OLFACTORY WORKING MEMORY: THE ROLE OF PERCEIVED ODOR NAME-ABILITY

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A Thesis Submitted to the Faculty of the University
of Tennessee at Chattanooga in Partial Fulfillment
of the Requirements for the Degree of
Master of Science in Psychology

The University of Tennessee at Chattanooga
Chattanooga, Tennessee

May 2013

ABSTRACT

The purpose of this study was to examine the relationship among three factors: perceived odorant name ability, whether the odorant was ingested through a single nostril or both nostrils, and how the odorant is represented in working memory. Participants smelled odorants through the left or right nostril or with both nostrils and then provided an identifying label for each odor and rated how accurately their label represented the odor. After a short delay, the participants were given a new stimulus set consisting of new and old odorants. Participants were asked to provide a label for the odor and determine whether the odor was new or old. These ratings were used to evaluate how odors are represented in working memory. A significant main effect showing a both nostril advantage in odor naming accuracy compared to single nostril accuracy was observed.

DEDICATION

To my parents for all of their encouragement and endless support; to my sister Chelsea for keeping me motivated. Thank you for all your support.

ACKNOWLEDGEMENTS

This thesis has been the culmination of a very long journey. First and foremost I would like to thank my advisor Dr. David Ross. Thank you for all the hours of tireless work you have put into this project with me and thank you for pushing me to become a better researcher and student. I would also like to thank my committee members Dr. Amye Warren and Dr. Brian O’Leary who have supported me and my work from the first day I entered the program. Thank you.

I would also like to thank my fellow students Dominick Atkinson, Paul Rosenberg, Joe Jones, Carrie LeMay, Kelsey Villamarin and Camille Harr who with their help made this project possible.

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INTRODUCTION

Background

Have you ever wondered why there are some scents you can name instantaneously after experiencing them, and yet other scents that you could never identify? If you smell an apple and then smell a lemon, most individuals can immediately recognize that these two smells are quite different. The process by which this act of memory is accomplished first begins with the volatile molecules from the apple. These molecules enter your nose via the nostrils and pass over the olfactory receptor sheet before continuing through your trachea and into the lungs (Wilson & Stevenson, 2006). Through a series of complex internal processes, these chemicals activate a temporary internal representation of the odor (White, 2009), but in order to determine that the scent of an apple is different than the scent of a lemon a comparison of these representations is required. While the ability to say that an apple and a lemon are two different scents seems quite simple, the cognitive processes and memory systems underlying this aptitude have been puzzling scientists for years.

The structure of olfactory memory has been a particularly difficult mystery to due largely to how differently olfactory memory appears to behave in comparison to the other sensory modalities. These differences appeared to thwart the understanding the scientific community had regarding the workings of olfactory memory. It has only been within the last twenty years that the olfactory memory was thought to have a short-term memory and long-term memory component (White, 2012). The significance of olfactory memory being thought to operate as a two-component system is that prior to this event, no widely accepted model of memory developed for the other senses could be generalized to explain olfactory memory with any real confidence (Annet, 1996), predominantly because they were developed to explain a two-component memory system.

The model most predominately used in sensory modality memory research is the multi-component model (Baddeley & Hitch, 1974). This model as the name suggests, consists of multiple components which allow long-term memory and short-term memory to interact through an additional memory system identified as working memory. The model operates as a hierarchical master/slave system in which communication and resources are controlled exclusively by one component. Within the multi-component model the master component is called the central executive, and serves to direct incoming information into the slave components which draw upon information in long-term memory to generate temporary internal representations, and then communicate this information back to the central executive component. In other words, when you smell an apple, the volatile chemicals that pass over the olfactory receptor sheet stimulate receptors to produce a specific response pattern. This pattern is then communicated to the central executive who then assigns a slave component to compare the pattern to any and all existing patterns held in long-term memory. If the pattern is recognized, then a previously existing representation of the odor would be activated and the slave component would communicate to the central executive that this pattern represents the smell of an apple (Baddeley & Hitch, 1974).

Research indicates that the olfactory system uses verbal representations and perceptual representations to hold information in long-term memory (Yeshurun, Dudai, & Sobel, 2008), and it is believed that these two representations utilize two separate slave components (Zelano, Montag, Khan, & Sobel, 2009). It is believed that the slave component that utilizes verbal representations resides in the language center of the brain (Zelano et al., 2009), which in 95% of right handed individuals is lateralized to the left-hemisphere (Homewood & Stevenson, 2010). It is also believed that this slave component which utilizes verbal representations is only activated for odors which are recognizable with a verbal label or nameable. In other words, if you can put a name to a particular scent, then you are using your left-hemisphere to perform verbal representation. However, due to the structure of the olfactory pathways it is unclear if information from the right nostril can communicate to the slave component utilizing verbal representation. As information presented to the left nostril is processed by the left hemi-sphere, and information presented to the right nostril is processed by the right hemi-sphere (Homewood & Stevenson, 2010).

The object of this study is to provide evidence that how olfactory information is represented in working memory is directly influenced by an individual’s ability to name an odor, represented by a self-reported measure of odor name-ability; as well as the method in which an individual receives olfactory input in terms of nostril input: left, right, or both.

The Olfactory System Pathways

To understand olfaction, one must first be aware of how information travels within the olfactory system. The flow of information in the olfactory system begins with the olfactory membrane, then to the olfactory bulb, and then to the primary olfactory cortex (Wilson & Stevenson, 2006).

In humans the olfactory membrane also known as the olfactory epithelium is located within the nasal cavity. The olfactory membrane is constructed of four cellular layers: supporting cells, olfactory receptor cells, basal cells, and brush cells. The first layer of the olfactory membrane is constructed of the supporting cells, which are long columnar cells that provide physical support and produces a mucus layer between themselves and the open nasal cavity so that items entering the nasal cavity first come in contact with the mucus layer and not the supporting cells. Embedded between the supporting cells are the olfactory receptor cells, which are actually bipolar neurons whose dendrites are located within the mucus layer and whose axons project through a sheet of bone called the cribriform plate into the olfactory bulb. Located above the olfactory neurons are the basal cells, these stem cells produce new olfactory receptor cells as the olfactory neurons are generally short lived. The final cellular layer is constructed of the brush cells, the function of these cells is poorly understood but it has been proposed that they might regulate neurogenesis (Brescia & Seiden, 2009).

The second structure in the olfactory pathway is the olfactory bulb, which receives incoming information from the olfactory receptor cells. The olfactory bulb is composed of five distinct lamina or cellular layers: the glomerular layer, external plexiform layer, mitral layer, internal plexiform layer, and the granule cell layer. The glomerular layer is comprised of olfactory cells known as glomeruli, which are structures where synapses between the terminals of the olfactory neurons and the dendrites of the mitral cells and tufted cells form. The next cellular layer is the external plexiform layer which is comprised of mitral cell dendrites proceeding towards the glomerular layer. Mitral cells form the succeeding layer, this layer is comprised of mitral cell bodies whose dendrites are projecting towards the glomerular layer and whose axons are project into the olfactory cortex. The final layer in the olfactory bulb structure is the granule cell layer. Granule cells are interneurons that form dendrodendritic synapses with mitral cells; the function of these cells is to mediate lateral inhibition of the mitral cells (Barrett, Barman, Boitano, & Brooks, 2009).

The mitral cell axons leaving the olfactory bulb form the olfactory tract which bypasses the thalamus and projects directly to the anterior olfactory nucleus, olfactory tubercle, piriform cortex, amygdala, and entorhinal cortex which is collectively called the olfactory cortex (Barrett, Barman, Boitano, & Brooks, 2009). The structures that constitute the olfactory cortex are all believed to play significant roles in the processing of olfactory information, but the exact role of each structure is not yet fully understood. The function of the anterior olfactory nucleus is unknown, but it is believed to project to the contralateral olfactory bulb (Barrett, Barman, Boitano, & Brooks, 2009). The olfactory tubercle is believed to be associated with the integration of olfactory and other sensory information, specifically with regards to the perception of odors (Zelano et al., 2009), and has projections to both the frontal cortex and thalamus (Barrett, Barman, Boitano, & Brooks, 2009).

The amygdala has been shown to play critical roles in the processing of emotions and memories, and has projections to the frontal cortex and hypothalamus (Barrett, Barman, Boitano, & Brooks, 2009). The entorhinal cortex is considered a transfer station between the hippocampus and neocortex and is involved with memory processes and in the olfactory system projects to the thalamus and the hippocampus (Brescia & Seiden, 2009). The final structure of the olfactory cortex is known as the piriform cortex. This structure is believed to be involved in odor discrimination and higher order processing (Stevenson, 2012), and projects to the orbitofrontal cortex, thalamus, and frontal cortex (Brescia & Seiden, 2009).

Olfactory Transduction

The term olfactory transduction refers to the sequence of events in which volatile chemicals are processed by the olfactory system and produce the perception of an odor (Wilson & Stevenson, 2006).

The process begins when odor molecules which are volatile chemical molecules, travel up the nasal passageway and become embedded in the mucus of the olfactory membrane. Once embedded in the mucus membrane these volatile chemicals bind to olfactory receptor sites located on the dendrites of olfactory neurons, these olfactory receptors are a type of G-protein-coupled receptors. These receptors operate when an odor molecule known as a ligand binds to a receptor site and activates a specific G protein. This G protein in turn activates the enzyme adenylate cyclase which acts as a catalysis to convert adenosine triphosphate into cyclic AMP. Cyclic AMP then binds to cyclic nucleotide-gated ion channels. The cyclic nucleotide-gated ion channels open as a result and Na+ and Ca2+ ions enter the cell depolarizing the cell. The increase of Ca2+ ions within the cell then activates Ca2+ dependent chloride channels which cause Cl- ions within the cell to flow out of the cell, increasing the depolarizing and producing an action potential (Ma, 2007). In humans each olfactory neuron expresses only one type of olfactory receptor and thusly binds to only one type of molecule. However, because most odors are composed of multiple molecules it has been proposed that each olfactory receptor responds to a specific element of the odor molecules and produces an action potential signaling the presence of that element. These action potentials if summated would then produce a set of features which would describe the odorant (Wilson & Stevenson, 2006).

The action potentials resulting from the binding of odor molecule components to specific olfactory receptors proceed down the axons of the olfactory neurons and terminate in glomeruli, structures located in the glomerular layer of the olfactory bulb (Wilson & Stevenson, 2006). Glomeruli vary in size; however, each structure contains several thousand olfactory neurons axons all of which express the same receptor gene (Barrett, Barman, Boitano, & Brooks, 2009). This means that each glomerulus contains the axons of several thousand olfactory neurons all of which only respond to the presence of a specific chemical molecule. This produces glomerulus cell specific activity within the glomerular layer, and because odors are composed of multiple molecules when these molecules bind to olfactory receptors and produce action potentials, only specific glomeruli cells will display activity. This produces a spatial pattern consisting of active and non-active glomeruli cells (Wilson & Stevenson, 2006). This spatial pattern is then communicated to the olfactory cortex along the axons of the mitral cells (Barrett, Barman, Boitano, & Brooks, 2009).

While we are aware of what structures receive the spatial activation pattern produced at the olfactory bulb, the exact processes each structure undergoes in regards to olfactory information processing is not yet known, but a compelling amount of research has been conducted and is presented below.

Theorized Cognitive Processes of the Olfactory Cortex

Of all the structures which comprise the olfactory cortex the most studied and best understood is the piriform cortex. This structure is believed to be the location where three instances of olfactory information processing events occur.

The first processing event is the discrimination of odorant input pertaining to a specific source from that resulting from the environment, or in simpler terms the separation of environmental odors and non-environmental odors. The piriform cortex has been shown to have the capacity to rapidly adapt to the regular presentation of the same odorant (Sobel et al., 2000). It is believed that this rapid adaptation allows for recognition of new olfactory information independently from the competing environmental olfactory information (Stevenson & Wilson, 2007). Without the ability to rapidly adapt to the presentation of the same odorant our olfactory system would have a diminished capacity to identify new odors as the identifying characteristics of each odor would be diluted by the competing environmental olfactory information.

The second processing event that occurs in the piriform cortex is the loss of information regarding the structure and composition of the odorant. It is well documented that odorants with similar chemical structures do not produce similar odor qualities (Stevenson, 2012). Neuroimaging has shown that information regarding the chemical structure of an odor is managed by the anterior piriform cortex, and that qualitative information regarding an odor is managed by the posterior piriform cortex (Gottfried, Winston, & Dolan, 2006). Neuroimaging has also found that odor quality ratings were more highly correlated with activity in the posterior piriform cortex (Howard, Plailly, Grueschow, Haynes, & Gottfried, 2009). This process provides an explanation as to why chemically similar odorants can produce dissimilar odor perceptions. The information regarding the chemical structure of an odorant is not incorporated in perceiving odor quality and therefore the information is considered lost.

The third and final processing event in the piriform cortex is the “capacity to learn new input patterns and to match inputs to stored patterns” (Stevenson, 2012, p76). Kadoshisa and Wilson (2006) found that neuronal responses resulting from exposure to odorant mixtures become increasingly more unique with each repeated exposure. The capacity to match input patterns to stored input patterns is necessary to discriminate whether an odor has previously been encountered. Evidence supportive of the concept that the piriform cortex is involved in odor discrimination can be found in studies involving individuals who underwent ablative brain surgery. The best example of this is the individual known as HM. HM "received a bilateral temporal lobotomy for intractable epilepsy, which eliminated nearly all of both piriform cortexes" (Stevenson, 2012, p83). A study of his olfactory abilities found that HM performed at chance for tasks of discrimination when asked to discriminate between two different odors, but was able to discriminate between the same odor presented at differing concentrations (Eichenbaum, Morton, Potter, & Corkin, 1983). The fact that HM was showing only deficits in odor discrimination but not in threshold perception suggests that the areas of the piriform cortex are influential in discrimination but not threshold detection ability.

After the piriform cortex the second most studied olfactory cortex structure is the amygdala, however, the role this structure plays in olfactory processing is not well understood. It has been demonstrated in lesion studies involving rats that the destruction of the anterior amygdala produced no effect on the learning or retention of olfactory information on tasks of discrimination (Slotnik, 1985). Ablation studies involving primates in which only the amygdala or parts of the amygdala is removed do not report any alterations to olfaction (Narabayashi, 1977).

As detection and identification deficits are not observed in individuals who have all or part of their amygdala removed, it is not believed that these processes rely specifically on this structure. Instead, because the primary role of the amygdala is thought to be the processing of memory and emotional reactions (Hughes, 2004), the role of the amygdala in the olfactory system is believed to be related to the processing of an odors hedonic tone. Imaging studies have supported this belief, finding that highly aversive odors produce increases in cerebral blood flow to the amygdala (Zald & Pardo, 1997), and that this increased blood flow is a reflection of the amygdala pairing emotional activation with olfactory information (Zald & Pardo, 2000).

Almost no research exists regarding the roles of the olfactory tubercle and anterior olfactory nucleus in olfactory information processing and is an area of interest that future science hopes to elaborate upon.

Historical Perspective of Olfactory Memory

Compared to the other sensory modality memory systems, our knowledge of how olfactory memory processes operate is extremely limited. In addition one of the least understood areas of olfactory memory is olfactory working memory.

The terms short-term memory and working memory are not interchangeable as they refer to two different memory systems. Short-term memory is the capacity to hold limited amounts of information for a short period of time and is a component of working memory. While working memory is a cognitive system which temporarily maintains information through mental representations and is active during tasks which require monitoring or manipulation of information. Working memory is necessary to perform tasks that require integration of old and new information. As stated previously, one of the least understood areas of olfactory information processing is olfactory working memory. This understandable when one considers that the concept of olfactory short-term memory, a fundamental component of olfactory working memory, was only accepted within the past twenty years (White, 2012).

The results of early studies found that olfactory short-term memory behaved so differently from other known sensory memory systems that the existence of olfactory short-term memory was heavily debated. One of the ways the olfactory system differs in memory performance from other sensory systems is that the rate of learning olfactory information is below that of other sensory systems such as vision (Lawless, 1978). A potential explanation for this is that olfactory information is encoded with few features in comparison with visual information which is encoded with many features (Engen, Gilmore, & Mair, 1991). Another way the olfactory system differs from other sensory systems in terms of memory is in the rate of forgetting. Early studies found that olfactory information retention was the relatively unaltered at periods of 30 seconds (Engen, Kuisma, & Eimas, 1973) to 3 months (Engen & Ross, 1973). While at the time it was believed that no other stimuli could produce a similar retention rate, it has since been shown that simple visual forms (Lawless, 1978), and voices (Legge, Grossman, & Peiper, 1984) produce similar retention rates. Additionally, memory in the olfactory system is quite inaccurate, with the ability to accurately identify a common odor by name under 50% (Hertz, 2012). Finally, unlike visual or verbal memory which shows serial position effects reliably, serial position effects are not reliably observed in olfactory memory (Gabassi & Zanuttini, 1983; Lawless & Cain, 1975) and when serial position effects do occur the shape of the curve produced is not consistent (Miles & Hodder, 2005; Reed, 2000; White & Treisman, 1997).

The olfactory system differs not only in memory performance from other sensory systems but also in neural architecture. In contrast with other sensory systems such as the visual system which has only one method to receive input to its receptors, the olfactory system has two methods. Input can be received orthonasally by sniffing with the nose (Mainland & Sobel, 2006), or retronasally by inhaling with the mouth (Pierce & Halpern, 1996). Unlike other sensory systems the receptors in the olfactory system project ipsilaterally, meaning that an odorant which enters the left nostril will be processed by the left hemisphere. While an odorant which enters the right nostril will be processed by the right hemisphere. In contrast to the ipsilateral nature of the olfactory system is the visual system which projects contralaterally, meaning that information entering the right eye is processed by the left hemisphere and information entering the left eye is processed by the right hemisphere (Homewood & Stevenson, 2010). The most unique aspect of the olfactory system when compared to the other sensory systems is the lack of processing conducted by the thalamus. In vision for example, the thalamus conducts information processing functions as well as information relaying functions which is known as thalamic relay. Unlike all other sensory systems, the primary olfactory system pathways do not include a thalamic relay. The significance of this is that for all other sensory systems some degree of information processing occurs in the thalamus (Shepard, 2005); however in the olfactory system processing occurs at non-thalamic locations like the olfactory bulb, and the piriform cortex.

The unique neural architecture of the olfactory system is purported to be responsible for the differences in memory performance when compared to other sensory systems. Intuitively this is very logical, other sensory systems such as the visual system or the auditory system display similarities in neural design and these similarities result in similar cognitive and memory processes. The olfactory system is very different in neural design and as a result is very different in cognitive and memory processes (White, 2012). Support for the existence of short-term olfactory memory store came with the understanding that olfaction memory is processed in a serial method (Engen et al., 1991), meaning that information is dealt with sequentially. Because olfactory memory utilizes serial processing any comparison between two odors requires that information about one odor must be maintained in a temporary memory store while information regarding the other odor is being processed.

With the acceptance that short-term olfactory memory exists, the concept of olfactory working memory began to be addressed. While neuroimaging studies support the existence of a temporary olfactory memory system (Rolls, Grabehorst, Margot, Da Silva, & Velazco, 2008) evidence at the experimental level is somewhat inconsistent. A requirement of working memory is that the temporary representation of information must be manipulated in some way. In the visual system primacy serial positioning effects are held to indicate manipulation has occurred. However, in the olfactory system primacy serial positioning effects are not readily observable, but recency serial positioning effects have been observed (Miles & Hodder, 2005). The strongest evidence that olfactory memory has a working memory component comes from studies which utilize a two-back task (White, 2012). A two-back task is a task of working memory in which participants "have to determine whether a target item is the same as a comparison item that was presented two trials before. Because the comparison item is constantly changing, the information in working memory must be continually manipulated" (White, 2012, p143). Olfactory memory performance on two-back tasks involving familiar odors is found to be similar to that of visual memory performance (Dade, Zatoree, Evans, & Jones-Gotman, 2001). As a whole these studies provide support for the existence of working memory in the olfactory system.

Nameability

Odor nameability is defined as the ability to apply a label to a given odor; accuracy is assessed on terms of how close the given label matches the actual label. The ability to accurately provide an odor label is limited, with unaided odor identification performance commonly reported to be between 40 to 50% (Schab, 1991). There are several theories that have been developed to explain why accurate label performance for odors remains so low. One of the most cited theories it the poor link view (Hertz, 2012; Schab, 1991). The poor link view relies on the fact that the olfactory system developed in mammals prior to the development of language centers and because of this, the connections between the olfactory system and the language areas of the brain have sparse and weak connections that communicate poorly (Engen, 1987) and that this poor communication results in low odor label accuracy performance.

Another theory is that odor naming, that is correctly identifying an odorant with a verbal label is not important and this results in poor odor naming performance (Engen, 1987). This concept is better understood when one considers the two accepted functions of the olfactory system are in ingestive and social behavior. The role of the olfactory system in ingestive behavior is to identify food stuffs which should or should not be consumed, in simpler terms the olfactory system allows us to determine which food to consume and which food to avoid. This behavior does not require language, and for this reason this might explain why odor naming performance is so poor (Schab, 1991). Another function of the olfactory system is in social behavior, specifically in selection of social circles (Wilson & Stevenson, 2006), this task as with ingestive behavior does not require a specific language component and therefor may also explain why odor identification performance remains poor.

Lastly accurate odor naming performance may be most influenced by the fact that odors are experienced and learned in different circumstances for every individual and that this creates odor names which vary for each individual. This means that two individuals may smell lavender and each individual attributes a different name for the same odor, and it is this non-consensual naming of odors that may decrease olfactory naming performance (Engen, 1982).

Multi-Component Model of Memory

The most widely utilized model of working memory applied to the senses is the multi-component model of memory (Baddeley & Hitch, 1974). This model initially developed to explain visual and auditory memory systems, typically consists of five separate components arranged in a hierarchical master/slave structure. The master component is called the executive function, and is responsible for receiving incoming information and communicating this information to the slave components. In the model developed for the visual system, the slave components consist of: a visuospatial sketchpad which is responsible for holding information within working memory through visual and symbolic representations, a phonological loop which holds information within working memory through acoustic or verbal representations, and an episodic buffer which integrates information from both the phonological loop and the visuospatial sketchpad. The arrangement of the master/slave system is such that the slave components cannot communicate to the master component without first being activated by the master component. This means that the phonological loop component will not communicate to the central executive without first being activated by the central executive. In this system the central executive is first provided sensory input, and then determines which slave component to activate. The component the central executive activates is then provided the sensory input information. So when the central executive receives a pattern of sensory input which is represented in an acoustic form this pattern is communicated to the phonological loop component, which then holds the acoustic representation within its temporary store and compares the pattern of this representation to the patterns stored in long-term memory (Repovs & Baddeley, 2006). If the pattern of the acoustic representation is the same as one previously committed to memory and residing within long-term memory, the phonological loop component then communicates this finding to the central executive and the sensory input is recognized. If the pattern of the acoustic representation is different from all the patterns stored within long-term memory, them the phonological loop component communicates this finding to the central executive and the sensory input is determined to be new (Repovs & Baddeley, 2006).

While the overall structural organization and operation of the master/slave system for the multi-component model of memory applied to the olfactory system is the same, the model employed in olfactory memory research differs in terms of the slave components. Unlike visual and auditory sensory systems, the olfactory system does not appear to utilize spatial representations (Zelano et al., 2009). Instead information in olfactory working memory appears to be represented verbally and perceptually (Yeshurun et al., 2008). In a neuroimaging study Zelano et al. (2009), measured the activity of participants remembering odors that they could name and thus were highly nameable and odors which they could not name and thus were poorly nameable. Remembering the highly nameable odors resulted in sustained activation of areas associated with language information, while remembering poorly nameable odors resulted in sustained activation in the piriform cortex. These findings were interpreted to indicate two important concepts regarding olfactory working memory. First, the activation of language areas signified the verbal representation component of olfactory working memory, and that the activation of the piriform cortex signified the perceptual representation component of olfactory working memory. The component of olfactory working memory that performed the verbal representation was believed to be the phonological loop component which is present in other sensory models of the multi-component model of memory. The component of olfactory working memory that performed the perceptual representations was believed to be a novel olfactory memory buffer (Zelano et al., 2009). The second, and most important concept to the present study, is that odorants are processed and represented differently in working memory as a function of the ability to name the odorant.

The olfactory buffer presented by Zelano et al. (2009) as an additional slave component to the multi-component model of memory has not yet been thoroughly evaluated; however, at this current time the evidence presented does support the existence of this component. This component may or may not operate by the same rules as the other slave components whose rules were developed based on sensory modalities whose sensory input include a thalamic processing which the olfactory system performs independently (Shepard, 2005). In the visual system sensory information is relayed from receptors to the thalamus which performs both information processing functions as well as information relaying functions (Shepard, 2005), however in the olfactory system processing occurs at non-thalamic locations like the olfactory bulb and the piriform cortex (White, 2012). In the traditional model, the slave components communicate only when activated by the central executive, and the slave components not directly accessed remain dormant. The olfactory model of the multi-component model may violate this rule because olfactory information will always first be processed to some degree within the piriform cortex, which is the theorized location of the olfactory buffer (Zelano et al., 2009). The olfactory information processed at the piriform cortex is then relayed to the orbitofrontal cortex, thalamus, frontal cortex, and prefrontal cortex; which is the theorized location of the phonological loop (Repovs & Baddeley, 2006; Yeshurun et al., 2008; Zelano et al., 2009). Due to the direction of information processing which occurs in the olfactory system, the olfactory buffer component provides the information necessary for the phonological loop component.

The direction of communication indicates that it is possible that olfactory memory does not follow the traditional arrangement of the master/slave system depicted by the multi-component model (See Figure 1). With sensory input traveling directly to the piriform cortex which compares a perceptual representation pattern against the patterns stored in long-term memory, and then automatically communicates this information to a central executive. The central executive would then activate the phonological loop component to determine if the pattern can produce a verbal representation.

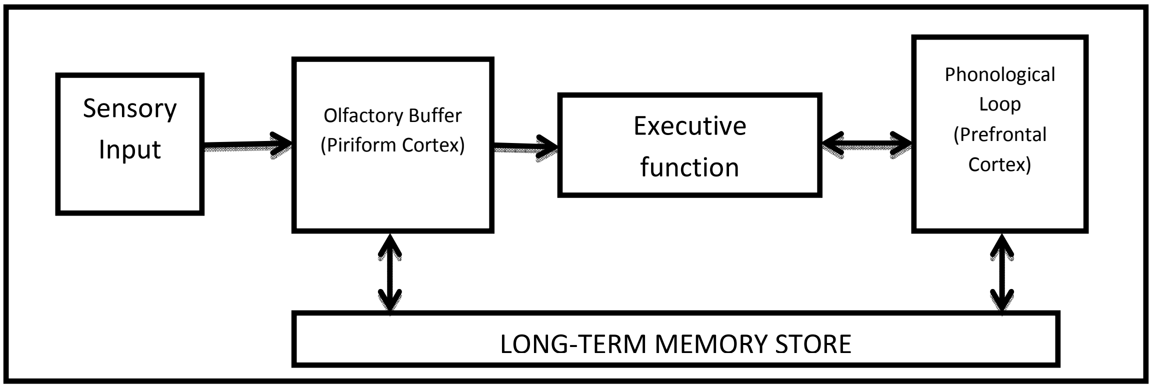

Figure 1 Non-traditional Multi-Component Model of Olfactory Working Memory

However, it may be possible that in the multi-component model of olfactory memory does not violate the traditional rules of the master/slave system (See Figure 2); the central executive first communicates olfactory information in a perceptual representation pattern which the olfactory buffer compares to perceptual patterns held within long-term memory. Then if the pattern is recognized, this information is communicated back to the central executive which then activates the phonological loop component to determine if the pattern can produce a verbal representation.

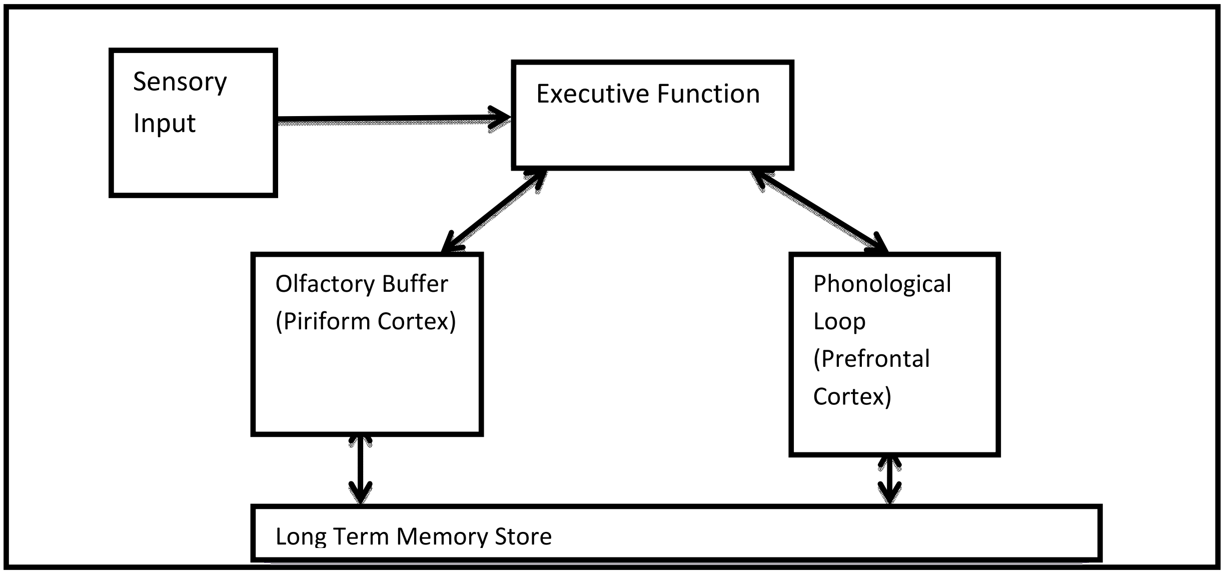

Figure 2 Tradition Multi-Component Model of Olfactory Working Memory

The Biological and Cognitive Processes of Perceiving an Odor:

The biological and cognitive processes that operate within olfactory memory have been described thus far as working independently. This section will demonstrate how these two processes operate concurrently when perceiving an odor.

When an individual smells an apple, the scent of that apple would be the result of perceiving the volatile chemicals being naturally produced by the biochemical process of that fruit ripening. These volatile chemicals travel up both nasal cavities and become embedded in the mucus layer of the olfactory membrane. Once within the membrane, the volatile chemical molecules produced by the apple would bind to olfactory receptors. The multiple molecules which compose the odor of an apple would be recognized by multiple receptor neurons, each binding to a unique feature of a particular chemical molecule (Wilson & Stevenson, 2006). The olfactory receptors which the apple odor molecules bind and successfully depolarize the cells to threshold would then produce and action potential. This action potential would then travel out of the olfactory membrane and into the olfactory bulb. Within the olfactory bulb, these action potentials would produce site specific activation, with each area that becomes activated representing a specific odor feature. Collectively, this activation produces a spatial pattern which represents all the features of the apple scent. The spatial pattern representing all the features of the aroma of an apple is then projected from the olfactory bulb to the olfactory cortex (Barrett, Barman, Boitano, & Brooks, 2009).

The axons of the mitral cells exiting the olfactory bulb form the olfactory tract carry the spatial pattern representing the aroma of an apple into the piriform cortex. Here the piriform cortex separates the spatial pattern associated with the competing environmental odors, and isolates the spatial pattern associated with the scent of the apple. Once isolated, the olfactory buffer which resides in the piriform cortex attempts to match the input pattern of the apple aroma to stored patterns (Stevenson, 2012; Zelano et al., 2009). Assuming that the individual has a stored pattern representing the aroma of an apple, the piriform cortex identifies the odor as having been experienced before and projects information regarding the odors qualities to higher order brain areas like the orbitofrontal cortex, thalamus, and frontal cortex (Homewood & Stevenson, 2006). At the point when the piriform cortex matches the input pattern of the apple aroma with a stored pattern, the individual is only aware that they have smelled this odor before. The memory processes occurring at this location would only be able to provide an individual with a sense of how familiar they are with the odor, but not be able to provide an accurate verbal label.

The spatial pattern representing the aroma of the apple would also be projected into the amygdala. At this location the role of the spatial pattern is most likely related to evaluating the hedonic tone of the odor; that is information communicated to this structure would be likely used to determine if the odor is pleasing or displeasing emotionally (Hughes, 2004).

The apple aroma olfactory information that projected from the olfactory cortex proceeds into the orbitofrontal cortex and frontal cortex, and connects with the prefrontal language areas located in the left hemi-sphere of the brain. At this location the pattern representing the apple aroma is attempted to be matched to a stored pattern in long-term memory by the phonological loop which resides in the prefrontal language areas (Repovs & Baddeley, 2006; Zelano et al., 2009). Assuming a stored input pattern representing the aroma for an apple exists, the individual would at this point be able to provide a verbal label to the odor. That is at this point the individual would be able to say, this smells like an apple.

The Present Study

The purpose of this research study is to determine whether or not odor name-ability is the mechanism behind selecting how an odor is represented in working memory. In the present study participants will be divided into 3 conditions and exposed to sets of odorants. During exposure to the first odorant set (Time 1) participants will be asked to generate odorant labels and provide ratings of perceived odorant name-ability for 12 unique odorants. The second odorant set (Time 2 which occurs 45 minutes after being exposed to the first set of 12 odorants) participants are exposed to will consist of 6 odorants from the first stimulus set and 6 new odor stimuli. The 6 odorants which the participant will encounter twice will be the odorants they rated as being the most nameable and the least nameable. For each participant the 3 odorants with the highest perceived name-ability ratings and the 3 odorants with the lowest perceived name-ability ratings will be incorporated into the second stimulus set. During exposure to the second stimulus set participants will be asked to discriminate if an odorant is new or old, and generate an identifying label. In the first condition participants will use both nostrils (birhinal) in acquisition, discrimination, and naming of nameable and unnameable odors. In the second condition participants will use only the left nostril (monorhinal) in acquisition, discrimination, and naming of nameable and unnameable odors. In the third condition participants will use only the right nostril (monorhinal) in acquisition, discrimination, and naming of nameable and unnameable odors.

This study utilizes several measures related to working memory. The first measure is that of odorant discrimination. Odor discrimination relies on matching input patterns to stored patterns, as odor familiarity increases the distinctiveness of input patterns associated with a given odor also increases. Highly distinct input patterns more accurately matched to stored patterns compared to less distinct input patterns. Odor discrimination accuracy will be scored as correctly or incorrectly discriminated.

The second measure is odor name-ability. It has been proposed that the perceived name-ability of an odor determines whether the odor will be represented verbally or perceptually in working memory. Nameable odorants are believed to be represented verbally, while unnameable odorants are believed to be represented perceptually. Odorant name-ability will be assessed on a 1-7 scale.

The final measure is that of odor identification, or odor naming. Odor naming is thought to occur in the prefrontal language areas of the brain located in the left-hemisphere and is associated with nameable odorants. Two judges independently categorized the quality of generated labels as: (1) blank or no label, (2) totally wrong, (3) somewhat accurate label, and (4) completely accurate. An accurate label refers to the label provided by the participant during the first presentation phase. A somewhat accurate label refers to an incorrect label, but is precise and can be readily confusable with the stimuli, for example raspberry for strawberry. A totally wrong label refers to a clearly inappropriate name, for example, soy sauce for coffee. The inter-rater reliability equaled .95.

Hypotheses

If nameable odorants are represented verbally, and verbal representation can only occur in the left hemisphere due to the lateralization of language, then due to the ipsilateral nature of the olfactory system correct labeling of nameable odorants should be highest in left nostril and both nostrils conditions as these are the only conditions which allow left hemispheric processing.

If unnameable odorants are represented perceptually and not verbally, then correct labeling of unnameable odorants should be equal across all conditions.

CHAPTER II

METHODOLOGY

Method

Participants

The sample pool for this study consisted of 108 undergraduate students from the University of Tennessee at Chattanooga. The participants ranged in age from 18 to 44 years (M_{Age} = 21.57, *SD* = 3.83), and the sample was 81.5% female and 18.5% male. The racial composition of the same was 62% White, 12% Black, 4% Mixed Racial Background, 1% Hispanic, and 1% Asian. The average level of nasal congestion reported by the participants was approximately 20% ($M_{\text{Congestion}}$ = 2.02, *SD* = 2.08).

Materials

Odorants

The stimulus set consisted of 18 different microencapsulated scented labels purchased from Print-a-scent inc. a nationally recognized scented label manufacturer. The odorants used in this study were selected because they were shown to be the most realistic in accurately recreating the desired scent. After consulting with Print-a-scent inc. employees and sampling several hundred odorants, 40 odorants were identified as possible scents for this study. These scents were then explored extensively through repeated pilot testing until 18 scents were identified as being the most accurate and effective. Pilot testing was conducted using undergraduate psychology students studying at the University of Tennessee at Chattanooga. A total of four pilot tests were conducted. The first pilot test performed determined the appropriate inter-stimulus timing interval that would be used in the final study. The second pilot test reduced the number of possible odors that would be used in the study from a total of forty to a total of thirty. Two additional pilot tests were conducted from which 18 scents were identified as being common odors of a limited cognitive load and were accurate representations of real life odors. The odor labels consist of concentrated fragrance oil wrapped in a polymeric shell attached to an adhesive backing. The scent is released when the shell is broken. The items in the stimulus set meet the criteria of being generally regarded as safe by the U.S. Food and Drug Administration. All the scented labels appeared identical in appearance so that participants were unable to determine the identity of the odor by visual means. The scented labels were attached to the front of standard size white note card. The front of these cards had no markings and appeared completely nondescript, so that the participants were unable to determine the identity of the odor by visual means. The back of the business cards were marked with a specific number identifying which odor the scented label represents. The note cards with the affixed scented labels were then be stapled front side facing up to the response packets, so that the participants could not determine the identity of the odor by visual means. The scented labels were be used once per participant and the scented labels were never to be reused. It was discovered during pilot testing that the odorant material contained within the scent stickers would transfer to whatever object was used to break the microencapsulation. If that object was then reused on another scent sticker, the odorant material from the first sticker would then transfer to the second sticker creating altering how the sticker would smell. This was corrected by providing participants with 24 toothpicks to use on the scent stickers. Participants were instructed to use only one toothpick per scent sticker and then dispose of the item. This way each scent sticker would remain uncontaminated during testing.

Scales

During presentation of the first odorant set (Time 1), each participant first provided a label for each odorant. The participant then rated the odorant label on a perceived name-ability scale ranging from 1 to 7, where a value of 7 indicates that the label is a very accurate description of the odor, a value of 4 indicates that the label somewhat accurately describes the odorant, and a value of 1 indicates that the label does not describe the odorant at all.

The participant then rated how familiar they perceive the odor to be on a scale ranging from 1 to 7, where a value of 7 indicates that the odor is a very familiar, a value of 4 indicates that the odor somewhat is somewhat familiar, and a value of 1 indicates that the odor is not familiar at all.

Response Packet

Participants were provided with two response packets. The first response packet was provided prior to exposure of the first stimulus set (See Appendix C). For this response packet participants were asked to provide a label for each odorant and to complete the aforementioned name-ability scale for each of the 12 odors.

The second response packet was provided prior to presenting the second stimulus set (See Appendix D). For this response packet participants were asked to report whether an odorant was new or old, and to generate an identifying odor label.

The response packets were printed on different color paper so that participants would be constantly aware of what condition they were in. Participants in the left nostril condition were given lime green packets, participants in the right nostril condition were given red packets and participants in the both nostril condition were given white packets.

Procedure

The data was collected in a large auditorium-style class room. The study has three conditions. The first condition had participants smell odorants with both nostrils, and examined how nameable and unnameable odorants are represented in working memory under normal conditions. The second condition had participant smell odorants with only their left nostril, and examined if the lateralization of language influences processing nameable and unnameable odorants in working memory. The third condition had participants smell odorant with only their right nostril and examined how the nameable odorants are represented when access to the verbal processing is inhibited.

Participants were screened prior to the testing phase for food allergies, asthma, epilepsy, and pregnancy during the informed consent process and prevented from participating in the experiment if they indicated they had any of these conditions.

Participants in the both nostrils condition were instructed to inhale through both nostrils. Participants in left nostril condition were instructed to block their right nostril with their non-dominant hand by pressing their index finger to the side of their nostril and inhaling with their left nostril. Participants in the right nostril condition were instructed to block their left nostril with their non-dominant hand by pressing their index finger to the side of their nostril and inhale with their right nostril.

Participants were then instructed that they were to replicate, to the best of their ability, the same smelling technique for each odor. After all participants were done sniffing and rating all 12 odorants, the experimenter left the testing room instructing the participants that he would be returning with the second portion of the experiment, but that this time was necessary for them to cleanse their nasal palates. The true reason for the intermission was to allow the experimenter to create the packet used in Time 2 testing. During the intermission between Time 1 and Time 2, the experimenter reviewed each participant's response packet and identified for each individual the three odorants the participant rated as most highly nameable and the three odorants the participant rated as least nameable. The experimenter then included the six identified odorants (three most nameable and three least nameable) into a set of six new odorants for each participant. When the second stimulus set was assembled, the experimenter returned to the testing room for the final part of the experiment.

Participants were informed that they were to be exposed to a second set of odorant stimuli that may or may not include odorants from the previous set. Participants were then instructed to perform the same procedure they performed during the previous odor set, with the exception that they will no longer be providing ratings of perceived odorant name-ability. Instead for the second odorant set participants were asked to indicate whether an odorant is new or old and to generate a label identifying the odorant.

Demographic data collected for this study included, age, gender, class year, smoking habits, degree of current nasal congestion, and race.

Research Design

The design was a 2 (nostril condition) x 2 (perceived odorant name-ability) mixed model design. Nostril presentation was a between subjects variable with 2 levels (single nostril, or both nostrils) and odorant name-ability was a within subjects variable with 2 levels (nameable or unnameable). Nameable and unnameable odorants were defined as those rated most nameable and least nameable based on the perceived odor name-ability scale given at time one. The first dependent variable was discrimination, defined as the ability to distinguish an odorant as old or new during the presentation of the second stimulus set. An old odorant would be an odorant which the participant experienced in the first stimulus set, a new odorant would be an odorant which the participant is experiencing for the first time in the second stimulus set. The second dependent variable was the accuracy of odor labels provided. Accuracy was defined by scoring the odor label given during the second stimulus set as being accurate, somewhat accurate, totally wrong, or no answer/blank as determined by two judges who achieved an inter-rater agreement of .95. Participants were assigned by row to left nostril presentation only, right nostril presentation only, or both nostril presentation conditions.

CHAPTER III

RESULTS

Odor Label Accuracy at Time 1

Each participant was given an odor identification accuracy score based on his or her labeling each of the 12 odorants presented at Time 1. The accuracy of identifying each odorant was done using a three point scale ranging from 1 (low) to 3 (high) accuracy. A total accuracy score was generated by adding the participants accuracy score across the 12 odorants.

Of the odors presented at Time 1, the three that participants were most accurate in identifying were Baby powder (*M* = 2.392, *SD* = .836), followed by Lemonade (*M* = 2.368, *SD* = .820), and then PlayDoh (*M* =2.352, *SD* = .879). The three odors that participants were least accurate in identifying were Strawberry (*M* = 1.295, *SD* = .619), followed by Root beer (*M* = 1.152, *SD* = .533), and then Cherry (*M* = 1.104, *SD* = .389).

Table 1 Comparison of Mean Label Accuracy Scores Of All Time 1 Odorants

Odor Label	Mean	Std. Deviation	Accuracy
Root beer	1.152	.533	7.6%
Lemonade	2.368	.820	68.4%
Cherry	1.104	.389	5.2%
Strawberry	1.295	.619	14.75%
Baby powder	2.392	.836	69.6%
Popcorn	1.598	.856	29.9%
Fresh Cut Wood	1.729	.937	36.45%
PlayDoh	2.352	.879	67.6%
Coconut	1.368	.722	18.4%
Pineapple	1.821	.614	41.05%
Soap	1.625	.766	31.25%
Grape	1.682	.772	34.1%

Note. Accuracy Label Scores are mean scores across all groups. Accuracy label scores ranged from: (1) Wrong or Blank Label, (2) Somewhat Accurate Label, (3) Accurate Label.

To test the first hypothesis, that participants in the both nostril condition would have significantly higher odor label accuracy scores as compared with participants in the single nostril conditions, a multivariate analysis of variance was performed using total label accuracy as the dependent variable, and nostril condition as the independent variable. In this analysis the experimental conditions of right nostril and left nostril were combined to form the single nostril condition discussed in this analysis. The results of this analysis found a main effect of nostril condition *F*(1,82) = 5.035, *p* = .028, indicating that participants in the both nostril conditions were superior in odor label accuracy than participants in the single nostril conditions.

A second multivariate analysis of variance was performed using total label accuracy of each individual odor as the dependent variables and nostril condition as the independent variable. In this analysis the experimental conditions of right nostril and left nostril were combined to form the single nostril condition discussed in this analysis. The results of this analysis found a main effect of nostril condition for only the odor of baby powder, *F*(1,82) = 5.374, *p*=.033, indicating that participants in the both nostril conditions were superior in accurately labeling the scent of baby powder than participants in the single nostril conditions.

Discrimination: Identifying an Odor as Old versus New at Time 2

The second hypothesis was that odors described as difficult to identify would not vary by nostril condition in terms of recognition accuracy. However, odors described as easy to identify would be more likely to be accurately identified as old versus new as function of nostril condition. Specifically, with odors that are easy to identify, participants in the both condition should have had higher recognition accuracy scores than participants in the single nostril conditions. Each participant was asked to identify to rate the difficulty in identifying each odor on a seven point scale where 1 = highly un-namable, 4 = somewhat nameable, 7 = very namable. To capture the total variance in the nameability ratings, a regression analysis was conducted where the main effect of nostril condition, nameability, and the interaction term was regressed on discrimination of the odorant or the ability to identify each odorant as old or new at Time 2. The hypotheses were that 1) the discrimination scores would not vary by nostril condition for odors that were identified as difficult to name, 2) discrimination scores would be higher for odors described by participants as easy versus difficult to name, and 3) discrimination scores would vary by nostril condition for odors that were identified as easy versus difficult to name. Specifically, for easily identified odors, discrimination accuracy was hypothesized to be higher in the single nostril condition than the both nostril conditions. The results of the analysis indicated no significant main effect of nostril condition (F (1, 66) = .413, $p > .05$), odor label accuracy (F (28, 66) = 1.029, $p > .05$), and no significant interaction between odor label accuracy and nostril condition on discrimination accuracy (F (12, 66) = 1.280, $p > .05$).

CHAPTER IV

GENERAL DISCUSSION AND CONCLUSION

The results of this study do support the belief that the left hemi-sphere is the location of the phonological loop component of olfactory working memory. The findings of this study showed only a significant main effect in which participants in the both nostril condition out-performed participants in the single nostril conditions in terms of accurately labeling odorants. The participants in the both nostril condition were observed to have greater accuracy in naming odors than individuals in the single nostril condition; this finding supports the stated theory that the left hemisphere in right-handed individuals may be the location of the phonological loop component of olfactory working memory. The advantage of the both nostril condition outperforming the single nostril condition may be the result of many different factors. First as no different was observed between highly nameable and highly unnamable odors the both nostril condition advantage may be the result of the two nostrils processing the olfactory information with both the olfactory buffer and the phonological loop components. As both the right and left hemisphere would be active in receiving the olfactory information in the both nostril condition this may have increased the cognitive memory components the participant could activate during the task increasing his or her ability to identify the odors. This capacity to draw upon two components compared to one may have been the reason that the performance of the both nostril condition was significantly better in odor naming accuracy than the performance observed by the single nostril conditions.

The single nostril conditions were found to have the lowest mean odor accuracy scores compared to the both nostril conditions. Zelano et al. (2009) hypothesized that the right hemisphere did not house the phonological loop which represents information temporarily as a verbal representation. Due to the lack of verbal representation the right hemisphere was hypothesized to be less effective in providing accurate odor labels. This hypothesis was supported by the data which found that single nostril conditions showed a significantly lower mean accuracy labeling score compared to the both nostril condition.

Nameability and familiarity ratings were found not to be significant for overall odor identification. This result may be indicative of a lack of involvement of perceived odor nameability in olfactory memory which would contradict the findings of Zelano et al. (2009), but more likely is that there was not enough variability between odor nameability and familiarity scores for any significant finding to be detected.

The analysis of variance using nostril condition as the independent variable and individual odor label accuracy as the dependent variable found only one significant finding for all the twelve odors used in Time 1. The only odor that was observed to have a significant effect was the scent of Baby powder. Baby powder was found to a main effect of nostril condition on label accuracy with the both nostril condition having a greater label accuracy score when compared to single nostril conditions. There may be multiple factors why Baby powder was most accurately labeled by participants in the both nostril condition. One possible explanation for this result was that the both nostril condition has the capacity to draw upon both the phonological component as well as the olfactory buffer component which may have resulted in a more complete and accurate memory representation used to identify the odor. Overall Baby powder was shown to be the most accurately identified odor across all groups, therefor it is not unexpected that Baby powder label accuracy would be highest in the nostril condition that allows the greatest level of cognitive processing.

The second hypothesis was that odors described as difficult to identify would not vary by nostril condition in terms of recognition accuracy was not supported. As no significant results were observed this finding can be interpreted in several different ways. One interpretation of these results is that discrimination did not vary as a function of nameability, indicating that odor discriminative ability did not operate as a function perceived nameability. Another finding was that discriminative ability did not show a main effect of label identification, this finding was surprising as identification ability is theoretically limited by the ability to accurately discriminate an odor (Hertz, 2012). Additionally there was no significant interaction observed between label accuracy and nameability. These findings were most likely the result of a lack of variability among the nameability and discrimination scores reported by the participants.

There are several possible reasons that the results from this study may not be truly indicative of how olfactory working memory operates. The key limiting factor in this study is that the testing environment was not kept odor neutral. The testing environment was intended to remain odorless or as close to odor neutral as possible, however, participants were not screened to determine if they were odor-less. This lack of control allowed additional odors that were not introduced by the experimenter into the testing room. These additional odors would have created competing olfactory information that the participant would have had to separate from those odors being presented to them in the response packet. A solution to this for future experiments would be to run participants individually and screen them individually to assure that the testing environment remains odor neutral.

An additional limitation of this study was the lack of control regarding how participants performed the procedure. In this task participants were instructed how to perform the experiment through oral instruction. Due to the large size of the testing environment some participants may not have accurately heard the directions on how to perform the experiment. This limitation would be better controlled if participants were tested on an individual basis, allowing for greater instruction and the ability to monitor the participants for errors while performing the task.

One factor that was not addressed during this study was the effect of nasal cycling on the participant's performance on tasks of olfactory working memory. It has been shown that nasal cycling may impact olfactory memory performance as one nostril will demonstrate a greater airflow rate. Several methods have been developed to determine which nostril is displaying airflow dominance; the currently most widely used method is to use an anemometer which is a device specifically designed to measure nasal airflow. Studies have found that nasal airflow dominance occurs in an ultradian rhythm (Searleman, Hornung, Stien & Brzuskiewicz, 2005), therefore it is not known what nostril was dominate at the time the participants performed this experiment. In a study by Searleman, Horgun, Stien & Brzuskiewicz (2005), it was observed that handedness was related to nostril dominance. In the study it was found that nostril dominance was correlated with handedness such that the dominate nostril occurred on the same side as ones dominant hand 60% of the time. This means that for this study, which utilized only right handed individuals, the dominate nostril would have been the right nostril at least 60% of the time. This may have affected the results of this study but it may not have had a significant impact on the results as well. The impact of nasal cycling on the results of this study may have been minimized because individuals in the single nostril condition were instructed to block one nostril. This would have created force airflow in one nostril, artificially creating a dominate nostril.

The last limitation of the study that will be discussed was participant fatigue. In Time 2 of the experiment, the interval between Time 1 and Time 2 was approximately 45 minutes. This intermission was used by the experimenters to build the participant response packets used in Time 2 of the experiment. The time required to build the participant packets was underestimated and additional time was necessary to complete the task. This resulted in the administration of the testing phase at Time 2 to occur 10 minutes later than the participants had been instructed. This may have resulted in the participants becoming fatigued and disinterested in the task at hand. The consequence of this may have been that participants no longer performed to the best of their ability and this may have contaminated the results.

The directions for which future research could proceed from this study are limited. The lack of any significant findings should not be interpreted to mean that the concepts and beliefs of which this study hoped to explore are incorrect. I believe that, had the environment remained odor neutral and if there had been more stringent controls, that the results of this study would have been much different and would have supported the findings of previous studies that olfactory working memory utilizes both perceptual and verbal representations in working memory. Future research should focus on finding further evidence of the olfactory buffer and phonological loop components of working memory and exploring what the role of perceived odor name-ability is within olfactory memory.

Conclusion

The main finding of this study was that odor label accuracy was highest for participants in the both nostril condition when compared to the single nostril condition. A possible explanation for this is that the both nostril condition allowed the activation of both the olfactory buffer and the phonological loop components of olfactory working memory.

A secondary finding of this study was that there was no observed significant relationship between odor name-ability and the ability to accurately label an odor or the ability to discriminate between new and previously experienced odors. This finding does not support the previous findings of Zelano et al. (2009) which found that perceived nameability was the major determiner of what component was active in processing olfactory working memory information. The data collected in this study was gathered in a contaminated testing environment and produced contaminated data. This present study illustrates the need to conduct more controlled and in-depth research on how the olfactory memory operates and displays how sensitive the olfactory system is and the need for a controlled testing environment.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT FORM

PROTOCOL TITLE: OLFACTORY WORKING MEMORY: THE ROLE OF PERCEIVED ODOR NAMEABILITY.

UNIVERSITY OF TENNESSEE AT CHATTANOOGA

Please read this consent document carefully before you decide to participate in this study. This research has been approved by the University Institutional Review Board.

Purpose of the research study:

The purpose of this study is to examine factors affecting olfactory working memory.

What you will be asked to do in the study:

A brief screening and questionnaire will be administered first. Following the screening and questionnaire you will be asked to smell a large set of odorants and provide information about the odors. You will then briefly leave the testing room and then return and smell a second set of odorants and provide information about the odors.

Time required:

1 hour

Risks and Benefits:

You may be exposed to odors you find undesirable to experience. You will be excluded from the study if you have asthma, allergies, epilepsy, are pregnant. Additionally, we do not anticipate that you will benefit directly by participating in this experiment.

Confidentiality:

Your identity will be kept confidential to the extent provided by law. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file in my faculty supervisor's office. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

Voluntary participation:

Your participation in this study is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:

You have the right to withdraw from the study at any time without consequence.

Whom to contact if you have questions about the study:

Student Researcher: Spencer MacAdams
spencer-macadams@utc.edu
Faculty Advisor: Dr. David Ross
david-ross@utc.edu

Agreement:

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant: ____________________________________ Date: _________________

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact Dr. Bart Weathington, Chair of the Institutional Review Board, at 423-425-4289. Additional contact information is available at www.utc.edu/irb

APPENDIX B

DEMOGRAPHICS QUESTIONNAIRE

Name:______________________

Age:______

Gender: ___________________

Race:______________________

Class Year:__________________

How many cigarettes do you smoke a day?:____________________________

How would you rate the congestion are your nasal passageways on a scale of 0-10, with 0 indicating no congestion and 10 indication completely congested: _________

APPENDIX C

TIME 1 RESPONSE PACKETS

Name:________________________

Condition: **BOTH NOSTRILS**

ATTACH LABEL CARD HERE

Odor Identification: Please write in the space provided below what you believe the name of the odor is.

Odor Label: ________________________

Odor Name-ability: Please circle the response on the scale below that indicates how accurately your label describes the odor.

(1 = Not at all) (4 = somewhat accurately) (7 = Very Accurately)

○	○	○	○	○	○	○
1	2	3	4	5	6	7

Odor Familiarity: Please circle the response on the scale below that indicates how familiar the odor is.

(1 = Not at all) (4 = somewhat familiar) (7 = Very familiar)

○	○	○	○	○	○	○
1	2	3	4	5	6	7

Name:________________________

Condition: **LEFT NOSTRIL**

ATTACH LABEL CARD HERE

Odor Identification: Please write in the space provided below what you believe the name of the odor is.

Odor Label: ________________________

Odor Name-ability: Please circle the response on the scale below that indicates how accurately your label describes the odor.

(1 = Not at all) (4 = somewhat accurately) (7 = Very Accurately)

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7

Odor Familiarity: Please circle the response on the scale below that indicates how familiar the odor is.

(1 = Not at all) (4 = somewhat familiar) (7 = Very familiar)

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7

Name:________________________

Condition: **RIGHT NOSTRIL**

ATTACH LABEL CARD HERE

Odor Identification: Please write in the space provided below what you believe the name of the odor is.

Odor Label: ________________________

Odor Name-ability: Please circle the response on the scale below that indicates how accurately your label describes the odor.

(1 = Not at all) (4 = somewhat accurately) (7 = Very Accurately)

○	○	○	○	○	○	○
1	2	3	4	5	6	7

Odor Familiarity: Please circle the response on the scale below that indicates how the odor is.

(1 = Not at all) (4 = somewhat familiar) (7 = Very familiar)

○	○	○	○	○	○	○
1	2	3	4	5	6	7

APPENDIX D

TIME 2 RESPONSE PACKET

Name:________________________

Condition: **BOTH NOSTRILS**

ATTACH LABEL CARD HERE

Instructions:

Please indicate if this odor is Old meaning you smelled this odor previously in this experiment, or if the odor is New meaning that you have not smelled this odor in this experiment previously.

OLD ⟷ **NEW**

Odor Identification: Please write in the space provided below what you believe the name of the odor is.

Odor Label: ___________________________

Name:________________________

Condition: **RIGHT NOSTRIL**

ATTACH LABEL CARD HERE

Instructions:

Please indicate if this odor is Old meaning you smelled this odor previously in this experiment, or if the odor is New meaning that you have not smelled this odor in this experiment previously.

OLD ⟵————————————⟶ **NEW**

Odor Identification: Please write in the space provided below what you believe the name of the odor is.

Odor Label: __________________________

Name:________________________

Condition: **LEFT NOSTRIL**

ATTACH LABEL CARD HERE

Instructions:

Please indicate if this odor is Old meaning you smelled this odor previously in this experiment, or if the odor is New meaning that you have not smelled this odor in this experiment previously.

OLD ⟵――――――――――――――⟶ **NEW**

Odor Identification: Please write in the space provided below what you believe the name of the odor is.

Odor Label: ________________________

APPENDIX E

IRB APPROVAL LETTER

MEMORANDUM

TO:	Spencer MacAdams Dr. David Ross	**IRB # 12- 158**
FROM:	Lindsay Pardue, Director of Research Integrity Dr. Bart Weathington, IRB Committee Chair	
DATE:	October 31, 2012	
SUBJECT:	IRB # 12-158: Olfactory Working Memory: The Role of Odor Name-ability.	

The Institutional Review Board has reviewed and approved your application and assigned you the IRB number listed above. You must include the following approval statement on research materials seen by participants and used in research reports:

The Institutional Review Board of the University of Tennessee at Chattanooga (FWA00004149) has approved this research project #12-158.

Please remember that you must complete a Certification for Changes, Annual Review, or Project Termination/Completion Form when the project is completed or provide an annual report if the project takes over one year to complete. The IRB Committee will make every effort to remind you prior to your anniversary date; however, it is your responsibility to ensure that this additional step is satisfied.

Please remember to contact the IRB Committee immediately and submit a new project proposal for review if significant changes occur in your research design or in any instruments used in conducting the study. You should also contact the IRB Committee immediately if you encounter any adverse effects during your project that pose a risk to your subjects.

For any additional information, please consult our web page http://www.utc.edu/irb or email instrb@utc.edu

Best wishes for a successful research project.

VITA

Spencer MacAdams is a Connecticut native who completed his Bachelor of Science degree at Stetson University of Florida in Psychology. After graduation he attended the University of Tennessee at Chattanooga to complete his Master's degree in Research Psychology under the supervision of Dr. David Ross. His interests are a combination of biological psychology and pharmacology.