Are Odors the Best Cues to Memory?

A Cross-Modal Comparison of Associative Memory Stimuli[a]

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ABSTRACT: To test the claim that odors are the 'best' cues to memory, several cross-modal experiments were conducted in which odors were compared with verbal, visual, tactile and musical stimuli as associated memory cues. Each experiment comprised two sessions (encoding and retrieval) separated by 48 hr. At the encoding session, a series of stimuli were incidentally associated to a set of emotionally arousing pictures. At the retrieval session, memory accuracy and emotionality were assessed. Across experiments, results revealed that odors were equivalent to other stimuli in their ability to elicit accurate recall, but that odor-evoked memories were always more emotional. Notably, emotional responses did not vary as a function of stimulus type at encoding. These data indicate that emotional saliency, rather than accuracy, is responsible for the impression that odors are superior reminders, and that retrieval processes (cf. encoding processes) are responsible for the distinctive emotionality of odor-evoked memories.

INTRODUCTION

The claim has long been made that odors are the 'best' cues to memory. The purpose of the present research was to determine whether this statement is true and/or what it really means. Several descriptive scientific reports have illustrated the emotional potency of odor-evoked memory.[3,5] However, until very recently, direct cross-modal evaluations of memories associated to odors versus the same stimulus perceived through other sensory modalities have not been carried out. To test the proposition that odors are superior reminders, a series of cross-modal experiments was conducted in which odors were compared with verbal, visual, tactile and musical stimuli associated to emotionally evocative pictures. Memories were scored for accuracy and emotionality. Accuracy was determined by subjects' correct recollection of an associated picture, and emotionality was determined both by written reports and by changes in heart rate. The theoretical significance of this work is in the discovery of what is different and what is the same about odor memory in comparison to memory mediated through other sensory systems. On a higher level this relates to understanding and testing the concept of multiple memory systems.[6]

GENERAL DESIGN AND METHODS

Each experiment comprised two sessions (encoding and retrieval) separated by 48 hr. Subjects were never informed that their memory would be tested at the second session (retrieval), but instead were told that the purpose of the experiment was to explore

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the effect of different sensory experiences on the perception of pictures. The general experimental method follows (for more detail see Ref. 2).

Subjects

Subjects in all experiments were volunteer college students who were nonsmokers in good respiratory health with a self-reported normal sense of smell. Subjects were screened so that individuals with formal training in either art or music were not recruited. Depending on the specific experiment, between 22–36 subjects participated. Subjects were tested individually and received compensation either in the form or course credit or money upon completion of the retrieval session.

Procedure

At the *encoding session,* a series of olfactory stimuli and stimuli represented in at least one other modality were incidentally associated to a set of emotionally arousing pictures, as to-be-remembered items. Subjects first assessed a stimulus and rated it for pleasantness, familiarity and intensity (7-point scales). Subjects were then instructed to associate the stimulus with a picture that was presented to them on a large slide screen approximately 2 meters in front of them. The duration of each stimulus-slide trial was either 40 or 60 sec depending on the specific experiment. After each slide-stimulus trial, subjects were engaged in an incidental learning task where they wrote out a description of the picture, listed what emotions they felt, rated their emotions for intensity, and then rated the picture on several emotion 9-point scales. In the odor-vs-music experiment, subjects also wore a heart rate (HR) monitor for the duration of the experiment, so that a physiological index of emotional arousal could be recorded.[8]

In the experiments where odors were compared with verbal, visual and tactile stimuli, the stimuli were equated along the dimension of 'source object.' For example, a subject either smelled, saw, felt, or heard the word for the stimulus: lemon. The same subject received different source objects represented through different modalities; across subjects source objects were presented in all modalities examined. When odors and musical stimuli were compared, the criterion for stimulus selection was that the odors and musical passages be highly unfamiliar and nonverbally describable (*i.e.,* equally abstract and experiential). Notably, in all experiments, sensory information from the stimuli was restricted to the particular modality under investigation for that stimulus type. For example, in the odor condition, the only information was smell; there were no visual, auditory, or tactile features available.

Stimuli from the various sensory modalities were assessed as follows. When the stimulus was an odor, subjects unscrewed the lid of an opaque jar and sniffed inside at cotton covering two porous polyethylene pellets saturated with liquid odorant. When the stimulus was visual, the object was presented on a table in front of the subjects for them to see. When the stimulus was tactile, subjects put their hand into an black cardboard box and felt the stimulus inside. When the stimulus was verbal, the experimenter spoke the name of the object three times, saying "imagine the smell of . . ." When the stimulus was music, subjects put on headphones and listened to a tape of the musical passage.

In each experiment, the stimuli were paired with the pictures in blocks by stimulus type. In the odor-vs-word experiment, there were eight stimuli of each type paired with 16 pictures. In the odor-vs-visual and -tactile experiment, there were four stimuli of each type paired with 12 pictures. In the odor-vs-music experiment, there were six stim-

uli of each type each paired with 12 pictures. Picture order was systematically rotated across subjects such that every stimulus was paired with each picture in all the formats tested. Depending upon the specific experiment, the pictures were either pretested emotionally arousing paintings from a range of artists or photographs from Peter Lang's International Affective Picture System (IAPS) collection.

At the *retrieval session,* subjects were first re-presented with a stimulus and asked to describe what picture had originally been associated to it. After attempting to recall the associated picture, subjects assessed the stimulus again and wrote down whatever emotions were evoked and rated each one for emotional intensity. Subjects then experienced the stimulus a final time and rated whatever picture memory was recalled on several 9-point emotion scales. If no memory was recalled, subjects indicated this and left the memory ratings blank. Stimuli were presented in the same block order as they had been at encoding, but were re-randomized within stimulus blocks to attenuate primacy and recency effects. No pictures were ever seen at the retrieval session. After all the stimuli were assessed, subjects were fully debriefed and compensated. Note, that the same measures of emotion were recorded at both the encoding and retrieval sessions.

OVERALL RESULTS

Analyses of variance with stimulus type as the independent variable were performed on the stimulus ratings, and the accuracy and emotionality dependent measures. In general, there were no differences in the pleasantness, familiarity or intensity ratings given to stimuli presented as odors vs any of the other sensory formats. Thus, within each experiment, the stimuli were comparable along basic perceptual dimensions.

With regard to the accuracy of memory, the results uniformly showed that odors were equivalent to the other stimuli in their ability to elicit accurate recall (TABLE 1). However, in every experiment, odors evoked memories that were more emotional than memories elicited by the other stimulus types (TABLE 2). In the odor-vs-word, -visual and -tactile experiments, subjects listed more emotions, rated these emotions as having greater emotional intensity, and reported that the particular memory elicited by the cue was more emotionally loaded when the associated memory stimulus was an odor than when it was presented in any other modality. In the odor-vs-music experiment, HR increased more in response to the odors than to music during recall. It should be noted that HR measurements did not begin until 5 sec after stimulus exposure, and HR to an odor blank was also recorded. Thus, the HR levels observed were not artifacts of sniffing per se.

As described above, the same measures of emotion were recorded at both the encoding and retrieval session. Notably, at the encoding sessions, subjects' emotional responses did not vary as a function of the type of stimulus that was paired with the pictures in any experiment (TABLE 3).

TABLE 1. The Number of Memories Accurately Recalled as a Function of Stimulus Type

Experiment	Number of Memories (%) Accurately Recalled	*F* Value
Odor-word	odor = 22% word = 23%	$F(1,30) = 0.08$
Odor-visual-tactile	odor = 27% visual = 27% tactile = 26%	$F(2,68) = 0.88$
Odor-music	odor = 24% music = 22%	$F(1,21) = 0.94$

TABLE 2. Effects on Emotion as a Function of Stimulus Type at Retrieval

Experiment				
Odor-visual-tactile	Odor	Visual	Tactile	F and p Values
Number of emotions	1.93 ± 0.08	1.82 ± 0.08	1.65 ± 0.08	$F(2,70) = 2.67$, $p < 0.07$
Emotional intensity	6.12 ± 0.36	5.77 ± 0.33	5.16 ± 0.32	$F(2,70) = 3.47$, $p < 0.05$
Memory intensity	4.10 ± 0.24	3.82 ± 0.25	3.33 ± 0.24	$F(2,68) = 3.42$, $p < 0.05$
Odor-word	Odor	Word		
Number of emotions	1.25 ± 0.07	0.96 ± 0.07		$F(1,30) = 5.02$, $p < .05$
Emotional intensity	4.44 ± 0.28	3.48 ± 0.27		$F(1,30) = 4.12$, $p < 0.05$
Inferred emotion	14% ± 0.98	5% ± 1.0		$F(1,15) = 8.46$, $p < 0.01$
Odor-music	Odor	Music		
Heart rate increase	3.68 ± 0.15	2.89 ± 0.16		$F(1,21) = 8.88$, $p < 0.01$

TABLE 3. Effects on Emotion as a Function of Stimulus Type at Encoding

Experiment				
Odor-visual-tactile	Odor	Visual	Tactile	F and p Values
Number of emotions	1.62 ± 0.09	1.68 ± 0.09	1.64 ± 0.09	$F(2,56) = 0.23$
Emotional intensity	5.21 ± 0.33	5.65 ± 0.38	5.37 ± 0.40	$F(2,56) = 0.56$
Painting intensity	5.18 ± 0.17	5.27 ± 0.16	5.15 ± 0.16	$F(2,56) = 0.17$
Odor-word	Odor	Word		
Number of emotions	2.21 ± 0.06	2.24 ± 0.05		$F(1,30) = 0.20$
Emotional intensity	8.30 ± 0.25	8.71 ± .243		$F(1,30) = 2.14$
Inferred emotion	3.17% ± 0.02	3.83% ± 0.02		$F(1,30) = 0.71$
Odor-music	Odor	Music		
Heart rate increase	4.09 ± .19	3.91 ± .67		F(1,21) = 0.05

DISCUSSION

The present data demonstrate that odor-evoked memories are distinguished from other memory experiences by their emotional potency. This finding illustrates an important difference between memory mediated by olfaction in comparison to memory mediated by other sensory modalities, and supports the proposition that olfactory memory is a separate memory system.[4] Notably, odor-associated memories were not distinguished from memories mediated through other sensory modalities by their accuracy. Together the accuracy and emotionality data inform the statement that *odors are the best cues to memory.* It is now clear that odors are not superior memory cues if superiority is based on a stimulus' ability to elicit more accurate recollections. Rather, it is the emotional saliency of memories that makes them feel more real and hence seem better. Thus, the distinctive emotional intensity of odor-evoked memories explains the impression people have that odors are the 'best' cues to memory.

Neuroanatomical evidence supports the finding that odor-evoked memories are distinguished by their emotional potency. Projections from the lateral olfactory tract

synapse directly into the amygdala-hippocampal complex, which is known to be critically involved in the processing and experience of emotional memory.[1] In contrast, information apprehended by other sensory systems is first processed through the thalamus before being routed to the limbic area, and the representative sensory cortical areas are also more anatomically distant from limbic structures than olfaction is.[10]

A further important issue to emerge from the present data was that the emotional distinctiveness of odor-evoked memories is a product of retrieval not encoding. This implies that the mechanisms of retrieval are different from the mechanisms of encoding. Recent positron emission tomography (PET) research has revealed that encoding and retrieval are subserved by different neural areas, with encoding a function primarily of the left dorsal prefrontal cortex (dPFC), and retrieval a function of the right PFC.[9] It is noteworthy that both olfaction and emotion are primarily processed in the right hemisphere.[7,11] These neurological facts further support the emotional distinctiveness of odor-evoked memories and raise important questions regarding the functional localization of different sensory systems and the neural organization of memory and emotion. Currently needed are neuroimaging experiments that specifically evaluate what neural substrates are responsible for the emotionality of odor-evoked memory, and investigate the connections between the areas involved in encoding and retrieval processes and emotion with cues represented through different sensory modalities. Additionally, experiments which further explore the dissociation between accuracy and emotion in memory, and studies exploring the effects of odors as conditioned stimuli for emotion would be highly valuable.

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