Chem. Senses 29: 217–224, 2004 DOI: 10.1093/chemse/bjh025

A Naturalistic Analysis of Autobiographical Memories Triggered by Olfactory Visual and Auditory Stimuli

Rachel S. Herz

Department of Psychology, Brown University, Providence, RI 02912, USA

Correspondence to be sent to: Rachel S. Herz, Department of Psychology, 89 Waterman Street, Brown University, Providence, RI 02912, USA. e-mail: rachel_herz@brown.edu

Abstract

The emotional and content qualities of autobiographical memories evoked by three memory cue items (campfire, fresh-cut grass, popcorn) presented in olfactory, visual and auditory form were examined using a new repeated measures paradigm. Results revealed that memories recalled by odors were significantly more emotional and evocative than those recalled by the same cue presented visually or auditorily. However, there were no differences in the content features (vividness, specificity) of memories as a function of cue-form. These findings support previous research in both laboratory and naturalistic settings and is the first comparative sensory memory study to include auditory variants of memory cues. The present data contribute to a growing body of evidence indicating that there is a privileged relationship between olfaction and emotion during recollection. Various subject factors such as age, sex and region of residence were also examined and some were found to affect the quality of memories in interaction with the specific memory cue items, indicating that prior experience is a primary influence in autobiographical memory. Questions for future investigation regarding how odor-evoked memories may be different from other memory experiences are suggested.

Key words: auditory, autobiographical memory, emotion, demographics, odor

Introduction

Descriptive autobiographical memory studies have shown that odor-evoked memories are highly emotional as measured by self-report (Laird, 1935; Herz and Cupchik, 1992). Several cross-modal laboratory experiments have further demonstrated that memories associated to odors are more emotional than memories associated to cues perceived through other modalities (vision, tactile, verbal; Herz and Cupchik, 1995; Herz, 1996, 1998b). Chu and Downes (2002) also noted that compared to verbal odor labels, odors themselves were especially potent reminders of autobiographical experiences. Notably, naturalistic experiments involving odor-evoked memory have been rare. Aggleton and Waskett (1999) found that after an average of 6 years post-initial exposure, smells associated with a Viking museum exhibit were better reminders for details of the Viking exhibit (55% correct questionnaire responses) than smells that were not associated with the Viking exhibit (45% correct). This shows that odors associated to past events are effective recall cues after considerable delays, but does not show how they may be different from other sensory stimuli. The first comparative autobiographical memory study was conducted by Rubin *et al.* (1984). In two experiments, Rubin *et al.* (1984) gave participants 15 familiar stimuli (coffee, Johnson & Johnson baby powder, cinnamon, cigarettes, rubbing alcohol, mint, mothball, Ivory soap, banana, onion, peanut butter, chocolate, band-aids, bourbon, popcorn) in either olfactory, verbal or picture form. For each item, the participant described the memory that was evoked, and rated it on the following scales: age of memory, vividness, emotionality at time of event, emotionality at time of recall, how many times it had been thought of and when it was last recalled (prior to the experiment). From these measures, the only findings that were statistically reliable were that memories evoked by odors were thought of and talked about less often than memories evoked by words and pictures. There was a trend for odor-evoked memories to be more emotional, but this effect was not significant.

There are several possibilities for why the effect of emotion was not more reliably obtained in the Rubin study. One important factor that we have recently explored is that memory selection may have been confounded with memory recollection. That is, in Rubin *et al.* (1984) each sensory cue was provided prior to the selection of the memory thus creating the possibility that the memory cue itself influenced what particular autobiographical memory individuals chose to recall and as such the particular memories selected in the

olfactory, verbal and visually cued conditions were not necessarily comparable. The differences (or the lack there of) between conditions may thus have been due to the specific memories that individuals selected, rather than the sensory influence of the cue on the recollective process. In an effort to remedy this problem we recently conducted a study involving a new two stage protocol in which individuals were given a verbal odor name (e.g. 'Coppertone suntan lotion') and were then asked to think of a memory from their past and to rate it on a variety of dimensions. They were then given either a visual (a photograph of a Coppertone bottle) or an olfactory (the odor of Coppertone) version of the cue and were asked to think about their memory again. Selecting the memories in response to verbal names prior to the introduction of the sensory cues allowed for matching of the memories selected in the two cue conditions. Any difference in the quality of the memories that were subsequently observed could therefore be attributed to the effects of the cues on memory recollection rather than memory selection. We found that memories that were re-evoked by odors were reliably perceived as more emotional and more evocative than memories re-evoked by the visual variant of the same cue. From this data we concluded that the distinguishing emotional quality of odor-evoked memories is due to processes occurring during sensory recollection and not due to memory selection (Herz and Schooler, 2002).

Notably, the comparative autobiographical memory research to date has only tested olfaction against visual and verbal stimuli. Other sensory modalities, particularly audition, need to be evaluated before claims regarding the unique emotional potency of odor-evoked memories can be made. Audition is an especially important contrast cue because music is considered to be a very potent emotional reminder. However, there are obvious comparative confounds when contrasting the smell of a rose with the music of Stravinsky. I previously attempted to resolve this problem by using complexity and identifiability as the selection criteria for various memory cues and compared unusual odors with unfamiliar music and abstract art (Herz, 1998b). This study showed that odors elicited more arousal during recollection than the other stimuli, as measured by heart-rate, but this arousal was not necessarily the same as emotion since participants in the study did not believe that their odor-evoked memories were the most emotional. In fact, they believed that their musically recalled memories were. Furthermore, auditory sensation can itself be very evocative, as the sound of screeching tires or a baby wailing is known to elicit highly emotional reactions (Royet *et al.*, 2000). It is therefore important to contrast the experience of memories triggered by odors with memories triggered by the auditory variant of the same stimuli to establish the extent to which odor-evoked memories are unique in their emotional potency.

To resolve this research gap, a naturalistic autobiographical study similar to Herz and Schooler (2002) was conducted. The present study used the new repeated measures paradigm in which an olfactory, visual or auditory cue was introduced after the memory was initially retrieved. The present study differed from Herz and Schooler (2002) by including an auditory variant, using different memory items and having a larger population base. In addition, this study followed a within-subjects design where each participant experienced all the memory cues in all sensory formats. It was hypothesized that memories re-evoked by odors would be more emotional and evocative than memories re-evoked by the same item presented visually or auditorily. In previous research, odor-evoked memories have not been found to differ in concreteness (e.g. vividness, specificity) from memories elicited by other cues and thus similar results were expected here (Rubin *et al.*, 1984; Herz, 1998a,b; Herz and Schooler, 2002).

Materials and Methods

Participants were 70 visitors (42 female, 28 male; age range 7–79, mean = 33 years) to the Smithsonian Institution in Washington, DC who were attending 'Brain: The World Inside Your Head,' a 5 year traveling science exhibition sponsored by Pfizer and the National Institutes of Heath. Volunteers participated in this study if they visited the Sensory Memory installation developed by the author for the exhibition and provided their consent or, in the case of children, assent along with parental consent, to participate in the study. None of the participants were regular smokers and all stated that they had a normal sense of smell. The procedures of the study were a more involved version of what a visitor would normally do when interacting with the Sensory Memory installation. Each participant was tested individually.

The installation involved three memory items: popcorn, fresh-cut-grass and camp-fire. As in Herz and Schooler (2002), the memory items were specifically selected to be likely to elicit past personal memories. The olfactory version of the stimuli were oil-based beads obtained from Escential Resources, Inc. (CA). They were selected after careful pretesting to obtain the most realistic and prototypical scents. The beads were presented in sealed containers with an opening at the top for sniffing; air passed over the beads to increase circulation and volatility when a button was pressed for a sniff. Visual versions of the items were prototypic representations presented as 5 s movies. They were animated scenes of: a bowl of overflowing popcorn, a lawnmower moving over a field of grass and a brightly burning campfire in a dark night. The auditory versions were prototypic 5 s sound clips. They were the sound: of popcorn popping, a lawn mower starting up and mowing and a slow–moderate crackling fire. Visual and auditory stimuli were controlled by a computer console that was part of the installation and was engineered and prepared by the exhibit producers (BBH Inc.) after extensive consultation with the experimenter.

After providing consent, the participant was told that s/he had to come up with a specific personal memory concerning a particular person, place or event (i.e. an autobiographical memory) for each item presented. If the participant could not produce an autobiographical memory for a given item none of their responses were included in the data analyzed for this study (the present 70 subjects were only those volunteers with full memory responses). Following the procedures of Herz and Schooler (2002), the experiment was conducted in two phases carried out in sequence, for each memory item. In phase 1, the participant was asked to retrieve their memory to the verbal label for an item and in phase 2 the same memory was re-recollected to the sensory forms of the item (odor, visual, auditory). Thus, in phase 1, the participant was asked to think of a personal memory that the item (e.g. 'popcorn') was associated to. Note that participants selected a memory based on the word for the item and not the sensory item itself. After providing a brief verbal description of their memory to the experimenter, who jotted it down, they were asked to rate their memory on four scales: emotionality (how emotional to you feel now as you remember the event); vividness (how vivid or clear is your memory); evocativeness (as you think about the memory, how brought back to the original time and place are you); and specificity (how specific is your memory). Each response was made using a 1–9 Likert scale (1 = not at all, 9 = extremely). Phase 2 immediately followed in which the participant was presented with the same item (e.g. popcorn) in its various sensory forms (visual, olfactory and auditory), one at a time and for each sensory form was asked to think about their memory again and to rate it on the same four scales. Approximately 1 min intervals interceded between each sensory re-cueing presentation. Thus, participants evaluated each memory four times: first recalled verbally and then re-recalled visually, auditorily and olfactorily. Ratings of memory vividness, specificity, emotionality and evocativeness were therefore repeated measures. Item order and sensory format presentation were systematically counterbalanced across participants. The verbal cue for the memory was always presented first, so that in contrasting the sensory cue-forms it could be determined that memory recollection and not memory selection was the mediating factor (Herz and Schooler, 2002). However, the order of the sensory cues was systematically counterbalanced across subjects to minimize carryover and order effects. After each sensory-cued evaluation was made, participants were asked if they were thinking of the same memory as they had initially reported to the item's verbal label. All agreed. At the end of the experimental procedures, participants were asked several demographic questions, including where they currently lived (state or country and residential community type: city, suburbia, rural). Lastly, participants were given a short version (eight items, maximum score = 32) of the 'Attention to and Importance of Odors Questionnaire' (AIO questionnaire; Wrzesniewski *et al.*, 1999); the higher the score the greater the individual's orientation is to their odor world. After these final assessments, the purpose of the experiment was fully explained and participants were thanked. All components of the procedures were optional and all volunteers completed the entire study, except for six (three male, three female) who did not complete the questionnaire.

Results

Reponses to the memory ratings were analyzed using one-way within-subjects analysis of variance (ANOVA) by cue-form (verbal, visual, auditory, olfactory). Table 1 shows the mean responses obtained from the initial verbal memory cue and each subsequent sensory re-recollection cue. Statistical analyses revealed that when an item was presented in olfactory form it was evaluated as more emotional than in verbal, visual or auditory form [$F(3,207) = 3.18$ $P < 0.05$]. Newman–Keuls post-hoc comparisons ($P < 0.05$) showed that there was no statistical difference between the alternate sensory variants. Likewise, participants stated that they felt more brought back to the original event when the cue was in olfactory form than in the other sensory formats [$F(3,207) = 3.70$, $P < 0.01$] and again post-hoc comparisons confirmed that there was no difference between verbal, visual and auditory variants. There were no differences in how vivid or specific the memories were experienced as being as a function of cue-form: $F(3,207) = 1.35$ for vividness and $F(3,207) = 0.38$ for specificity. Further, analyses examining order effects were conducted and none were found. Thus, the results were not due to stimulus presentation artifacts.

To determine whether the specific memory items influenced the memory scale responses, a one-way within-subjects ANOVA by item (campfire, fresh-cut-grass, popcorn) was conducted on the data. Table 2 shows the mean responses to each item on each of the memory scales. Results revealed a significant main effect for memory emotionality ratings [$F(2,138) = 3.00$, $P = 0.05$], showing

Table 1 Means ± SEM for each memory rating scale by cue-form

Scale	Verbal	Visual	Auditory	Odor
Emotionality	4.44 ± 0.19	4.31 ± 0.26	4.45 ± 0.31	5.27 ± 0.29
Evocativeness	5.20 ± 0.24	5.07 ± 0.32	4.96 ± 0.34	6.12 ± 0.29
Vividness	6.44 ± 0.25	5.87 ± 0.31	5.74 ± 0.30	6.17 ± 0.29
Specificity	4.62 ± 0.32	4.23 ± 0.33	4.26 ± 0.33	4.22 ± 0.34

Table 2 Means ± SEM for each memory rating scale by item

Scale	Campfire	Grass	Popcorn
Emotionality	5.34 ± 0.26	4.78 ± 0.30	4.55 ± 0.28
Evocativeness	6.24 ± 0.24	6.27 ± 0.27	5.98 ± 0.25
Vividness	6.50 ± 0.26	6.06 ± 0.29	6.71 ± 0.23
Specificity	4.21 ± 0.35	4.44 ± 0.30	3.84 ± 0.31

that the item campfire led to the most emotional memories particularly when compared to popcorn (Newman–Keuls, $P < 0.05$). No other effects were found. Additional analyses to assess whether cue-form interacted with item were conducted and none were observed.

In an effort to determine whether any demographic factors (e.g. sex, age, region and type of residence) or personality attributes (AIO questionnaire) influenced the quality of autobiographical memory as a function of cue-form and whether any particular memory items (fresh-cut-grass, popcorn, campfire) might be more meaningful for certain individuals, additional tests were conducted. Analyzing the data by these demographic factors generated subject groups with unequal numbers. Histograms of the data were plotted to assess the normality of the distributions. From visual inspection it was concluded that the sex, age group and residential community data groups were normally distributed and, as such, parametric statistics were used. However, the geographical region data were not normally distributed in all groups and non-parametric Friedman ANOVAs by ranks were therefore performed on these data.

ANOVA with subject sex as the between-group factor and cue-form (verbal, visual, odor, sound) as the repeated measure revealed no effects or interactions with subject sex on any memory rating scale. Additionally, ANOVA with subject sex as the between-group factor and memory item (campfire, fresh-cut-grass, popcorn) as the repeated measure revealed no main effects on interactions.

To analyze the effects of subject age, participants were sorted into four age categories comprised as follows: group 1 = 7–18 years (12 F, 5 M), group 2 = 19–29 years (7 F, 11 M), group 3 = 30–49 years (11 F, 9 M), group 4 = 50–79 years (12 F, 3M). Sex was not included as a factor in these analyses. ANOVA with age-group (1–4) as the between-subjects factor and cue-form (verbal, visual, odor, sound) as the repeated measure revealed no significant interactions on any scale. However, analyses of age-group with memory item did yield some interesting results. Table 3 shows the mean memory rating scale responses obtained from each age-group as a function of memory cue item. A significant age-group by item interaction was found for memory emotionality ratings [$F(6,132) = 3.10$, $P < 0.01$] and memory vividness ratings [$F(6,132) = 2.26$, $P < 0.05$]. Post-hoc comparisons indicated that for memory emotionality ratings, when memories were generated to fresh-cut-grass, participants in the oldest age group (group 4) rated their memories as more emotional than participants in any other age group and when the memory item was popcorn, participants in group 2 rated their memories as less emotional than participants in any other age group. Overall, age-group 3 was more emotional about their campfire memories than about their fresh-cut-grass memories. For memory vividness ratings, post-hoc comparisons showed that as with memory emotionality, participants in the oldest age-group (group 4) had more vivid memories to fresh-cut-grass than participants in any other age group. The youngest age-group (group 1) experienced their most vivid memories to campfire, especially compared to fresh-cut grass, and their campfire memories were also more vivid than participants in the other age groups. No other significant effects or interactions were observed.

The geographical region of the United States and the type of residential community that participants lived in were examined as a possible influence on participants responses to the various memory items, as different living spaces may afford greater or fewer experiences with campfire, fresh-cut-grass and popcorn. To ascertain the residential community data, participants were asked whether where they lived could be best described as follows: (1) city, (2) suburbia, or (3) rural/country. Participants were self-defined as: group 1, city ($n = 22$); group 2, suburbia ($n = 37$); and group 3, rural/country ($n = 11$). ANOVA with residential community as the between-subjects factor and memory item (campfire, fresh-cut-grass, popcorn) as the repeated measure revealed significant interactions for ratings of memory vividness [$F(4,134) = 2.64$, $P < 0.05$] and memory specificity [$F(4,134) = 2.69$, $P < 0.05$]. Table 4 shows the means for each memory rating scale as a function of residential community type. Post-hoc comparisons showed that for memory vividness, participants who lived in the city had the most vivid memories to popcorn and people who lived in rural/country areas

Table 3 Means ± SEM for each memory rating scale by age group and item

	Group 1 (7–18 years)			Group 2 (19–29 years)			Group 3 (30–49 years)			Group 4 (50–79 years)		
Scale	Campfire	Grass	Popcorn	Campfire	Grass	Popcorn	Campfire	Grass	Popcorn	Campfire	Grass	Popcorn
Emotionality	5.70 ± 0.40	4.26 ± 0.43	4.91 ± 0.39	4.80 ± 0.39	4.36 ± 0.42	3.50 ± 0.38	4.70 ± 0.37	4.55 ± 0.40	5.25 ± 0.36	5.43 ± 0.42	5.77 ± 0.46	4.60 ± 0.42
Evocativeness	6.32 ± 0.42	6.00 ± 0.44	6.09 ± 0.42	5.38 ± 0.41	5.36 ± 0.43	4.92 ± 0.40	5.60 ± 0.38	5.53 ± 0.41	6.53 ± 0.38	5.77 ± 0.45	6.10 ± 0.47	5.77 ± 0.44
Vividness	6.79 ± 0.42	5.41 ± 0.42	6.00 ± 0.37	5.97 ± 0.41	5.38 ± 0.40	6.30 ± 0.36	5.98 ± 0.38	6.00 ± 0.39	6.65 ± 0.34	6.20 ± 0.44	7.10 ± 0.45	6.50 ± 0.40
Specificity	4.35 ± 0.51	4.70 ± 0.44	4.73 ± 0.44	4.55 ± 0.49	5.08 ± 0.43	4.14 ± 0.43	3.88 ± 0.47	3.98 ± 0.41	3.50 ± 0.41	4.10 ± 0.54	4.33 ± 0.48	3.10 ± 0.47

Table 4 Means ± SEM for each memory rating scale by residential community and item

	City			Suburbia			Country/rural		
Scale	Campfire	Grass	Popcorn	Campfire	Grass	Popcorn	Campfire	Grass	Popcorn
Emotionality	5.25 ± 0.36	4.39 ± 0.39	4.91 ± 0.36	5.08 ± 0.27	4.66 ± 0.30	4.32 ± 0.27	5.05 ± 0.51	5.41 ± 0.55	4.77 ± 0.50
Evocativeness	5.80 ± 0.37	5.91± 0.39	6.36 ± 0.37	5.73 ± 0.29	5.57 ± 0.30	5.70 ± 0.28	5.77 ± 0.53	5.86 ± 0.55	5.27 ± 0.52
Vividness	6.50 ± 0.36	6.20 ± 0.38	7.25 ± 0.32	6.26 ± 0.28	5.57 ± 0.29	6.05 ± 0.24	5.54 ± 0.52	6.63 ± 0.53	5.68 ± 0.45
Specificity	3.93 ± 0.44	4.57 ± 0.39	3.18 ± 0.38	4.20 ± 0.34	4.77 ± 0.30	3.94 ± 0.29	4.82 ± 0.63	3.54 ± 0.55	5.04 ± 0.54

had most vivid memories to fresh-cut-grass. For memory specificity, post-hoc comparisons showed that ratings was lowest for city dwellers to popcorn memories and lowest for country dwellers to fresh-cut-grass memories. For people who lived in suburbia, there were no differences between any of the items for memory vividness or specificity.

To examine how geographical region would influence memories associated to the various items, participants were asked to name the state or country that they were from. Six participants came from countries outside the US and they were not included in these analyses. US residents were regionally grouped as follows: region 1, Northeast — any New England state, New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia and West Virginia (n = 41); region 2, South — North and South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Tennessee and Texas (n = 11); region 3, Central — Ohio, Indiana, Illinois, Wisconsin, Arkansas, Missouri, Iowa, Montana, Michigan, Kentucky, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Minnesota, Wyoming, Colorado, New Mexico, Arizona, Utah, Idaho and Nevada (n = 5); region 4, West Coast — Washington, Oregon, California, Alaska and Hawaii (n = 7). Because these group data were not all normally distributed, non-parametric Friedman ANOVAs by rank were conducted on the memory responses for each region.

There were no effects observed based on geographical region for memory emotionality, vividness or specificity. However, how brought back subject's memories were to the three cue items was affected by the region in the US they lived in. Participants who lived in the Northeast (region 1) found popcorn to be the least evocative memory item [F_r = 11.04, $P < 0.01$]. The sum of the ranks were as follows: campfire = 92.50, fresh-cut-grass = 87.00 and popcorn = 66.50; there were no differences between campfire and fresh-cut-grass.

Finally, the personality factor of odor orientation was examined by analyzing the AIO questionnaire data. Total scores on the questionnaire were computed for each subject; the higher the score the greater the importance of odor in the subject's life. Correlations with the memory ratings given for each cue-form were conducted and no statistically significant effects were obtained. In fact, no r was >0.20, and no r for a memory cue in odor-form was >0.15. Thus there was no relationship between how important odors were to an individual and whether the memory cue was in olfactory form. This finding further attests to the fact that participants were unaware of the purposes or hypotheses of this research. A t-test with subject sex was also conducted and revealed that women were more oriented towards odors than men. Mean questionnaire scores were 26.59 ± 0.63 and 23.20 ± 0.95, for women and men, respectively [$t(62) = 3.09$, $P < 0.01$]. A one-way ANOVA with age-category as the grouping variable did not reveal any differences in odor orientation as a function of age [$F(3,60) = 0.10$].

Discussion

Herz and Schooler (2002) showed that autobiographical memories elicited by odors were more emotional and evocative than memories cued by the visual and verbal variant of the same item. This finding was replicated and extended here including auditory variants for the first time. When a memory item was presented in olfactory form it elicited a more emotional and evocative recollection than when the same item was presented in visual, verbal or auditory format. Moreover, by having participants select their memory prior to encountering the olfactory cue, it is clear that the unique qualities associated with odor cued memories were not due to what memories were selected, but rather with processes involved in recollection. The finding that odors elicited more emotional and evocative memories than visual as well as auditory cues is important because it clearly demonstrates that the distinguishing emotional characteristics of odor-evoked memory extends beyond the visual/verbal modality. The fact that auditory stimuli were less emotional than odors and no different from visual stimuli is further noteworthy because the subjective perception of auditory stimuli is that they can be very emotional and a serious rival to odors (Royet *et al.*, 2000).

In a previous laboratory study, odor-evoked memories were compared with tactile and visual variants of the memory items (Herz, 1998a). In the tactile condition, participants placed their hand inside a box with a sleeve and felt the object placed therein. The object was covered in a thin film of plastic so that the participant's hand would not retain the scent after touching it. Results showed that odor-evoked memories were the most emotional and tactile items were no different from visual items as memory cues. It is

therefore likely that an autobiographical study using tactile stimuli would yield similar results.

The present and previous data illustrating the emotional potency of odor-evoked memory is consistent with neuroanatomy. The olfactory area is unique among the senses in synapsing directly with the amygdala–hippocampal complex, the neural substrate of emotional memory (Aggleton and Mishkin, 1986; Cahill *et al.*, 1995). The amygdala is also essential for human olfactory memory (Buchanan *et al.*, 2003). Moreover, we have recently demonstrated using fMRI that there is a direct neurobiological correlation between the subjective experience of emotion during autobiographical recall to an odor cue and heightened activity in the amygdala. This is not the case when the same memory is triggered by the visual version of that same item or when a memory is triggered by a similar odor that was not related to a significant experience (Herz *et al.*, 2003). This finding is important in light of the fact that olfactory stimuli themselves have also been shown to be able to elicit amygdala activation in the absence of memory recollection (Anderson *et al.*, 2003). In our fMRI study personally significant odors elicited greater amygdala activation than similar but non-personally meaningful odors. Thus, despite the fact that odors can be inherently emotional stimuli, in cross-modal comparative autobiographical analyses only odors directly linked with a personal emotional event produced distinctively higher levels of amygdala activation. It is impossible to determine whether it is the odor or the memory that elicited this emotion, because an odor that is linked to an emotional association is just that — the scent and the emotional association are inextricably intertwined. However, one can say that because the memories in the present study were initially selected with a non-sensory (verbal) cue, it is the process of recollection with an odor that leads to greater emotionality and evocativeness experienced at recall.

In the present study, analyses on the memory ratings were also conducted including demographic factors such as subject sex, age and residential locale. No interactions with cue-form on any of these variables were found. The lack of any interactions with cue-form attests to the fundamental power of odors to elicit emotional memories and shows that this effect is not based on culture, expectation or experience. However, demographic factors were shown to affect the memory ratings in interaction with the specific memory items. Subject age was seen to influence responses to the various memory items for both emotionality and vividness ratings. In particular, the oldest age group (50–70 years) had the most emotional and vivid memories elicited by fresh-cut-grass and the youngest age group (7–18 years) had the most vivid memories elicited by campfire. It seems most likely that these item differences are due to the different experiential history that these age groups had with fresh-cut-grass and campfire, respectively. Older participants presumably had more prominent memories associated to cutting grass than younger age groups (i) because they have had more experiences and (ii) because 40–60 years ago the likelihood of an American family having a yard was greater and the family ritual of cutting grass was more prevalent. While the youngest age group's salient experiences associated to campfire is likely due to recent experiences at summer camp.

Town and country were also found to influence how subjects responded to the three memory items. Participants who were city dwellers had the most vivid memories to popcorn and participants who lived in rural/country areas had most vivid memories to fresh-cut-grass. However, city dwellers' memories to popcorn were their least specific as were country dwellers' memories for fresh-cut-grass. The differential salience of these two memory items for city and country dwellers is presumably due to the experience levels these different residential communities have with these items. City dwellers are more likely to go to movie theatres than country dwellers and hence would be more likely to form associations with popcorn. While country dwellers have more experience with fresh-cut-grass than those who live in concrete jungles. The specificity data which appears to be in contrast with the vividness results, most likely indicates that city and country residents had many similar memories associated to popcorn and fresh-cut-grass, respectively, and thus that the specific details of any one memory were less tangible. The geographical regional data also demonstrated effects that appear to be consistent with the specificity data. Participants from the Northeast found popcorn to be the least evocative memory cue. This regional group had proportionally the largest number of city and suburban dwellers (region 1 = 90%, region 2= 73%, region 3 = 80%, region 4 = 71%) and urbanites most likely have more experiences at movie theatres than people who live in rural areas. Therefore, as with the low specificity ratings, low evocative ratings are believed to be due to having many general memories associated to popcorn, rather than a single memorable one. The present residential locale data are consistent with previous work on regional differences in odor preferences (see Pangborn *et al.*, 1988; Ayabe-Kanamura *et al.*, 1998).

In terms of individual difference personality factors, analysis of the AIO questionnaire data revealed that women were more oriented towards odor than men, even though they did not differ from men in their memory ratings elicited by odors versus the other cue-forms. Previous findings have also shown that subject sex is a factor in olfactory perception and cognition and that when differences exist they favor females (Brand and Millot, 2001). One of the explanations given for these differences is the disparity of experiences with various odors in daily life (Cain, 1982). To the extent that the AIO questionnaire tapped into olfactory experiences in daily life, it appears that women tend to be more interested and attentive to odors than men. Thus, experiential differences could be due to a greater orientation to odors among women and not merely greater exposure. In general, the

demographic findings underscore the importance of experience on autobiographical memory.

It should be noted that demographic factors were not controlled for in this study and thus the present findings should be evaluated tentatively. For example, it is often reported than men and women perform differently in long-term episodic and autobiographical memory tasks (Ross and Holmberg, 1990; Herlitz *et al.*, 1997); however, no sex differences were found here. Although the lack of sex differences substantiates recent work by Rubin *et al.* (1999), showing that sex differences in autobiographical memory are negligible, it does not rule the possibility that in a controlled analysis of demographic factors, sex differences in cross-modal autobiographical memory research would be found. Further research involving a controlled analysis of demographic factors is therefore necessary to fully elucidate the mediating conditions in cross-modal autobiographical memory.

Previous and current findings together strongly argue that there is a privileged and possibly unique connection between emotion and olfaction during recollection. However, this does not entirely resolve the question of how odor-evoked memories may be different from other memory experiences. Odor-evoked memory research in my laboratory was instigated by an interest in investigating the frequent claim that 'odors are the best cues to memory'. From over a decade of research involving laboratory, naturalistic and neuroimaging methods, we have shown that odors elicit very emotional memories. It has been suggested that the unusual emotional intensity and evocativeness of odor-evoked memories therefore adds a life-like quality to recollection that can be misconstrued as veridicality (Herz, 1998a). However, odors do not elicit memories that are more accurate than other cues. Memory certainty based on high emotional involvement but uncorrelated with accuracy is similar to what is observed under other highly emotional memory situations, such as eye witness testimony (Wells and Loftus, 2003).

It currently remains unknown whether the reason why odors are thought to be 'the best cues to memory' is not only because of their emotionality, but more importantly because they may be able bring to consciousness memories that would otherwise be forever forgotten. That is, Proust's childhood memories of his aunt's house in Combrey that he describes in *Swann's Way* may never have come back to him had he not smelled the linden tea and madeleine biscuit concoction. One reason why odors may be able to evoke memories that might otherwise not be remembered is due to their low rate of exposure interference. An odor has a far greater chance of never being encountered again than a visual or auditory stimulus does. The specificity of odors as encoding cues may therefore enable them to elicit memories where no other cue can suffice. In addition, proactive interference is very strong in odor memory while retroactive interference is weak (Lawless and Engen, 1977). That is, the first association made to an odor is very hard to unlearn and subsequent associations to the same scent are difficult to form. Both the low probability of subsequent exposure and strong proactive interference may enable odors to reawaken memories for events in our past that we might never otherwise retrieve. Comparative tests examining interference and exposure rates for various memory cues in relation to the potential for these cues to evoke memories that could not otherwise be recollected is needed. A growing body of evidence is establishing that odor-evoked memories are distinguished from other memory experiences by their emotional potency. Other ways in which odors might be special and/or superior memory cues now need to be explored.

Acknowledgements

This study was conducted with the expert assistance of Sophia Beland. Many thanks to Peter Radetsky for orchestrating the Sensory Memory installation and to Lorane Wasserman of Escential Resources Inc. (CA) for developing and providing the odor stimuli. Much appreciation is extended to the visitors to the Smithsonian Institution who participated in this study and to the Smithsonian and BBH staff who helped facilitate the installation. This research was funded in part by a Faculty Development Award to R.S.H. from Brown University.

References

Aggleton, J.P. and **Mishkin, M.** (1986) *The amygdala: sensory gateway to the emotions*. In Plutchik, R. and Kellerman, H. (eds), Emotion: Theory, Research and Experience. Vol. 3: Biological Foundations of Emotion. Academic Press, Orlando, FL.

Aggleton, J.P. and **Waskett, L.** (1999) *The ability of odours to serve as state-dependent cues for real-world memories: can Viking smells aid the recall of Viking experiences?* Br. J. Psychol., 90, 1–7.

Anderson, A.K., Christoff, K., Stappen, I., Panitz, D., Ghahremani, D.G., Glover, G., Gabrieli, J.D. and **Sobel, N.** (2003) *Dissociated neural representations of intensity and valence in human olfaction*. Nat. Neurosci., 6, 196–202.

Ayabe-Kanamura, S., Schicker, I., Laska, M., Hudson, R., Distel, H., Kobayakawa, T. and **Saito, S.** (1998) *Differences in perception of everyday odors: a Japanese-German cross-cultural study*. Chem. Senses, 23, 31–38.

Brand, G. and **Millot, J.-L.** (2001) *Sex differences in human olfaction: between performance and enigma*. Q. J. Exp. Psychol., 54B, 259–270.

Buchanan, T.W., Tranel, D. and **Adophs, R.** (2003) *A specific role for the human amygdala in olfactory memory*. Learn. Mem., 10, 319–325.

Cain, W.S. (1982) *Odor identification by males and females: predictions versus performance*. Chem. Senses, 7, 129–142.

Cahill, L., Babinsky R., Markowitsch, H.J. and **McGaugh, J.L.** (1995) *Amygdala and emotional memory*. Nature, 377, 295–296.

Chu, S. and **Downes, J.J.** (2002) *Proust nose best: odors are better cues of autobiographical memory*. Mem. Cognit., 30, 511–518.

Herlitz, A., Nilsson, L.G. and **Backman, L.** (1997) *Gender differences in episodic memory*. Cognition, 52, 55–79.

Herz, R.S. (1996) *A comparison of olfactory, visual and tactile cues for emotional and non-emotional associated memories*. Chem. Senses, 21, 614–615.

Herz, R.S. (1998a) *Are odors the best cues to memory? A cross-modal comparison of associative memory stimuli*. Ann. N. Y. Acad. Sci., 855, 670–674.

Herz, R.S. (1998b) *An examination of objective and subjective measures of experience associated to odors, music and paintings*. Empir. Stud. Arts, 16, 137–152.

Herz, R.S. and **Cupchik, G.C.** (1992) *An experimental characterization of odor evoked memories in humans*. Chem. Senses, 17, 519–528.

Herz, R.S. and **Cupchik, G.C.** (1995) *The emotional distinctiveness of odor-evoked memories*. Chem. Senses, 20, 517–528.

Herz, R.S. and **Schooler, J.W.** (2002) *A naturalistic study of autobiographical memories evoked by olfactory and visual cues: testing the Proustian hypothesis*. Am. J. Psychol., 115, 21–32.

Herz, R.S., Eliassen, J.C., Beland, S. and **Souza, T.** (2003) *Neuroimaging evidence for the emotional potency of odor-evoked memory*. Neuropsychologia, 42, 371–378.

Laird, D.A. (1935) *What can you do with your nose?* Scient. Monthly, 41, 126–130.

Lawless, H. and **Engen, T.** (1977) *Associations to odors: interference, mnemonics and verbal labeling*. J. Exp. Psychol. Hum. Learn. Mem., 3 52–59.

Pangborn, R.-M., Guinard, J.-X. and **Davis, R.G.** (1988) *Regional aroma preferences*. Food Qual. Pref., 1, 11–19.

Ross, M. and **Holmberg, D.** (1990) *Remembering the past: gender differences in the recall of events in the history of a close relationship*. In Zanna, M.P. and Olson, J.M. (eds), The Ontario Symposium: Vol. 6, Self-inference Processes. Erlbaum, Hillsdale, NJ, pp. 135–152.

Royet, J.P., Zald, D., Versace, R., Costes, N., Lavenne, F., Koenig, O. and **Gervais, R.** (2000) *Emotional responses to pleasant and unpleasant olfactory, visual, and auditory stimuli: a positron emission tomography study*. J. Neurosci., 20, 7752–7759.

Rubin, D.C., Groth, E. and **Goldsmith, D.J.** (1984) *Olfactory cuing of autobiographical memory*. Am. J. Psychol., 97, 493–507.

Rubin, D.C., Schulkind, M.D. and **Rahhal, T.A.** (1999) *A study of gender differences in autobiographical memory: broken down by age and sex*. J. Adult Dev., 6, 61–71.

Wells, G.L. and **Loftus, E.F.** (2003) *Eyewitness memory for people and events*. In Goldstein, A.M. (ed.) Handbook of Psychology: Forensic Psychology. John Wiley, New York, Vol. 11., pp. 149–160.

Wrzesniewski, A., McCauley, C. and Rozin, P. (1999) *Odor and affect: individual differences in the impact of odor on liking for places, things and people*. Chem. Senses, 24, 713–721.

Accepted January 26, 2004