The fidelity of visual and auditory memory

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Abstract

Recent studies show that recognition memory for pictures is consistently better than recognition memory for sounds. The purpose of this experiment was to compare the fidelity of auditory and visual memory to better understand the reported differences in the two memory systems. Participants received a study phase with pictures/sounds, followed by a same-day memory test or a delayed recognition memory test. During the memory test, participants were presented with pictures/sounds that were old (presented during study), novel foils not presented during study, or exemplar foils that were variants of objects presented during study. Participants were instructed to classify each picture/sound as “old” or “new” by pressing a corresponding key. The same-day memory task revealed fundamental differences in visual and auditory memory: auditory representations are coarse and gist-based, while visual representations are highly detailed. However, auditory and visual memory performance was similar after a delay of 2 and 7 days and both types of memory representations were more coarse and gist-based. The results make an important contribution to our understanding of how the world is represented in auditory and visual memory.

Keywords Visual memory · Auditory memory · Long-term memory · Recognition memory

Introduction

Decades of research on visual recognition memory have revealed that visual memory has an impressive capacity to retain large sets of pictures (e.g., Brady, Konkle, Alvarez, & Oliva, 2008; Standing, 1973). In the typical paradigm for measuring visual recognition memory (e.g., Shepard, 1967), participants are instructed to memorize a set of pictures presented during a study phase. The study phase is followed by a memory test in which participants are presented with a studied picture and/or a foil picture and are asked to determine whether the picture is “old” (i.e., previously studied) or “new” (i.e., not presented during the study phase). Using this paradigm, Shepard (1967) presented over 600 pictures during the study phase and found that participants were 98% accurate on the memory test. In a similar study, Standing, Conezio, and Haber (1970) presented over 2,500 pictures during the study phase and found that participants were approximately 90% accurate on the memory test. Standing (1973) presented participants with 10,000 pictures

during a study phase and found that recognition memory accuracy was still as high as 83%. These findings seem impressive; however, the memory test foils in these early investigations were categorically distinct from the studied pictures. So, it is possible that participants could have used general, conceptual knowledge to perform well on the memory test without actually retaining much detailed information about the specific picture that was studied. It would be easier to determine that one had previously seen a dog rather than a bus than to determine which of two similar dogs had been seen.

More recent research has addressed this issue and has indicated that long-term visual memory representations do appear to be highly detailed. For example, Brady et al. (2008) presented 2,500 pictures of familiar objects, such as food and furniture, during a study phase. In a following test phase, observers were presented with two pictures, one that had been presented during the study phase and one foil. There were three different types of foils in the memory task: A novel object that was categorically distinct from any of the studied objects, an exemplar object from the same category as a studied object, and a state object that was one of the studied objects presented at a different angle or pose. The results indicated that recognition memory was near perfect when the foil was a novel object (92% correct), but still remarkably high when the foil was an exemplar (88% correct) and a state foil (87% correct). These results indicate that not only does visual

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recognition memory have a remarkably high capacity, but it also stores representations with high fidelity (see also Urgolites & Wood, 2013).

The high fidelity of visual recognition memory has been further demonstrated by paradigms in which multiple exemplars are presented during the study phase. For example, in one experiment the study phase contained up to 16 same-category exemplars, for example, 16 different butterflies were presented (Konkle et al., 2010a). Participants then completed a memory task during which they had to select which of two pictures was from the study phase. Recognition memory performance decreased as the number of exemplars presented during study increased, but accuracy was still 82%, with 16 different exemplars presented during study. The high fidelity of visual memory also seems to generalize to representations of complex scenes, such as beaches, forests, and cities. In one study, recognition memory performance was nearly perfect after as many as 64 same-category exemplars of scenes were presented during study (Konkle et al., 2010b).

An important issue from a cognitive science perspective is whether the quantity of items that can be remembered, the detail with which items can be remembered, and the durability of long-term memory representations are general properties extending across all the senses. Sound is also an important component to long-term memory representations, but do we have a large capacity to remember the sounds we hear?

Cohen, Horowitz, and Wolfe (2009) compared memory for pictures with memory for environmental sounds, music, and speech. Participants were presented with sound stimuli or pictures during a study phase. The study phase was followed by a memory test in which participants were presented with one “old” object and one “new” object. Recognition memory for pictures was significantly better than recognition memory for all types of sounds. Recognition memory for sounds was only similar to recognition memory for pictures when the picture stimuli were blurred to the point of being unrecognizable. In a follow-up study, Cohen et al. (2011) found that musicians were more accurate than non-musicians on the auditory memory test; however, both groups were significantly better at recognizing pictures than recognizing sounds.

Short-term and long-term memory for visual, auditory, and tactile stimuli was compared in Bigelow and Poremba (2014). Short-term memory of auditory, visual, and tactile stimuli was compared using a delayed matching to sample task with delays between a target and a probe stimulus ranging from 1 to 32 s. Participants were required to determine whether the probe stimulus and the target were the same or different. There were no differences in performance to the visual, auditory, and tactile probe stimuli at short delay intervals (less than 4 s). However, at longer delay intervals (8–32 s), accuracy on the auditory task was significantly lower than accuracy on the visual and tactile tasks. Long-term recognition memory of auditory, visual, and tactile stimuli was also compared: Participants were presented

with the stimuli during a study phase, followed by a memory test that required participants to determine whether each stimulus was “old” or “new.” The results indicated that visual and tactile recognition memory performance was better than auditory recognition memory performance.

Although auditory recognition memory is consistently worse than visual recognition memory, auditory memory appears to be more resistant to information loss or to decay at a slower rate. In one recent study, visual and auditory recognition performance was compared at a same-day memory test and at a delayed test 2 days later (Gloede, Paulauskas, & Gregg, 2017). Visual recognition memory was superior on the same-day memory test; however, visual memory performance dropped substantially over the course of a couple of days. Auditory memory, on the other hand, was similar at the same-day and delayed-memory test, indicating that auditory memory is more resistant to information loss over time (see also Bigelow & Poremba, 2014).

Although previous research has revealed that the differences between auditory and visual memory are less apparent over time (Bigelow & Poremba, 2014; Gloede, Paulauskas, & Gregg, 2017), it is not clear why there are differences between auditory and visual memory on a same-day memory test but not at a delay. In this project, we address this issue by examining the resolution of auditory and visual memory as well as the time course of information loss in the two memory systems. We measured the fidelity of auditory memory representations, which to our knowledge has not been examined empirically, and we compared the fidelity of auditory and visual memory. Similar to previous studies (e.g., Konkle et al., 2010a), the fidelity of memory representations was assessed by performance on memory test foils that were novel (requiring access to coarse, conceptual representations) and foils that were exemplars from the same category as a studied object (which require access to highly detailed information to correctly reject as a studied item). The nature of our foils allowed us to determine the extent to which memory in one modality is more global and gist-based versus specific and detailed.

We examined the time course of information loss by measuring auditory and visual recognition memory during a same-day memory test and during a delayed-memory test 2 and 7 days later. Testing memory at multiple points in time allowed us to examine how the fidelity of both types of memory representations changes over time, which in turn will provide a better understanding of the two memory systems and the general properties of long-term recognition memory.

The Experiments

Three experiments were conducted to measure the fidelity of auditory memory representations and to compare the fidelity of auditory and visual memory representations. Fidelity was

examined by comparing performance on two different types of foils during a memory test: novel objects that were categorically distinct from any of the studied objects and exemplars that were from the same category as a studied object. Experiment 1 was conducted to ensure that perceptual discriminability between old items and exemplars were similar. In Experiments 2–4, we examined the differences in auditory and visual memory representations by measuring how the fidelity of auditory and visual memory representations changes over time.

Method

Participants Seventy-four undergraduate students (15 in Experiment 1, 20 in Experiment 2, 20 in Experiment 3, and 19 in Experiment 4) participated in this experiment. Participants reported no known hearing deficits, had normal or corrected-to-normal vision, and were compensated with course credit for their time. Sample size was chosen to be similar to or larger than what was used in other studies investigating auditory and visual recognition memory (e.g., Cohen et al., 2009).

Stimuli Stimuli for the visual memory task consisted of 96 pictures of common objects. The study phase images were 64 categorically distinct objects (e.g., dog, apple). The test phase images consisted of half of the study phase images. An additional 16 novel foil objects were used that were categorically distinct images from the images used in the study phase (e.g., vacuum), and 16 exemplar foil objects were used that were different exemplars from the same category as pictures used during the study phase (e.g., a different breed of dog). The visual stimuli were approximately 8 × 8 in. on a flat-screen computer monitor with a visual angle of approximately 25°.

Stimuli for the auditory memory task consisted of 96 environmental sounds, each of which corresponded to one of the pictures (e.g., the sound of a dog barking corresponded to the visual image of a dog barking). As with the visual stimuli, the study phase sounds were 64 categorically distinct objects. The test phase sounds consisted of half of the study phase sounds, 16 novel sound objects that were categorically distinct from the sounds used in the study phase, and 16 exemplar sound objects that were different exemplars from the same category as sounds presented during the study phase. All sounds were 5,000 ms in duration, digitized to a sampling rate of 44.1 kHz, matched for RMS amplitude, filtered for noise, and off-ramped to avoid abrupt transients.

Procedure In the Perceptual Discrimination Experiment (Experiment 1), all participants completed a visual and an auditory discrimination task (the order was counterbalanced across participants) in which pairs of stimuli were sequentially presented. The listeners' task was to label each pair as "Same"

or "Different" by pressing the corresponding response key. On Different trials, there were 16 possible stimulus exemplar pairs (e.g., dog A and dog B). The 16 pairs were presented six times (three times in each order), resulting in 96 Different trials. On Same trials, each stimulus was paired with itself (e.g., dog A and dog A). The 32 possible pairs were repeated three times to equate the number of Same and Different trials. There were 192 trials in total, which were presented randomly and split into two blocks to allow for a brief rest break. There was a 500-ms inter-trial interval.

In the Memory Experiments (Experiments 2–4), all participants completed a visual memory task and an auditory memory task (the order was counterbalanced across participants). Each memory task began with a study block, which was followed by a test block (i.e., the study and test block were completed in one modality, auditory or visual, before completing the study and test block in the other modality). Figure 1 presents a schematic of example trials. During the study block, participants were presented with each image or sound for 5,000 ms and were instructed to try to commit the picture or sound to memory as best they could. All subjects received the same stimuli during the study block, trials were not repeated, and stimuli were presented in a random order. Participants were instructed to press the "Enter" key to view the next image or hear the next sound. The next stimulus was presented 500 ms after the key press. The study block took approximately 10 min to complete.

During the test block, each participant was presented, in a random order, with 64 pictures or sounds, half of which had been presented in the study block and half of which were foils (16 were exemplar foils that were from the same basic level category as the previously studied objects and 16 were novel foils that were categorically distinct from any of the studied objects). Participants were instructed to classify each picture or sound as "old" or "new" by pressing a corresponding key on the keyboard. There was a 500-ms inter-trial interval between the test block trials. The test block took approximately 10 min to complete. In Experiment 2, the study and test block were completed on the same day. In Experiment 3, the study and test block were completed on Day 1, then the memory test was repeated 2 days later (i.e., Day 3). In Experiment 4, the study and test block were completed on Day 1, then the memory test was repeated 7 days later (i.e., Day 8).

Results and discussion

Experiment 1: Perceptual discrimination Performance on the discrimination task was assessed by calculating percent correct scores on Same and Different trials and by calculating the proportion of hits (responding "Different" on Different trials) and false alarms (responding "Different" on Same trials) for each group of participants. Values for d' were calculated by subtracting the z-score transformation of the false-alarm rate

Study Block

Test Block

Fig. 1 During the study block, 64 pictures (in the visual memory task) or sounds (in the auditory memory task) were presented one at a time for 5,000 ms each. During the test block, one picture or sound was presented and participants had to indicate if the picture or sound was “old” or “new.” In the old condition, the picture/sound had been presented during the

study block. In the novel foil condition, the picture/sound was categorically distinct from any stimulus presented during the study block. In the exemplar foil condition, the picture/sound was a new exemplar from the same category as a stimulus presented during the study block

from the z-score transformation of the hit rate. Percent correct scores revealed that the visual and auditory exemplars were highly discriminable: Performance was at ceiling on the visual task (mean = 97.6% on Same trials and 98.7% on Different trials) and the auditory task (mean = 97.9% correct on Same trials and 98.8% correct on Different trials). The d' prime values on the visual and auditory discrimination task were also high (means were 4.52 and 4.46, respectively). A paired-samples t-test indicated no significant difference in d' scores, $t(14) = .68, p > .05$.

Experiment 2: Same-day memory test In Experiments 2–4, performance on the memory test was assessed by calculating percent correct scores on the memory test for the old, novel foil, and exemplar foil conditions. The percent correct scores were submitted to a within-subjects ANOVA with Memory Type (visual, auditory) and Memory Probe (old, exemplar foil, novel foil) as factors. Planned comparisons among the three conditions used the Least-Significant Difference adjustment.

As can be seen in Fig. 2, visual memory was significantly better than auditory memory (mean = 95% and 80.1%, respectively). This difference contributed to a significant effect of Memory Type, $F(1, 19) = 53.95, p < .001, \eta_p^2 = .74$. This

finding is consistent with previous research demonstrating that visual memory performance is substantially better than auditory memory performance.

Fig. 2 Mean percent correct on the visual and auditory memory test in Experiment 2 (* indicates a significant difference between the novel and exemplar foil). Error bars represent the standard error of the mean

There were differences in the fidelity of visual and auditory memory representations. This was confirmed by a main effect of Memory Probe, $F(2, 38) = 7.15, p = .002, \eta_p^2 = .27$ and by an interaction between Memory Probe and Memory Type, $F(2, 38) = 3.27, p = .049, \eta_p^2 = .15$. Planned comparisons revealed no differences among the visual memory probe types: percent correct on the visual memory test was high in all probe conditions (means: old = 94%, novel foil = 97.2%, exemplar foil = 93.8%). The high performance across all memory probe types in the visual task indicates that visual memory representations are quite precise and detailed. Performance on the auditory task, however, was not uniform across the different types of memory probes. Performance on the novel foil memory probe (mean = 86.6%) was significantly higher than on the exemplar foil probe (mean = 72.8%). Accurate performance on the exemplar foil probe would require storage of a detailed representation, so the low accuracy in this condition indicates that auditory memory representations are not as high in fidelity as visual memory representations.

Experiment 3: Delayed memory test on Day 3 As can be seen in Fig. 3, visual memory was better than auditory memory on Day 1 (mean = 94% and 78%, respectively). This contributed to a significant effect of Memory Type, $F(1, 19) = 95.7, p < .001, \eta_p^2 = .83$. However, the difference between visual and auditory memory had diminished on Day 3 (mean = 65.7% and 61.7%, respectively), and there was no significant effect of Memory Type, $F(1, 19) = 1.00, p > .05$.

There were differences in accuracy on the types of memory probes at the same-day memory test: there

was a main effect of Memory Probe, $F(2, 38) = 15.79, p < .001, \eta_p^2 = .45$ and an interaction between Memory Probe and Memory Type, $F(2, 38) = 5.77, p = .006, \eta_p^2 = .23$. As in Experiment 2, the pattern of performance indicated that visual memory representations have higher fidelity than auditory memory representations. Planned comparisons revealed no differences among the visual memory probe types (means: old = 92%, novel foil = 96.8%, exemplar foil = 93.4%), but auditory recognition accuracy was higher in the novel foil (mean = 85.6%) than in the exemplar foil condition (mean = 70.3%), $p < .05$.

On Day 3, the pattern of memory performance was quite different. There was a main effect of Memory Probe, $F(2, 38) = 24.54, p < .001, \eta_p^2 = .56$, but there was not a significant interaction between Memory Probe and Memory Type, $F < 1$. Planned comparisons revealed that the pattern of performance in the different memory probe conditions was similar in the visual and auditory memory tests. Percent correct in the old conditions (mean = 80.2% in vision and 76.1% in audition) was significantly better than performance in the novel foil condition (mean = 65.3% in vision and 63.1% in audition), and performance in the novel foil condition was significantly better than performance in the exemplar foil condition (mean = 51.6% in vision and 46% in audition), $p < .05$. The pattern of performance across all memory probe types in the visual and auditory task indicates that visual memory representations are only precise and highly detailed during a same-day memory test. Over time, visual and auditory representations are similar in detail and both types of memory representations are conceptual, gist-based.

Fig. 3 Mean percent correct on the delayed visual and auditory memory test in Experiment 3 (* indicates a significant difference between the novel and exemplar foil). Error bars represent the standard error of the mean

Experiment 4: Delayed memory test on Day 8 As can be seen in Fig. 4, visual memory was again better than auditory memory on a same-day memory test (mean = 94.9% and 79.9%, respectively). This contributed to a significant effect of Memory Type on Day 1, $F(1, 18) = 89.9$, $p < .001$, $\eta_p^2 = .83$. However, there was no significant difference between visual and auditory memory on Day 8 (mean percent correct on the memory test was 70.3% and 66.1%, respectively), $F(1, 18) = 3.38$, $p > .05$.

As in Experiments 2 and 3, the pattern of performance indicated that visual memory representations have higher fidelity than auditory memory representations. There was a main effect of Memory Probe on Day 1, $F(2, 36) = 10.1$, $p < .001$, $\eta_p^2 = .36$. The interaction between Memory Probe and Memory Type, $F(2, 36) = 2.49$, $p = .09$, $\eta_p^2 = .12$, was not significant; however, planned comparisons revealed different patterns of performance on the visual and auditory memory test: there were no differences among the memory probe types during the visual memory test (means: old = 94.4%, novel foil = 98.4%, exemplar foil = 92.1%), but auditory recognition accuracy was higher in the novel foil condition (mean = 88.2%) than in the exemplar condition (mean = 74.3%), $p < .05$.

On Day 8, the pattern of memory performance was similar to the results of the delayed memory test in Experiment 3. There was a main effect of Memory Probe, $F(2, 36) = 14.0$, $p < .001$, $\eta_p^2 = .44$, and no significant interaction between Memory Probe and Memory Type, $F < 1$. For both the visual and the auditory tasks, percent correct in the old condition (means: visual = 77.8%, auditory = 73.4%) and in the novel foil condition (means: visual = 75.3%, auditory = 67.4%) was significantly better than performance in the exemplar foil condition (means: visual = 57.9%, auditory = 57.6%), $p < .05$.

General discussion

In this study, we compared the fidelity of auditory and visual memory, as well as the time course of information loss in the two memory types. Our results replicated the finding that visual recognition memory performance is better than auditory recognition memory performance (e.g., Bigelow & Poremba, 2014; Cohen, Horowitz, & Wolfe, 2009) and that the differences in auditory and visual memory become less apparent over time (Gloede, Paulauskas, & Gregg, 2017). More critically, however, the present study demonstrates why the difference between auditory and visual memory is apparent at a same-day memory test but not at a delay: the fidelity of visual memory is better than the fidelity of auditory memory. Auditory memory representations are more coarse and gist-based, rather than richly detailed representations of an event. Visual memory representations are more fine-tuned, specific, and detailed. The second major finding of the present investigation was that memory between the two modalities is similar after a delay, and both types of memory are ultimately conceptual, gist-based representations of environmental events. Collectively, the results indicate that there are same-day differences in auditory and visual memory; however, over time the capacity and precision of visual and auditory memory is more similar than different.

The results of the present investigation demonstrate that one reason for the reported differences between visual and auditory memory (e.g., Cohen et al., 2011) is that the two memory systems differ in fidelity; however, future research is needed to examine why auditory and visual memory are qualitatively different. We speculate that there may be inherent

Fig. 4 Mean percent correct on the delayed visual and auditory memory test in Experiment 4 (* indicates a significant difference between the novel and exemplar foil). Error bars represent the standard error of the mean

properties of auditory objects that predispose listeners to process them in a coarse, conceptual manner. Typical observers are visually-oriented (e.g., Colavita, 1974; Koppen & Spence, 2007; Posner et al., 1976) and more attentive to visual objects and scenes, which could result in highly detailed memory representations. Sound, on the other hand, often serves to support vision and provide additional conceptual information to aid in an interpretation of the environment. Another potential explanation for the difference in auditory and visual memory fidelity could be that vision has extended access to information because visual features and objects in a scene are simultaneously available, whereas in audition information from the environment must unfold over time. Unlike the case in vision, in which objects can often be viewed for extended periods of time, the acoustic signal will not be present for further analysis if the initial analysis of the sound was not successful.

The results of our delayed memory test in Experiments 3 and 4 were consistent with previous research demonstrating that there is substantially more visual information loss than auditory information loss over the course of time (Gloede, Paulauskas, & Gregg, 2017), and as a result, performance on the two memory tests is similar after a delay. Our measure of the fidelity of auditory and visual memory representations indicated that auditory memory is more resistant to information loss because auditory representations are initially stored in a conceptual-based manner with relatively low fidelity. There is a well-established finding that conceptual information is more resistant to decay and/or interference than fine detail information (e.g., Lampinen, Copeland, & Neuschatz, 2001; Tuckey & Brewer, 2003; but see Andermane & Bowers, 2015). This conclusion is notably limited to long-term recognition memory. One important issue to consider in future research is whether there are differences in the fidelity of auditory and visual short-term memory. There is evidence that accurate detection of auditory and visual stimuli are similar at delays of 4 s or less (Bigelow & Poremba, 2014).

One important direction for future research will be to investigate whether the differences in capacity, durability, and resolution of auditory and visual memory are due to fundamentally different memory systems or are a product of experience. For example, it is possible that auditory memory is lower in fidelity and capacity at a same-day memory test because auditory memory is neuroanatomically inferior and/or coded with less neural precision. An alternative interpretation, however, is that typical observers have more experience attentively viewing visual objects and scenes, which, as we mentioned above, may result in more detailed and precise memory representations. There is some evidence that individuals with extensive musical experience perform better than non-musicians on an auditory memory test (Cohen et al., 2011), but one could argue that musicians still have more experience actively attending to visual stimuli.

One particularly promising avenue would be an examination of the fidelity of auditory representations in individuals who have been deprived of vision. Several studies have shown that visually impaired people have superior auditory memory compared to sighted people. For example, congenitally blind participants perform better than sighted participants on an auditory memory test for words (Raz, Striem, Pundak, Orlov, & Zohary, 2007; Roder, Rosler, & Neville, 2001) and environmental sounds (Roder & Rosler, 2003). Research utilizing special populations who have been deprived of a sensory modality would have the potential to demonstrate how experience affects memory systems (e.g., by affecting representational precision).

In summary, we demonstrated a novel distinction between auditory and visual recognition memory: Visual memory is capable of storing more items and more details of items than auditory memory; however, the nature of visual memory representations changes over time. Auditory memory begins and stays coarse, whereas visual memory representations are initially fine-grained and detailed but become coarse with the passage of time. After a delay, the quantity and fidelity of the two memory systems is remarkably similar and both types of memory representations retain conceptual, semantic information rather than much fine detail. The results of this study further our understanding of visual and auditory recognition memory and demonstrate the importance of incorporating a delayed memory test to accurately characterize the nature of long-term memory in vision and audition.

Open Practices Statement The data and materials for all experiments reported here are available by contacting the corresponding author. None of the experiments were preregistered.

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