Title
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Verbal and Nonverbal Cues Activate Concepts Differently, at Different Times

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Abstract

Although the word "dog" and an unambiguous barking sound may point to the same concept DOG, verbal labels and nonverbal cues appear to activate conceptual information in systematically different ways (Lupyan & Thompson-Schill, 2012). Here we investigate these differences in more detail. We replicate the finding that labels activate a more prototypical representation than do sounds, and find that sounds activate exemplars consistent with the source of the sound, such that after hearing a barking sound, people are faster to recognize a dog with an open-mouth than a closed mouth, but critically, only when the sound and picture are presented simultaneously. The results are consistent with perceptual cues indexing their source while labels activating a more decontextualized representation of the target category.

Keywords: categorization, concepts, sounds, recognition, cross-modal effects, language

Introduction

Most concepts are multimodal and can be activated in a variety of ways (Hoffman & Ralph, 2013). For example, the concept DOG can be activated by seeing a wagging tail, hearing a bark, or petting its furry coat. However, the concept DOG can also be activated by hearing the word 'dog'—without seeing, hearing, or touching an actual dog. This raises the question of how concepts activated by nonverbal sensory cues compare to those activated by verbal category labels.

In the experiments reported here we compare how verbal and nonverbal cues activate representations of purportedly the same concepts. In particular, we focus on visual aspects of familiar animals and artifacts as cued by natural sounds: auditory events with a distinct source (e.g., cat meowing, chainsaw revving), and how these same concepts are activated by verbal labels (words like "cat" and "chainsaw").

The mechanisms underlying recognition of nonverbal sounds and of speech appear to be quite similar. Recognition of both words and natural sounds varies as a function of familiarity, frequency, and context (Ballas, 1993; Stuart & Jones, 1995). Perception of both natural sounds and speech is influenced by signal ambiguity and noise in similar ways (Aramaki, Marie, Kronland-Martinet, Ystad, & Besson, 2010; Gygi, Kidd, & Watson, 2004). Both labels and natural sounds elicit similar N400 event-related potentials—a coarse index of semantic processing (Cummings et al., 2006; Van Petten & Rheinfelder, 1995)—even when the identification of the natural sound is incidental to task demands (Orgs, Lange, Dombrowski, & Heil, 2008). Functional imaging during similar sequential processing tasks reveals largely overlapping cortical areas recruited in processing labels and natural sounds (Dick et al., 2007). Lastly, patterns of naming deficits in patients with aphasia suggest the labeling of everyday objects and the visual recognition of natural sound sources rely on similar cognitive resources (Goll et al., 2010; Saygin, Dick, Wilson, Dronkers, & Bates, 2003).

The perception of meaningful nonverbal sounds and of words is thus dependent on many of the same properties and activate largely the same semantic networks. Although it may seem that verbal and nonverbal cues are in important respects equivalent, there are critical differences. One such difference is that natural sounds, unlike labels, have a causal relationship with a specific physical source (Ballas, 1993). Recognizing these relationships requires learning, but the relationship between a referent and its natural sound is not arbitrary. We call these relationships "motivated": that is, they are determined by physics (e.g., thunder) or driven by biology (e.g., large dogs—and agitated dogs—have deeper barks). Auditory perceivers are able to exploit such "motivated" relationships and surmise features of a hidden physical source, such as the size of a barking dog (Taylor, Reby, & McComb, 2008), the shape of resonating plates (Kunkler-Peck & Turvey, 2000), or the hardness of percussion mallets (Freed, 1990). The perception of these auditory sources is surprisingly accurate, reflecting the lawful relationships between signals and sources in the environment (Fowler, 1990). Importantly, sounds covary lawfully *within* as well as *between* categories. For example, a barking sound informs us not only that its source is a dog, but can inform us of the approximate size of the dog.

In contrast, the relationship between labels and their referents is "unmotivated." By this term we do not simply mean that words are arbitrary, i.e., that "dog" refers to dogs by convention (cf. Hockett, 1966), but that there exists a word "dog" that denotes the entire category of dogs rather than a particular type or instance (dachshund, German shepherd, dog-on the left, dog-far away, etc.). In short, barks index specific occurrences of dogs. Even though we can interpret natural sounds at a more categorical level, the surface properties of a specific bark still indexes a *particular* dog. Verbal labels, on the other hand, abstract over these specifics. When we say "dog" we can leave all that information unspecified. On this view, labels may activate concepts in a more categorical way. This prediction has been supported by a variety of findings (Lupyan, 2012). For example, Lupyan & Thompson-Schill (2012) found that label cues resulted in faster visual processing over equally predictive nonverbal cues. This advantage persisted across a number of cue-to-image delay periods and extended to artificially created objects with novel labels and "natural" sounds, suggesting that labels do not activate conceptual representations faster but differently than nonverbal cues. In our view, labels activate representations that emphasize the differences between categories, and thus play a facilitative role in category learning (Lupyan, Rakison, & McClelland, 2007). These categorical representations enable faster recognition of category-typical objects (Lupyan & Swingley, 2012), but blur within-category differences reflected in biased exemplar memory (Lupyan, 2008).

However, what is not clear from these previous results is how "unmotivated" and "motivated" cues differ in activating different instances of purportedly the same concept. If "unmotivated" verbal cues activate more categorical representations, then what do "motivated" nonverbal cues activate? Given the inherent causal link between a natural sound and its particular physical source, we predicted that natural sound cues would lead to faster processing of images depicting the production of the auditory cue. The results ended up being more interesting.

Figure 1: Sample stimuli from Experiment 1. Does hearing the sound of a revving chainsaw activate a representation of a chainsaw in action?

Experiment 1

Hearing a sound characteristic of an animal or artifact may automatically activate particular instances of that category. Consider the kind of chainsaw one might expect upon hearing a chainsaw sound (Fig. 1). Here, we asked whether verbal and nonverbal cues lead to different expectations about subsequent visual information. In Experiment 1 we investigated if label and natural sound cues influence visual processing differently based on the action depicted in target images. In line with previous research, we predicted that when presented a label cue, participants would respond faster to category-typical images. Conversely, we predicted that when presented a natural sound cue, participants would respond faster to sound-matched images.

Methods

Participants 14 University of Wisconsin—Madison undergraduates participated for course credit.

Materials Auditory cues were spoken labels and natural sounds for 12 target categories of familiar animals and artifacts used in Lupyan & Thompson-Schill (2012).[1] Visual images were 4 color photographs for each category: 2 category-typical images and 2 sound-producing images. The images were normed, ensuring unambiguous identification. In addition, participants in a separate image rating study evaluated each picture on one of two dimensions (category typicality and sound match) using a 5-point Likert scale. For category typicality, participants viewed e.g., a dog, and were asked: "How typical is this dog of dogs in general?" For sound match ratings, participants listened to e.g., a bird chirping, saw a picture of a bird, and were asked: "How well does that sound go with this picture?" Each participant performed either category-typicality or sound-matching judgments. As expected, the canonical images were rated higher on category typicality (M=4.57) than on sound match (M=3.49), while sound-producing images were rated higher on sound match (M=4.37) than on category typicality (M=4.05). These ratings were standardized (z-score) and used as predictors in subsequent analyses.

Procedure Participants completed a category verification task in which an auditory cue—either a spoken category label (e.g., 'cat') or a natural sound (e.g., <meow>)—preceded a visual image. Participants determined if each cue-image pair matched on a category level by pressing 'Yes' or 'No' using a labeled gaming controller. For example, if they heard a chainsaw revving or the spoken word "chainsaw" and then saw a picture of a chainsaw, they would press the 'Yes' button. The picture disappeared after each response, and performance feedback was given. Cue type (label, natural sound) and picture exemplar (4 per category) varied randomly within-subjects. There were a total of 576 trials per subject (50% cue-image category match). Each trial began with a 250 msec fixation cross followed by the auditory cue. The target image appeared 1 sec after auditory cue offset. This long delay ensured that participants had ample time to process sounds and labels (see Lupyan & Thompson-Schill, 2012). The experiment took 30 minutes to complete.

Results and Discussion[2]

Overall accuracy was high (96%). Only correct response times (RTs) on matching trials were included. RTs less than 250 msec or greater than 1500 msec were excluded (<4% of correct trials). We fit the data with linear mixed regression (Bates, Maechler, & Bolker, 2012) to predict response times (RTs) from the interaction between cue type (label, natural sound) and image rating (category-typicality or sound-

[1] Target categories for Experiment 1: *bird, bee, toilet, scissors, dog, chainsaw, bowling ball, cat, car, keyboard, river, baby*.

[2] Portions of Experiment 1 were presented at the Vision Sciences Society Meeting, May 2011.

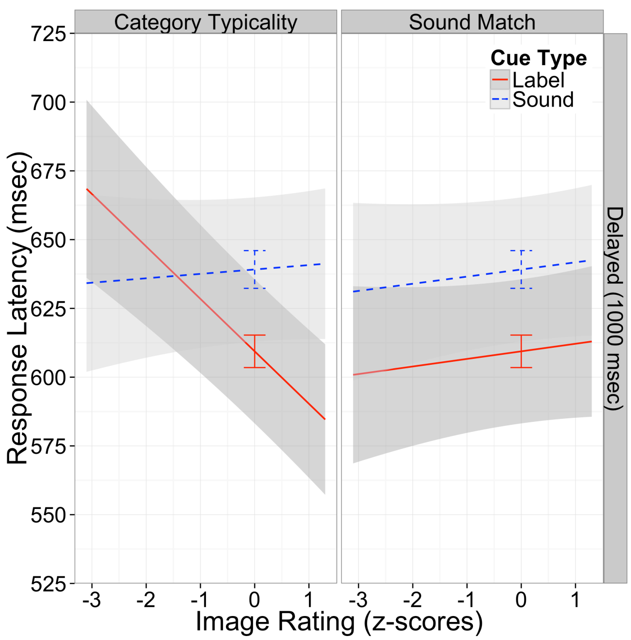

Figure 2: Significant interaction between cue type and category typicality, but not between cue type and sound match when the target picture lagged auditory cue offset by 1000 msec. Confidence bands denote ±1 standard error of linear mixed regression point estimates (Mazerolle, 2012). Error bars denote ±1 standard error of main effect of cue type.

match) with random subject and item effects (target category). As expected (Lupyan & Thompson-Schill, 2012), responses to label cues (M=609 msec) were reliably faster than responses to natural sound cues (M=639 msec), $F(1,13)=22.03$, $p<0.001$.[3] The effect of cue type was moderated by category-typicality, $F(1,13)=10.45$, $p=0.002$ (Fig. 2, left), but not by sound-match, $F(1,13)=0.001$, $p=0.98$ (Fig. 2, right).

To summarize, labels, but not natural sounds, resulted in faster processing of category-typical images, but neither cue resulted in faster processing of sound-matched images. These results replicate previous findings that labels facilitate visual processing more effectively than nonverbal cues (Lupyan & Thompson-Schill, 2012) and that labels improve recognition of category-typical exemplars (Lupyan & Swingley, 2012). The results clearly show that labels and natural sounds activate familiar concepts differently and that labels appear to activate a representation that is more categorical/typical. Unexpectedly, natural sounds did not selectively facilitate recognition of pictures that were better matches to the sound-cues. This finding is investigated further in Experiment 2.

Experiment 2

Our second experiment extends the first in two important ways. First, we compiled a more extensive set of stimuli by sampling from the 2-dimensional space of category typical and sound-matched category exemplars (Fig. 3). Second, we varied the cue-to-image delay. We did this because natural sounds, unlike labels, *index* the animals and objects that produce them. While labels often occur in the absence of the referent (we talk about things not presently in view), sounds are temporally contingent on the presence of the referent. If we hear a bark, chances are a dog is in the vicinity.

In Experiment 2, we investigated if label and natural sound cues influence recognition speed based on the fit between an auditory cue and an image, and on the delay between the cue and the image. In line with the results of Experiment 1, we predicted a label cue would improve processing of category-typical images. We also predicted that a natural sound would improve processing of a fuller set of sound-matched images—that is, where the image depicted an animal or object that was the likely source of the natural sound—and that this effect would be greater when the cue and image were temporally coupled—that is, presented simultaneously.

Methods

Participants 56 University of Wisconsin—Madison undergraduates participated for course credit.

Materials Auditory cues comprised spoken labels and natural sounds for 10 of the 12 target categories used in Experiment 1 (categories *river* and *toilet* were excluded; all sounds edited to 600 msec). Image ratings (category-typicality and sound-match) for an augmented set of images were collected via Amazon's Mechanical Turk (mTurk). mTurk workers (N=42) heard either 10 spoken labels or 10 natural sounds to be used in Experiment 2, and were

Figure 3: Sample stimuli from Experiment 2. Category-typicality was measured independently of sound-match.

[3] All p-values were generated using Markov chain Monte Carlo sampling (10,000 simulations).

presented 8 to 10 pictures for each category with the following instructions: "Please listen to the following audio clip and report how well each image fits with the audio file." Ratings were given on a 5-point Likert scale. From these data, we selected 4 images for each category corresponding to the quadrants depicted in Fig. 3. There was a positive correlation between category-typicality and sound-match (Pearson's r=0.27). These ratings were standardized (z-score) and used as predictors in subsequent analyses.

Procedure The procedure was the same as in Experiment 1. Cue type (Label, Natural Sound), picture exemplar (4 per category), and image delay (Simultaneous or Delayed 400 msec) varied randomly within-subject for a total of 427 trials per subject (75% cue-image category match[4]). Each trial began with a 250 msec fixation cross. On a random half of the trials, the auditory cue and picture were presented simultaneously; on the remaining trials the picture was presented 400 msec after the offset of the auditory cue. The experiment took 30 minutes to complete.

Results and Discussion

Overall accuracy was high (M=97%), except trials in which pictures of scissors were cued by a sound of scissors cutting paper (M=91%, SD=1.8). Participants also reported difficulties with these trials during debriefing (24 out of 56 participants; next most frequent was 5 for *bee*), and these trials were removed from subsequent analyses (<5%).[5] We excluded trials using the same exclusion criteria as in Experiment 1 (<2% of correct trials removed). Again, we fit the data with linear mixed regression to predict response times from cue type (label, natural sound), delay (simultaneous, delayed), and image rating (category typicality or sound typicality) allowing random subject and item effects (picture category).

Delay and Cue Type We first report how the effect of cue type varied by image delay. As in Experiment 1, responses to label cues were reliably faster than responses to natural sound cues, $F(1,41)=30.14$, $p<0.0001$. The effect of cue type was moderated by delay, $F(1,41)=6.86$, $p=0.009$. The RT advantage of labels over natural sounds was greater on simultaneous trials than it was on delayed trials (Fig. 4).

Category Typicality We next report how image ratings of category typicality influenced RTs differently by cue type and by image delay. Category typicality was a reliable predictor of RTs, $F(1,41)=10.30$, $p=0.001$. Importantly, this effect remained constant across both cue types and both image delays. That is, the RT advantage for more category-typical images over less category-typical images was equivalent for label and natural sound cues, on both simultaneous and delayed trials (Fig. 4, left column). Responses following natural sound cues were predicted by category-typicality of the image during simultaneous and 400 msec delayed trials, an effect not found at the longer delay in Experiment 1.

Sound Match We now report how image ratings of sound-match influenced response times differently by cue type and

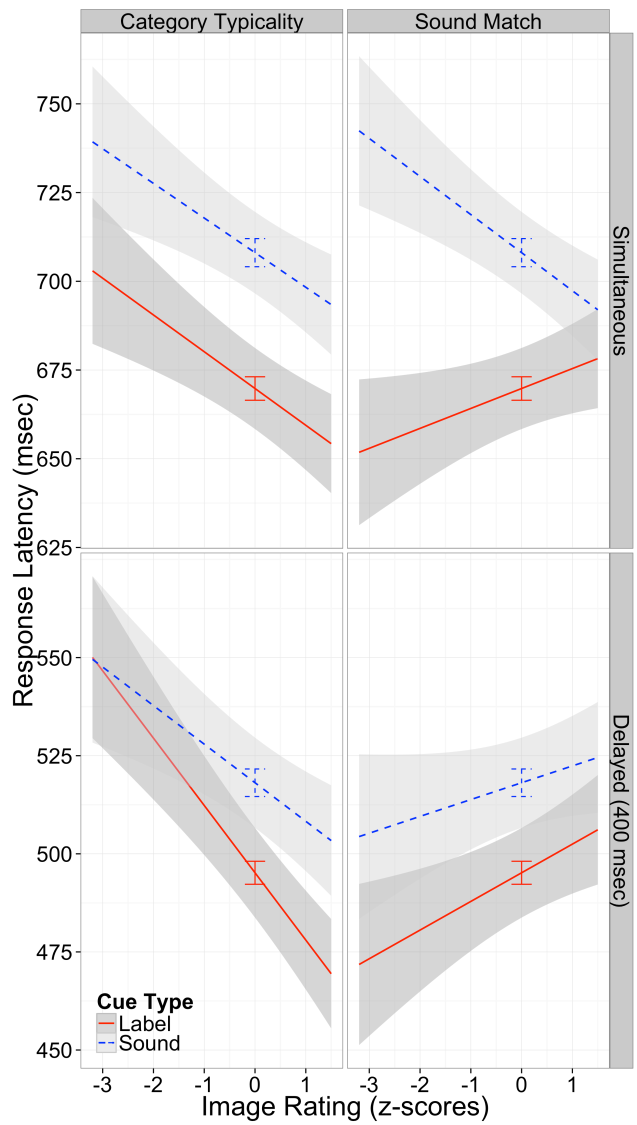

Figure 4: Label and natural sound auditory cues affect response latencies differently by cue-image delay (rows) and by image rating (columns). Confidence bands denote ±1 standard error of linear mixed regression point estimates (Mazerolle, 2012). Error bars denote ±1 standard error of main effect of cue type.

[4] This increase in response validity compared to Exp. 1 allowed us to fully counterbalance all trial variables on matching trials while keeping the length of the experiment manageable.

[5] It is possible some of the natural sound cues were simply harder for participants to identify. To ensure unambiguous recognition of the remaining natural sounds used in Experiment 2, we enlisted 29 additional participants (mTurk) to report the source of each auditory cue in a free response task. Participants correctly identified the source of the natural sound 78% of the time. There was no relationship between cue identification (percentage correct by cue category) and response latencies on the sound cued trials (Pearson r=-0.025).

by image delay. There was a reliable three-way interaction between sound-match, cue type, and image delay, $F(1,46) = 4.67$, $p=0.03$. On simultaneous presentation trials, RTs following natural sound cues decreased as the sound-match of the image increased, while RTs following label cues did not vary by sound-match, $t(46)=-3.47$, $p<0.001$, (Fig. 4, upper right). However, there was no such cue type × sound-match interaction at the 400 msec delay, $t(46)=-0.44$, $p=0.66$ (Fig. 4, lower right). That is, sound-match predicted RTs following natural sounds and not labels when the delay was simultaneous, but not with a 400 msec delay.

To summarize: the image ratings for category-typicality and sound-match correlated with response times based on the cue and the cue-image delay. First, when presented with a spoken label, RTs were predicted by category-typicality of the image, and this effect held across both cue-to-image delay periods. Second, when presented with a natural sound, the sound-match of the image correlated with the response time to that image, *but only when the cue-image pair was presented simultaneously.* That is, hearing a natural sound improved processing of a particular kind of visual image: a picture depicting an object that could have made the sound at the moment the sound was detected. These results show that the ways in which an auditory cue influences recognition of visual images depends on both the fit of the image to the auditory cue and the time course of the presentation.

General Discussion

In two experiments we demonstrated that verbal and nonverbal cues systematically differ in how they activate conceptual information, as tested by the speed of visual recognition of category exemplars. Experiment 1 revealed more category-typical exemplars were recognized faster following a spoken label cue but not a natural sound. In addition, Experiment 1 revealed that exemplars that were more sound producing were not recognized faster following either auditory cue. Importantly, responses following natural sound cues did not vary as a function of category-typicality while those following labels did, suggesting that verbal and nonverbal cues are indeed operating on different gradients. Experiment 2 added to these results with a fuller stimulus set and varying image delays. In Experiment 2, but not in Experiment 1, responses following natural sounds *did* vary with category-typicality. We believe this result to be due to the shorter delays used in Experiment 2 (see Lupyan & Thompson-Schill, 2012 for differences between labels and natural sounds at longer delays). In Experiment 2, but not in Experiment 1, responses to natural sounds varied as a function of the match between the sound and image, but the relationship was time sensitive. In particular, high sound-matched exemplars were recognized faster following a natural sound only during simultaneous presentation, and sound-match did not predict RTs following verbal cues.

Together, the two experiments reported here highlight the role of multisensory integration as a feature of what we have called "motivated" cues. We associate barking with dogs, but the bark informs us about the *particular* dog that made it—a deeper bark is likely to come from a larger dog, and hearing a bark usually temporally coincides with seeing the actual animal. Such contingencies result in audiovisual integration of simultaneous auditory and visual cues that improves detection (Laurienti, Kraft, Maldjian, Burdette, & Wallace, 2004). For example, Chen & Spence (2011) reported increased visual detection of masked pictures when presented with a congruent natural sound cue, and that the effectiveness of an auditory cue varied by cue-image delay. The present results support the time sensitivity in cross modal priming of natural sounds and pictures, and measure the strength of this relationship through a "motivated" sound-to-image match.

In contrast, word-to-referent mappings are "unmotivated" (cf. Hockett, 1966). Saying "dog" in a deeper voice does not *systematically* imply a larger or angrier dog.[6] So, even though both "dog" and a dog-bark may be unambiguously associated with dogs, the dog-bark indexes a specific dog with a specific size, location, and temperament. The word "dog", while varying systematically with aspects of the *speaker* (e.g., the lower the pitch, the more likely the speaker is to be male), does *not* systematically vary with the referent. We can talk about particular dogs, of course, but the word "dog" can and often does remain categorical, abstract.

In addition, these findings establish a heretofore underappreciated relationship between an auditory cue and a sound-matched image in similar cognitive processing tasks. Future attempts to compare semantic and conceptual processing of labels to that of natural sounds may benefit from operationalizing what we have termed the sound-match between a natural sound and its purported referent (e.g., Saygin, Dick, & Bates, 2005).

Conclusion We found verbal and nonverbal cues activate different conceptual representations evident in patterns of response latencies to recognize and verify different category exemplars. In a replication of previous findings, verbal cues facilitated recognition of category-typical images. We extended these findings to discern the specifics of conceptual representations activated via natural sound cues: Natural sounds facilitated visual processing of images that fit with the presented sound, but only if the sound and image were presented simultaneously. Critically, these effects were mediated by time, with natural sound cues improving responses to sound-matched images only during simultaneous presentation.

[6] There is intriguing evidence that sometimes, speakers do modulate pronunciations of words in a graded fashion and that listeners are sensitive to these modulations (Nuckolls, 1999; Parise & Pavani, 2011), e.g., speaking faster or slower to describe a faster or slower moving object (Shintel, Nusbaum, & Okrent, 2006). Language can be easily stripped of these features however (e.g., in written form) while still being perfectly understandable.

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