knowledge and word retrieval for proper names (Damasio et al., 2004). This framework posits that the LTP is a critical region for naming categories of items that are numerous, visually similar, and unique. Similarly, this framework proposes that increased stimulus specificity and complexity relies on more anterior temporal lobe structures, the LTP being the most anterior zone for such processing. Our findings with musical melodies are consistent with this account; melodies appear to be similar to other categories of unique entities in that name retrieval relies on the LTP. This finding also extends our original account beyond categories presented solely in the visual modality. As has been confirmed by other work using famous voices (Abel et al., 2015; Bethmann, Scheich, & Brechmann, 2012; Papagno et al., 2017; Waldron et al., 2014), the LTP appears to be a "heteromodal" convergence region, critical for naming unique entities regardless of stimulus modality.

It is also important to consider where these results fit within the functional roles of the temporal pole more broadly. Within the semantic processing framework put forth by Binder, Desai, Graves, and Conant (2009), the LTP may fall into the broad categories of heteromodal conceptual and association areas and medial limbic areas, as the LTP is often referred to as a paralimbic region (Olson, Plotzker, & Ezzyat, 2007). Studies of patients with semantic dementia suggest that the anterior temporal lobes may function as amodal "hubs" for semantic memory, linking semantic and sensory specific (dorsal ATL – auditory information; ventral ATL – visual information) associations (Olson, McCoy, Klobusicky, & Ross, 2013; Patterson, Nestor, & Rogers, 2007). Moreover, there is evidence that the temporal pole is important for socioemotional processing, theory of mind, and socially salient narratives (Olson et al., 2013, 2007). With regards to the present work, poor performance in musical melody naming in patients with damage to the LTP may have been associated with the socioemotional roles of the TP. Music has been shown to evoke vivid autobiographical memories (Belfi et al., 2016; Janata, Tomic, & Rakowski, 2007); these salient emotional cues may have been dampened or impaired in the LTP group. Other work has indicated that the temporal poles are associated with emotional knowledge of music: Patients with damage to the anterior temporal lobes show impairments in recognizing musical emotions (Gosselin, Peretz, Hasboun, Baulac, & Samson, 2011; Gosselin et al., 2005; Omar et al., 2010). A conjunction of both semantic memory impairments and impairments in social and emotional processing may account for the current findings in patients with LTP damage.

Although our "convergence region" theoretical framework accounts nicely for findings that the LTP is critical for melody naming, the relationship between the LTP and instrument naming is less straightforward. It is interesting that musical instruments, which are nonunique entities, might also rely on this region. However, musical instruments may differ from other nonunique categories in that their visual characteristics are quite similar within sub-categories: for example, similarities between viola, violin, and bass may require fine-grained visual distinctions similar to those necessary to discriminate between persons. This visual similarity may partially account for the relationship between LTP damage and impaired instrument naming. Omar and colleagues (2010) have also identified a relationship between the anterior temporal lobe and instrument knowledge. They suggest that the involvement of the anterior temporal lobe in instrument knowledge is analogous to processing similar types of information in voices and other auditory objects.

Although associated with LTP damage, musical instruments were also associated with a broader network of left hemisphere regions, including motor and sensory regions (Belfi et al., 2016). Naming instruments may require more perceptual analysis than other categories of items. It may be that damage to those regions presumably used for playing or listening to musical instruments also influences the ability to name these entities. Musical instruments are rated more highly on manipulability than other categories of items, including tools or vehicles (Tranel, Logan, Frank, & Damasio, 1997). It might be that manipulation is a critical characteristic of musical instruments, and damage to regions of the brain used for object manipulation may impair the ability to name instruments. Similarly, the inferior frontal gyrus is important for naming objects with characteristic actions (Grabowski, Damasio, & Damasio, 1998), as well as naming actions themselves (Damasio & Tranel, 1993; Kemmerer, Rudrauf, Manzel, & Tranel, 2012; Shapiro, Pascual-Leone, Mottaghy, Gangitano, & Caramazza, 2001).

Further evidence that sensorimotor regions are critical for naming musical instruments comes from our findings that damage to the STG is associated with impaired instrument naming (Belfi et al., 2016; Damasio et al., 2004). This suggests that areas that process auditory perceptual information may be important for naming musical instruments, even when the items are presented visually. It is unclear whether impaired music perception would lead to impairments in instrument naming; future work could test this possibility. Neuroimaging work has also implicated the STG in retrieval of conceptual knowledge of musical instruments (Hoenig et al., 2011), although this was modified by musical experience. These authors suggest that increased familiarity with musical instruments leads to a richer representation that includes sensory cortices. It is possible that damage to auditory regions may more severely impair instrument naming in individuals with musical experience, although our data cannot speak to that point. However, it is difficult to predict whether musical expertise would lead to more impaired or less impaired naming ability, given that prior work has also shown evidence for sparing of musical naming in musicians (Tzortzis et al., 2000).

Despite prior work suggesting an influence of musical experience on semantic knowledge for musical entities, the present work suggests that musical experience is not strongly related to melody or instrument naming. However, it is important to note that the present data represent a small number of participants, and we are defining "musical experience" as "years of formal musical training." Possible inconsistencies as to the influence of musical training may arise from differences in (a) definitions of "musical training" and (b) definitions of "semantic memory for music." For example, preserved semantic memory for music has been indicated in patients with semantic dementia, even in patients without prior musical experience (Hailstone, Omar, & Warren, 2009). However, in this particular case, "semantic memory for music" was assessed as melody completion – this patient with semantic dementia was able to accurately sing a melody when given a name. A second case study reporting preserved semantic memory for music in semantic dementia identified a patient with substantial formal musical training who was able to perform musical pieces and even improvise (Weinstein et al., 2011). Given what we have outlined here, the precise role of musical training in semantic knowledge of music remains unclear. Future work could explore in more detail how musical background of the participants relates to naming of various musical entities.

One consistent finding across prior work and new analyses reported here is that musical entities appear to be more difficult to name than other categories of items. When compared directly, both melodies and instruments were impaired relative to other categories in our current sample, and instruments have been found to be most severely impaired in other samples (Barbarotto et al., 2001). For instruments, one reason behind this effect could be that musical instruments are less familiar and more complex. Musical instrument knowledge is also typically acquired somewhat later in life. For example, when participants were asked to rate the age of acquisition, familiarity, and visual complexity of items, musical instruments were found to have less familiarity, more complexity, and a higher age of acquisition than other categories of nonunique items including fruits/vegetables and tools/utensils (Snodgrass & Vanderwart, 1980; Tranel et al., 1997). Specifically, musical instruments had an average age of acquisition between 6 and 7 years old, whereas these other categories had an average age of acquisition around 5 years or younger (Tranel et al., 1997). Prior work in patients with temporal lobectomies indicated that age of acquisition was the strongest predictor of naming performance such that objects acquired later in life were less likely to be named (Bell, Davies, Hermann, & Walters, 2000). However, it remains unclear why melody naming may be more difficult; this could be due to differences in familiarity, frequency, or recency of experience between melodies and other categories, although this has yet to be investigated systematically.

In sum, musical concept knowledge, at both unique and nonunique levels, relies on a distributed set of regions including the left temporal lobe and more specifically the LTP. In addition to sharing similar neural correlates, both melody and instrument naming seem to share the trait of being difficult to name compared to other, similar categories. For musical instruments, naming these entities seems to rely on a more broadly distributed network beyond the LTP, including sensorimotor regions important for both perception and action. Therefore, naming for melodies and instruments is served by partially separable neural structures, although those underlying melody naming appear to be more specific than those for musical instruments.

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ORCID

Amy M. Belfi http://orcid.org/0000-0002-1469-4117

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Appendix A. Melodies included in the Famous Melodies Task (Belfi & Tranel, 2014)

Melody name
Alouette
Amazing Grace
America the Beautiful
America (My Country 'tis of Thee)
Ault Lang Syne
Bingo
Blue Danube Waltz
Do Re Mi
Edelweiss
Frere Jacques
Fur Elise
Hallelujah Chorus
Happy Birthday
Have Yourself a Merry Little Christmas
Hey Jude
I've Been Working on the Railroad
Jingle Bells
Joy to the World
Little Drummer Boy
Bach's Minuet in G
My Bonnie Lies Over the Ocean
My Favorite Things
O Christmas Tree
Ode to Joy
Old MacDonald
Over the Rainbow
Pomp and Circumstance
Pop Goes the Weasel
Puttin' on the Ritz
Row, Row, Row Your Boat
Rudolph the Red-Nosed Reindeer
Scarborough Fair
She'll Be Coming 'Round The Mountain
Silent Night
Singin' in the Rain
The Star Spangled Banner
Theme from "Star Wars"
Swing Low, Sweet Chariot
Take Me Out to the Ballgame
The Entertainer
The Farmer in the Dell
The Pink Panther
This Land is Your Land
Twinkle, Twinkle Little Star
We Wish You a Merry Christmas
When the Saints Go Marching In
White Christmas
William Tell Overture
Yankee Doodle
Yesterday
You Are My Sunshine
Zip-a-dee-doo-dah

Appendix B. Famous Faces in the Iowa Famous Faces Task (Damasio et al., 1996)

Name	
Adolf Hitler	Dustin Hoffman
Al Gore	Dwight Eisenhower
Al Pacino	Ed McMahon
Alan Alda	Eddie Murphy
Albert Einstein	Elizabeth Taylor
Andy Griffith	Elton John
Angela Lansbury	Elvis Presley
Anthony Hopkins	Fidel Castro
Arnold Schwarzenegger	Frank Sinatra
Barbara Bush	Gene Hackman
Barbara Streisand	George Burns
Barbara Walters	George Clooney
Barry Manilow	George Foreman
Bette Midler	George H.W. Bush
Bill Clinton	George W. Bush
Bill Cosby	Gerald Ford
Bill Gates	Goldie Hawn
Bob Barker	Harrison Ford
Bob Dole	Henry Kissinger
Bob Hope	Hillary Clinton
Brad Pitt	Jack Lemmon
Brooke Shields	Jack Nicholson
Bruce Springsteen	Jackie Kennedy Onassis
Burt Reynolds	James Dean
Carol Burnett	Jane Fonda
Cary Grant	Janet Reno
Charles Manson	Jay Leno
Charlie Chaplin	Jerry Seinfeld
Charlton Heston	Jesse Jackson
Cher	Jesse Ventura
Clint Eastwood	Jimmy Carter
Colin Powell	Jodie Foster
Dan Rather	John Belushi
Danny Kaye	John Denver
David Letterman	John Kennedy Jr.
Demi Moore	John F. Kennedy
Dennis Rodman	John Lennon
Denzel Washington	John Travolta
Diana Ross	John Wayne
Dick Clark	Johnny Carson
Dick Van Dyke	Judy Garland
Dolly Parton	Julia Roberts
Katherine Hepburn	Robin Williams
Kathy Lee Gifford	Ron Howard
Kenny Rogers	Ronald Reagan
Kevin Costner	Roseanne Barr
Kevin Spacey	Rosie O'Donnell
Kirk Douglas	Ross Perot
Lily Tomlin	Saddam Hussein
Liza Minelli	Sally Field
Luciano Pavarotti	Sean Connery
Lucille Ball	Sharon Stone
Lyndon Johnson	Sonny Bono
Madeline Albright	Steve Martin
Madonna	Steven Spielberg
Magic Johnson	Susan Sarandon
Marie Osmond	Sylvester Stallone
Marilyn Monroe	Ted Koppel
Marlon Brando	Tiger Woods

Martin Luther King
Marylou Retton
Meg Ryan
Mel Gibson
Meryl Streep
Michael Douglas
Michael Gorbachev
Michael J Fox
Michael Jackson
Michael Jordan
Michael Landon
Mother Theresa
Muhammad Ali
Nancy Reagan
Nelson Mandela
Newt Gingrich
OJ Simpson
Oprah Winfrey
Paul Newman
Peter Jennings
Prince Charles
Princess Diana
Queen Elizabeth
Ray Charles
Regis Philbin
Richard Nixon
Robert De Niro
Robert Redford
Tom Brokaw
Tom Cruise
Tom Hanks
Tom Selleck
Walter Cronkite
Walter Matthau
Whoopie Goldberg
Winston Churchill
Woody Allen