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The Influence of Odor and Emotion on Memory

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ABSTRACT

Past research has suggested that there is a special neural connectivity between the olfactory cortex, amygdala and hippocampus that is related to the connection between smell, emotion and memory (Herz & Cupchik, 1995). This experiment looked at the differences in memory recognition and memory recall between conditions with a pleasant or unpleasant scent and a positive or negative emotional state. Intrusion errors were used to estimate connections between odor, emotion, and memory. Results found that intrusion errors were equally likely to occur between all sources, suggesting source confusion. However, the specific source of the confusion did not affect memory. These results suggest that the relationship between odor, emotion and memory may not be as direct as previously thought or that these relationships are limited to autobiographical memory.

Olfaction's general relationship to emotion and memory has been previously well documented (Chu & Downes, 2000; Herz et al., 2004; Maratos et al., 2001; Martin et al., 2007; Yeshurun & Sobel, 2010). Much of this research looks at the connection between emotion and memory, olfaction and emotion or olfaction and memory. A portion of the research looks at the relationship between all three. Past research has suggested that there is a special neural connectivity between the olfactory cortex, amygdala and hippocampus that is related to the connection between smell, emotion and memory (Herz & Cupchik, 1995). It has been suggested that these relationships occur partly due to the interactions of the sensory and limbic areas of the brain (Martin et al., 2007).

The amygdala has been discovered to interact with the hippocampus. The amygdala has been discovered to be of utmost importance in the expression and understanding of human emotion (Dolan et al., 2002; Herz et al., 2004). Buchanan (2007) suggested that emotion and memory are connected on a neuroanatomical level. Enhanced memory for emotional experiences is attributed to this connection (Buchanan, 2007). This study found that recognition for words with negative emotional content enhanced the activity of the left amygdala and the hippocampus. Negative emotional content was found to cause more activation of the amygdala (Buchanan, 2007; Zald & Pardo, 1997).

While the location of these structures in the brain does not fully imply that the function must be related, there is much evidence that suggests this to be true (Chu & Downes, 2000). Research has found that emotion plays a prominent role in general memory retrieval, specifically long term memory retrieval (Buchanan, 2007). The research found that during cases of autobiographical retrieval there was a special connectivity between the amygdala and hippocampus. Additional research found that areas of the brain that are activated when an

emotional event is encoded also appear to be active during retrieval of that emotional memory (Maratos et al., 2001). Another way that emotion and memory appear to be connected can be seen by the effect one's emotional mood can have on the emotionality of the memory recalled. For example, if one begins in a positive mood state, research suggests that one will be more likely to recall memories of a more positive valence (Leppänen & Hietanen, 2003). Autobiographical memories of emotional events in general also are often recalled with more accuracy and vividness than those events with no emotional content (Buchanan, 2007).

Other studies have found that the olfactory bulbs protrude straight into the amygdala. There is, however, no direct neurobiological evidence that supports a special connection between olfaction and emotion. Even so, functional magnetic resonance imaging has shown that perception of odors does activate the amygdala along with several other closely related areas such as the piriform, thalamus and the hippocampus (Herz et al., 2004; Poellinger et al., 2001). Research has found that the nature of the odor, whether it is pleasant versus unpleasant, affects amygdala activation. Aversive odors were shown to be more likely to activate the amygdala than non-aversive odors (Zald & Pardo, 1997).

According to Zald & Pardo (1997), the direct connection between the olfactory bulbs and the amygdala offers support to the theory that the amygdala plays a critical role in the emotional processing of olfactory stimuli. That role entails having the ability to alter someone's emotional state (Lehrner et al., 2005; Yeshurun & Sobel, 2010). Lehrner et al. (2005) found that exposing patients to the odors of lavender or orange while they were waiting for various dental procedures lowered their anxiety and increased their mood. These results were found using pleasant scents. If the study had used unpleasant scents, different results may have been gathered. One's emotions are very closely linked with the hedonic rating of how pleasant or unpleasant a scent is

considered to be (Yeshurun & Sobel, 2010).

Like the amygdala, studies have also found the hippocampus to be activated when odors are present (Gottfried et al., 2004). This could be due to the close anatomical positioning of the hippocampus and the olfactory regions of the brain (Gourevitch et al., 2010). Diffusion tensor imaging of the limbic system has noted the circuit connections found between the hippocampus and other structures such as the olfactory bulb and amygdala (Concha et al., 2005).

Research has found that the sense of smell is able to act as a potential effective memory cue (Schab, 1990). Further studies have shown that there is support for the idea that olfactory stimuli are the most effective cues for autobiographical memories when compared with other sensory cues such as visual, auditory or tactile stimuli (Chu & Downes, 2000). This could be because odors are able to increase memory's evocative strength. Odors can persist despite the degradation of all other types of memory stimuli. Thus, olfactory components of autobiographical memories are longer lasting than other parts of the same experience, such as visual or auditory components (Chu & Downes, 2000). Because of the enduring strength of the olfactory components, they tend to be more effective as retrieval cues (Chu & Downes, 2000). The influence an odor has on memory often depends on its distinctiveness. Herz (1997b) found that more distinct odors contributed to enhanced memory retrieval.

This area of research originally was based on the idea of the Proust phenomenon which says that odors have the ability to cue vivid autobiographical memories (Chu & Downes, 2000). Willander & Larsson (2006) found that autobiographical memories triggered by olfactory stimuli tend to be older than memories evoked by other sensory cues. This study suggests that most olfactory memories are from the first ten years of one's life. During the first ten years of life is also when people encounter the majority of odors they will ever encounter. It is during this time

that the brain makes links between scents and people, places, events, etc. It was suggested that this could be one of the reasons why some people prefer certain scents while others do not. If a scent reminds them of a positive experience, they may think the scent to be more pleasant (Willander & Larsson, 2006). Another study found that along with being able to recall the most autobiographical memories, the most vivid memories, and the most important memories from the time in their life when they were ten to thirty years old, older adults were also able to accurately remember factual, semantic and general knowledge from that time of their life as well (Rubin & Rahhal, 1998).

Schab's (1990) study found odor to be an effective memory cue only if the odor was present at both encoding and retrieval. Gottfried et al. (2004) found that the presence of odors during memory encoding, increased memory retrieval, even if the odor was not present during the retrieval. This suggests that odor memories are stored in "modality-specific sensory brain regions" (Gottfried et al., 2004). Gottfried et al (2004) also found that effect of odor on the memory related brain structures was not influenced by emotional context in this particular study. This suggests that emotion does not always have to play a role in the remembrance of an odor cued memory.

The influence of odor and emotion on memory may have some limitations. One limitation is that some research shows odors to be an effective memory cue only in context-dependent conditions (Aggleton & Waskett, 1999; Baker et al., 2004). The odor must be present during encoding and retrieval, otherwise, the effect does not occur. This is opposite of the Gottfried et al. (2004) study which found increased memory retrieval even if the odor was not present at the time of retrieval.

Another possible limitation is the type of memory that odor and emotion effect. Most

research has looked at the influence odor and emotions have on autobiographical memory (Buchanan, 2007; Maratos et al., 2001; Schab, 1990). Most of this research has found that odor and emotions have a positive effect on memory, meaning that they increase one's ability to remember memories or that they make the memories more vivid. The research on semantic memory has suggested that different retrieval processes are used when compared to those used in retrieval of autobiographical memories (Chu & Downes, 2000). The different retrieval pathways could affect the influence odor and emotion have on memory.

Emotion may not have to be present in an odor-cued memory, however, research has found that olfactory evoked memories tend to be associated with high emotional arousal (Willander & Larsson, 2007). Some research shows that memories evoked by odors have more emotional value than memories evoked from other cues, such as visual or auditory cues (Herz & Cupchik, 1995; Herz et al., 2004; Herz & Schooler, 2002). The emotionality of the memories is what separates odor stimulated memories from other cued memories (Herz & Cupchik, 1995). Another study found that odors called to mind many memories that were pleasant and emotional in nature (Cann & Ross, 1989). They found that olfactory cues can be very helpful memory aids, but the effectiveness of the olfactory aids depends on the familiarity of the odor. When people recognize the odor, it acts as a much stronger memory cue than when the participant is unable to label the odor (Cann & Ross, 1989).

Previous research has shown that there are connections between smell and memory (Chu & Downes, 2000; Herz et al., 2004; Willander & Larsson, 2006; Schab, 1990), as well as between emotion and memory (Dolan et al., 2002; Maratos et al., 2001; Yeshurun & Sobel, 2010; Zald & Pardo, 1997). Several studies have also started to suggest that odor, emotion and memory are related. To our knowledge, there is no research that seeks to discover the order of

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influence odor has on emotion and memory. In order to further the understanding of the relationship between the three, the purpose of the present study was to determine how these three systems interact. In essence, what influence do odor and emotion have on memory? Based off of previous research, this study hypothesized that odor would stimulate memory and emotion would be secondary. Evidence suggests that odor can have a large influence on memory (Chu & Downes, 2000; Herz et al., 2004; Willander & Larsson, 2006; Schab, 1990). Odors also seem to affect emotion, however, they primarily affect the type of emotion one displays (Zald & Pardo, 1997). Emotions do appear to affect memory as well, but not to the same extent that odors do (Banich et al., 2009). When looking at odor, emotion and memory, the emotion seems to be an additional asset to assist the odor-memory cue.

In the current study, the participant was presented with several word memorization tasks in the presence of a positive or negative odor, along with being put into a positive or negative desired emotional state. Memory intrusion errors were measured between the various scent valence and emotional valence combinations. If odor drives memory and emotion is secondary, as the researcher suggests, then it would be expected that there should be more intrusions due to scent. For example, participants may remember words from list B while exposed to vanilla and a positive story, when they were supposed to remember words from list A, during which they were also exposed to vanilla and a negative story. This is different from if they would remember words from list C during which they were exposed to fish sauce and a negative story, when they were supposed to remember list A (vanilla and positive story) words. If, however, odor influences emotion first, the results would show the opposite. There would be more intrusions errors due to emotional content. If the data shows equal amounts of intrusions between the odors

and the emotions, then perhaps the influence on memory is bidirectional. However, if there appears to be only a very random selection of intrusions, then that would suggest that the systems are more independent of each other and do not act in a specific order.

METHODS

Participants

The study consisted of 32 participants, however, one data point was lost due to computer error. The remaining 31 participants (14 men; 17 women) were aged between 18 and 22 years, with a mean age of 19.9 years ($SD = 1.33$). The participants were undergraduate students enrolled in the College of St. Benedict (St. Joseph, MN) and St. John's University (Collegeville, MN). The participants consisted of students in introductory level psychology courses who received credit for their participation and a convenient sample of other students on campus. All participants were recruited via email. Participants were prescreened to make sure they did not suffer from chemical sensitivity to scents.

Apparatus and Stimuli

Participants were tested individually on a computer in a small, well-lighted lab room. Two clear, plastic, 100mm diameter petri dishes were used to hold the two scents. The scents used were Kirkland Signature Pure Vanilla Extract and Tiparos Thai Fish Sauce. The petri dishes were filled with fresh scents each day by placing a small amount of liquid in the petri dish. In between each word memorization task and during the time between participants, a small fan was turned on and the door was opened to help circulate the air and remove the previous odor from the room.

All pre-tests, memorization tasks, and post tests took place on the computer. The computer programs used to run the tasks were MediaLab v.2010 and DirectRT Research

Software v.2010. During each of the memorization tasks, a word list was presented in one of the four quadrants of the screen for one minute (fig. 1). Words were of neutral emotional valence and consisted of five to seven letters. A participant saw four different word lists throughout the experiment.

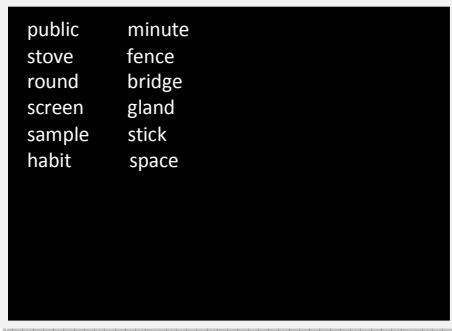


Figure 1. Example screen shot of word list presented during memorization task. A different word list was shown in each quadrant of the screen.

Design and Procedure

The experiment consisted of a 2 (scent valence) by 2 (emotional valence) within subjects design looking at the differences in memory recognition and recall between conditions involving a pleasant (vanilla) or unpleasant (fish sauce) scent and having the participant in an emotional or non-emotional state (fig. 2). The participants were randomly assigned to be in one of 8 conditions. The conditions consisted of different combinations of the order of the words presented, the order of the story presented and the scent presented with each word list.

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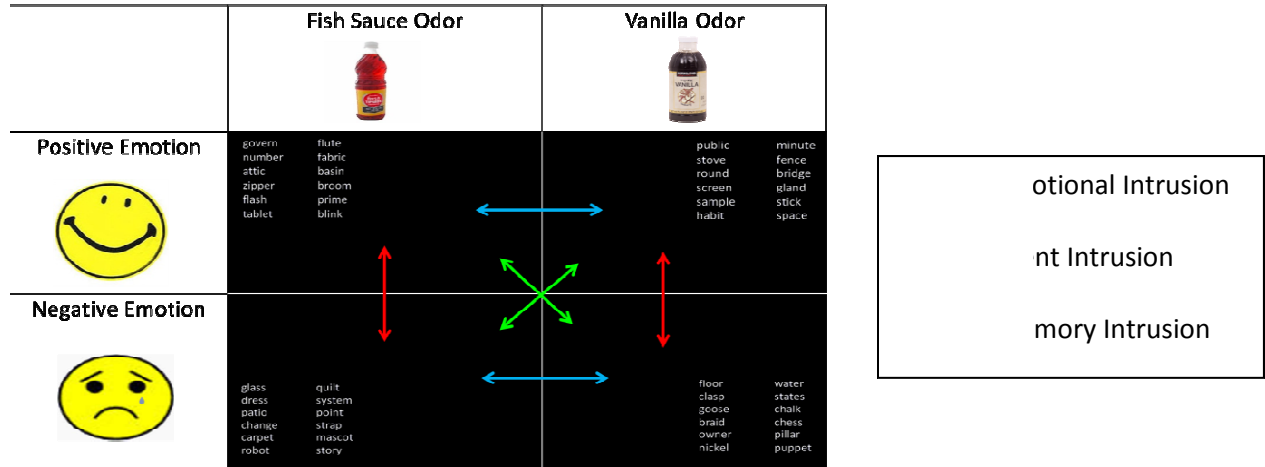


Figure 2. Graphic showing the 2 x 2 experimental design, along with the location of word lists in each of the quadrants of the screen. Intrusions were used to estimate connections between odor, emotion, and memory.

When the participant walked into the lab room, an open petri dish was present on the side of the table exposing one of the two scents. The experiment began with a basic demographic survey and a short pre-mood indicator test adapted from Watten, Syversen & Myhrer (1995).

Prior to seeing each word list memorization task, the participants were presented with a brief story to read. Throughout the experiment, four different stories were presented that contained varying emotional content. The stories related to either a positive or negative experience of an individual or a community. The stories were presented to put the participant in a desired emotional state.

After reading the story, the participant was presented with a wordlist and instructed to memorize the words (fig. 1). They were informed that the quadrant on the screen that the words appeared in was important. The participants had one minute to memorize the word list. After the wordlist, the participant was given a sheet of paper with maze of intermediate difficulty level to complete. They were told that they should try to complete it to the best of their ability. They had two minutes to complete the maze. This maze acted as a filler task in order to try to prevent

memory rehearsal between memorization tasks.

While the participant completed the maze, the fan was turned on to remove the previous scent from the room. The experimenter brought in the next scent. The odors were switched in between each of the four word lists. Over the course of the experiment, the participant was exposed to the pleasant and unpleasant odors along with the positive and negative emotional stories in a 2 x 2 design. When the two minutes were up, the experimenter prompted the participant to continue with the computer part of the experiment. The second story was then presented. This procedure was repeated until the participant had read four stories and was presented with each of the four word lists to memorize.

Once the fourth maze was completed, the participant moved on to the word recognition part of the experiment. Sixteen words were shown individually in one quadrant of the screen and the participant was supposed to select whether or not each word presented was previously seen in that list (quadrant of the screen), in a different list (different quadrant of the screen) or if it was absent from all lists and had not been previously presented (fig. 3). Out of the sixteen words presented in each quadrant, six of the words were in the correct location, six were in a different location and four were absent from all lists. For this portion and the remainder of the experiment, there were no odors present.



Figure 3. Example screen shot of word presented during recognition task.

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After the word recognition tasks, the participant was asked to recall as many words as they could from each list. They typed the words they remembered into each of the four quadrants (fig. 4). Both this task and the word recognition tasks were looking to see if the participants remembered the words in different locations. This data was used to determine if there were memory intrusions between the different word list tasks.

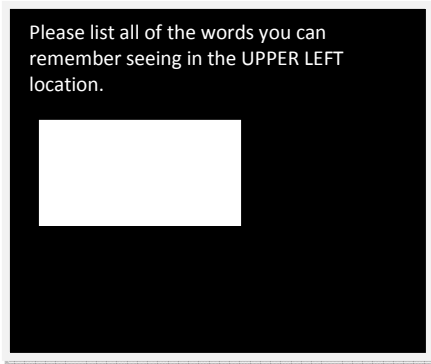


Figure 4. Example screen shot of the recall task.

The final part of the experiment consisted of two brief post tests. One asked three questions about how smells affect them and whether they could determine what the presented scents were. They were also asked about their current sinus condition. The second post test used a questionnaire adapted from Coren (1988) which calculated an emotional index score.

To analyze the data, descriptive statistics were obtained for the memory recognition, memory recall and all intrusion data. One sample t-tests and a 1-way ANOVA were performed in SPSS to see if the difference in location of correctly identified words, along with the source of intrusion errors were significant.

RESULTS

Memory Recognition Data

The mean and standard deviation of the percentage of correctly identified memory recognition data was obtained (fig. 5). This data shows the percentage of times participants were able to correctly identify the source of a word previously seen. A one sample t-test found that memory recognition performance on correctly identifying which word had been seen in which location was significantly greater than chance (test value=.33), $t(30)=4.56$, $p<.001$. On average, participants were correct 55% of the time.

The data shows that there were higher recognition scores for absent words than to correct locations, $t(30)=2.65$, $p=.013$, and different locations, $t(30)=2.418$, $p=.022$. Participants were better at recognizing words they had never been presented with compared to determining which location a word had previously been presented in.

Memory Recall Data

The mean and standard deviation for the memory recall data were calculated (Table 1). If participants correctly recalled all words that they were previously shown, they should have recalled 64 words. Participants recalled an average of 13.9 words (SD = 6.46).

Intrusion Data

The mean and standard deviation for intrusion sources of the memory recognition data (fig. 6) and the memory recall data (fig. 7) were attained. No effect was shown from the intrusion source in the memory recognition data, $F(2, 60)=1.059$, $p=.353$, or in the memory recall data, $F(2,60)=.008$, $p=.992$. The intrusion data was collapsed from positive and negative scent and emotion intrusions to just scent and emotion intrusions. There was no real difference between positive and negatives of either scent or emotional intrusions.

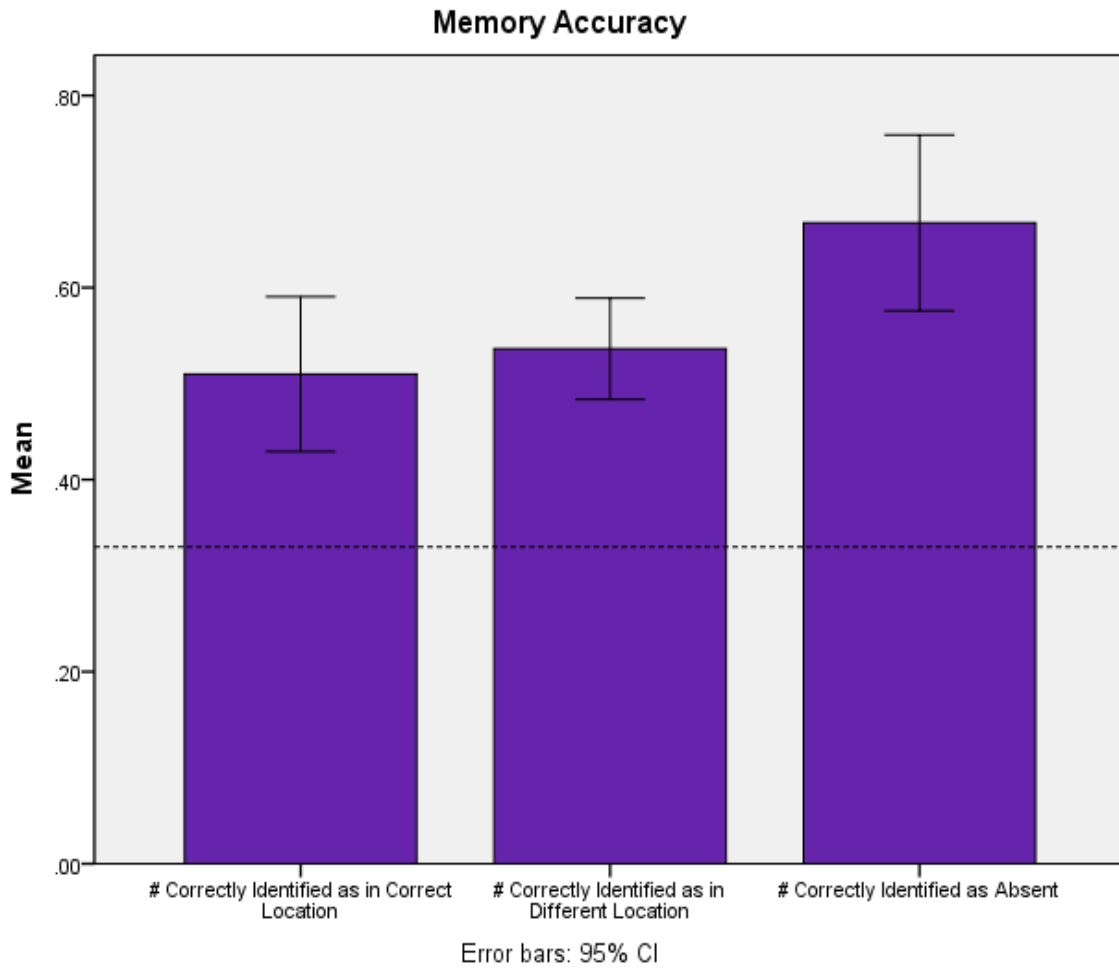


Figure 5. Percent correctly identified words in the memory recognition tasks. Percent correct yes is the percentage of times participants correctly identified words as being from that location when the word was previously seen in that location. Percent correct different is the percentage of times words were correctly identified as being from a different list when it was from a different list. Percent correct absent is the percentage of times words were correctly identified as absent when the word had not been previously presented.

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Table 1. Mean and standard deviation of the number of words participants recalled. Rows are divided into categories based on what type of words the participants recalled. Correct words are words recalled in the correct quadrant of the screen. Absent words are words recalled that were presented as absent during the memory recognition task and not in the memorization word lists. Random words are words that participants recalled that were not related to the study in any way.

Recall Data	Mean	Standard Deviation
# Total words	13.9	6.46
# Correct words	9.32	7.74
# Absent words	0.45	0.67
# Random words	0.67	0.91

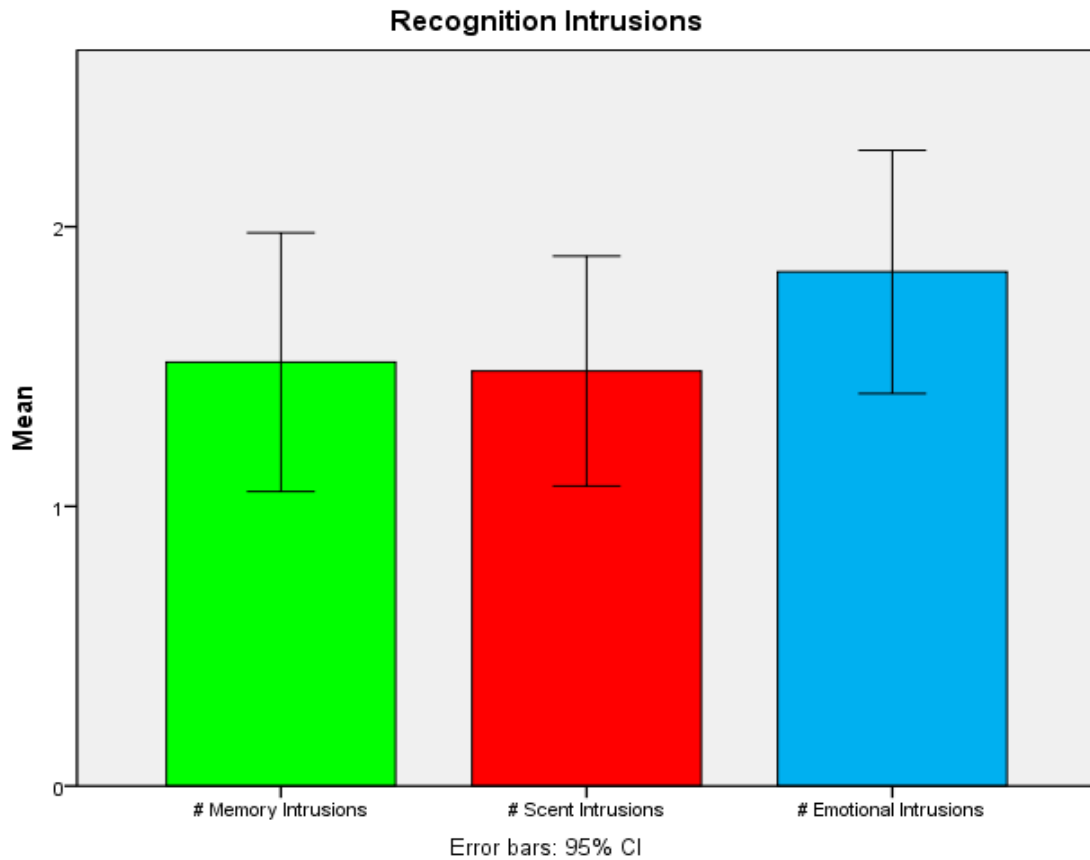


Figure 6. Number of intrusions due to scent, emotion or memory in the memory recognition data. An intrusion occurred when a participant would identify a word as being from the correct location when it was actually from a different location. A scent intrusion was when both the word presented and the location in question were previously presented with the same scent. An emotional intrusion was when the word and the location in question were previously presented in the same emotional state. A memory intrusion was when the word and the location in question did not match either in scent or emotion, thus the intrusion was just due to memory alone.

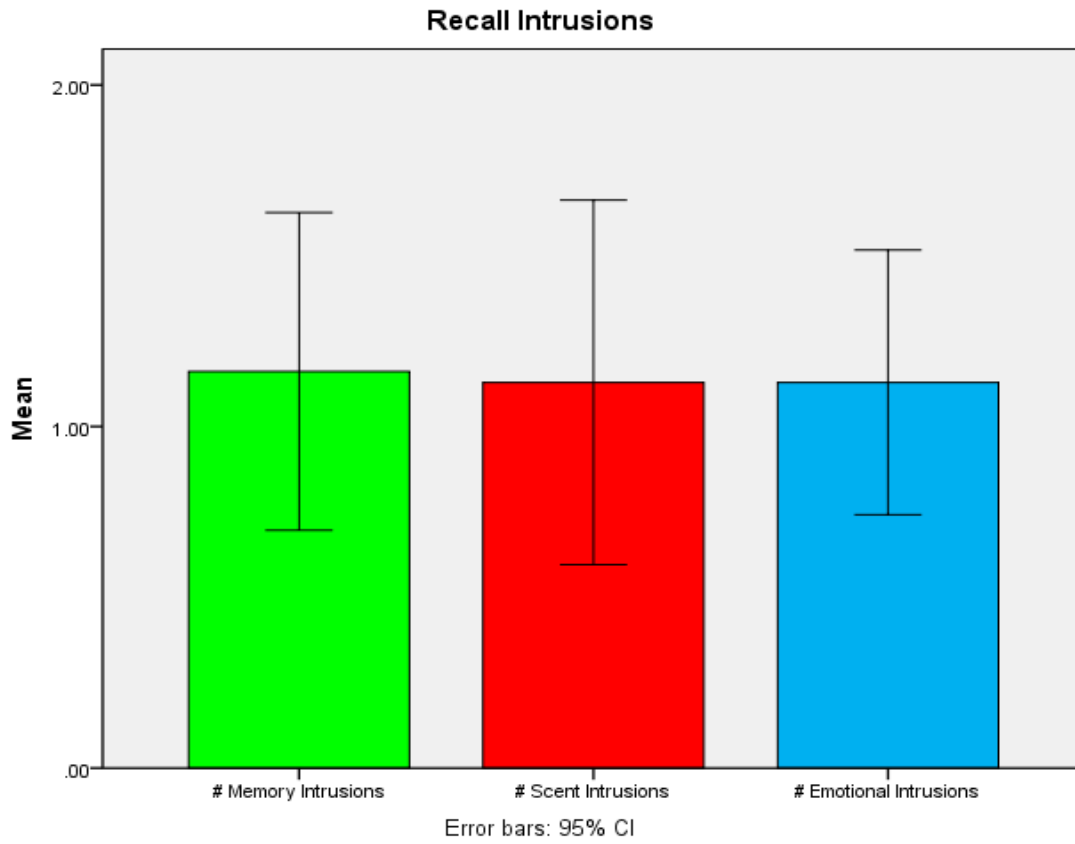


Figure 7. Number of intrusions due to scent, emotion or memory in the memory recall data. Intrusions were measured in a similar way to recognition intrusions (as described in Table 3 caption). Data was analyzed based on the screen location in question and the words that participants recalled.

DISCUSSION

The memory recognition results showed that participants were able to correctly identify the location of the word with accuracy significantly greater than that due to chance. This implies that participants were not merely guessing random answers for each word presented to them. The results also found that participants were better at identifying words as absent (never presented before) than they were at identifying the previous location of the word. This suggests that the participants experienced source confusion. The intrusion data confirmed this idea.

Many studies have found odor and emotion to influence memory, usually enhancing memory retrieval in some way. The present study attempted to determine how the three systems of odor, emotion and memory interact. The hypothesis was that odor would stimulate memory and emotion would be secondary. If this is true, odor drives memory, then the data should have shown more memory intrusions due to the repeated presence of a scent. However, the results found that there was no significant effect from intrusions in both the recognition and recall data. Memory performance appeared to be identical between all three intrusion sources. Thus, odor content and emotional content during encoding had basically no effect on memory recognition and recall. The almost equal amount of intrusions between sources suggests that odor and emotion had a weak to null effect. This is opposite to what much of the previous research suggested. Strong connections between smell and memory have been found in previous research (Chu & Downes, 2000; Willander & Larsson, 2006; Schab, 1990), along with connections between emotion and memory (Dolan et al., 2002; Maratos et al., 2001; Yeshurun & Sobel, 2010; Zald & Pardo, 1997).

One of the major contributing factors causing the data to be insignificant could be that most of the previous research involved autobiographical memory, whereas this experiment

analyzed semantic memory tasks. Chu & Downes (2000) note that there are prevalent differences in odors' influence between autobiographical and semantic memory. Research has found that odor can be beneficial in semantic memory tasks, such as word list learning, however, semantic memory is more context-dependent (Wilkinson et al., 2002). Odor may only be an effective memory cue in context-dependent conditions (Aggleton & Waskett, 1999; Baker et al., 2004). This implies that for odor to influence semantic memory, the odor must be present at both encoding and retrieval. Research has found that emotional content does enhance semantic and autobiographical memory in word memorization tasks (Kensinger & Corkin, 2003). Memory increases when emotional words were used in comparison to neutral words. The emotional content of words was not context-dependent.

This difference in the influence of odor and emotion on semantic and autobiographical memory may be in part due to the difference in the route of memory retrieval (Chu & Downes, 2000). It has been proposed that these two types of memory depend on independent retrieval routes. In a conceptually based search (such as in a semantic memory task), the retrieval process is more thematically based meaning it is more direct. When an odor is presented, it acts a perceptual cue. These perceptual cues facilitate autobiographical memory retrieval (Parr et al., 2002). This allows the retrieval process to bypass the thematically based approach and seek out other mechanisms by which to retrieve the memory (Chu & Downes, 2000). Thus, semantic memory may not be affected as much by odor or emotional cues because the route in the brain may be more direct and not as easily stimulated by perceptual cues. Research suggests that the reactivation of sensory regions of the brain involved in encoding is what is largely responsible for autobiographical memory retrieval (Gottfried et al., 2004). The hippocampus is able to bind a trace that is maintained across the sensory-specific regions of the brain. Greenberg et al. (2005)

found that there was a pronounced functional connectivity between the amygdala, hippocampus and right inferior frontal gyrus during autobiographical memory retrieval but not during semantic memory retrieval. This further supports the theory that there are independent pathways based on the type of memory retrieval occurring.

Along with the difference in odor and emotion's influence depending on the type of memory, another contributing factor to the insignificant data could be perhaps the procedure did not accurately measure what it was supposed to. The data reflects a general memory effect, meaning that the participants were only capable of remembering so much. The tasks presented to the participants may have been too difficult. They were asked to memorize a large number of words in a very short amount of time. Perhaps the study asked a little too much of the brain's memory capabilities.

Another potential confound to the study could be that the influence of emotion was not accurately measured. The stories used that contained emotional content may not have had a high enough emotional valence to influence participant's memory. All of the words in the memorization word lists were neutral. Perhaps if the words themselves had an emotional connotation to them, we would have seen more of an effect due to emotion. Research has found that participants are better able to remember words of emotional content compared to neutral words (Kensinger & Corkin, 2003). Maybe the effects of emotion are more specific to the words that are used and not the emotional state the participant is in during the memory encoding. Also, the participants perceived emotional rating of the story was never tested. A pre-mood and post-mood test was administered, but nothing was done to analyze how the stories affected the participants' emotions.

The influence of odor may not have been accurately measured. Perhaps the scent was not

prominent enough or of a high enough valence to have any impact on the participants' memory. A few questions were asked at the end of the experiment regarding the strength of the odors and the type of odors. None of the questions provided any statistically significant responses.

Conclusion

After looking at the literature on these topics, one can conclude a few things from the results of the present study. The results could imply that odor and emotion do influence memory, this experiment just did not accurately measure the effect. This would be supported by several previous studies that found strong connections between smell, emotion and memory (Chu & Downes, 2000; Dolan et al., 2002; Herz et al., 2004; Maratos et al., 2001). This could be attributed to the ideas that autobiographical memory is influenced more by odor and emotion than semantic memory (Chu & Downes, 2000). The confounds present may have impacted the data. One could also conclude that the experiment was accurate and the influence of odor and emotion just did not significantly affect the memory of the participants. Perhaps the neural connection between the three systems does not cause as strong of a functional connection as previously thought. This is harder to conclude based off of all of the previous research showing the many neural connections between the three systems and how the three systems do functionally interact (Chu & Downes, 2000).

Future research could further explore the limits of the influence of odor and emotion on semantic memory. Perhaps a different procedure could be used to analyze the influence on semantic memory. Or at least a more specific process of analyzing the effect of emotion should be used to gain more control and eliminate potential confounds.

Additional research could also involve a study comparing the influences of odor and emotion on both autobiographical and semantic memory. The use of fMRI or other brain images during the study could help researchers to better understand the routes taken and how they differ between autobiographical and semantic memory.

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