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Essence: Olfactory Interfaces for Unconscious Influence of Mood and Cognitive Performance

Judith Amores
MIT Medialab,
Cambridge, MA, USA
amores@mit.edu

Pattie Maes
MIT Medialab,
Cambridge, MA, USA
pattie@mit.edu

ABSTRACT

The sense of smell is perhaps the most pervasive of all senses, but it is also one of the least understood and least exploited in HCI. We present Essence, the first olfactory computational necklace that can be remotely controlled through a smartphone and can vary the intensity and frequency of the released scent based on biometric or contextual data. This paper discusses the role of smell in designing pervasive systems that affect one's mood and cognitive performance while being asleep or awake. We present a set of applications for this type of technology as well as the implementation of the olfactory display and the supporting software. We also discuss the results of an initial test of the prototype that show the robustness and usability of Essence while wearing it for long periods of time in multiple environments.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation: Miscellaneous

Author Keywords

Olfactory Interfaces; Wearable Computers; Behavior Change; Unconscious; Pervasive; Prototyping/Implementation; Fabrication; Fashion/Clothing; Health - Wellbeing; Smell.

INTRODUCTION

A considerable amount of effort in HCI has been directed to make the user experience more seamless, natural and integrated in our physical lives. When designing user interfaces, we aim to create tools that will enable the user to accomplish certain tasks with a minimum effort, time and difficulty. When evaluating these tools, we take into account individuals perception of the system such as utility, easy of use and efficiency. However, we tend to consider the user as a conscious thinking mind. In reality, a lot of our perception of the environment and our behavior is unconscious and does not involve deliberate rational thinking.

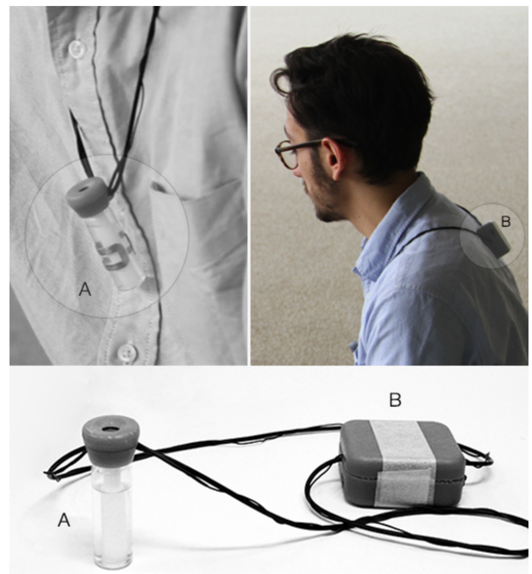

Figure 1. The Essence necklace. (A) A 3D printed cover holds the piezoelectric on top of the cotton stick filter, soaking up the fragrance from the container. Once the fragrance is depleted, the user can easily unscrew the cap and refill the container. (B) Back part of the necklace that contains the micro-controller and the rest of electronics to control the release of scent.

We perceive the world indirectly by processing and interpreting the raw data from our senses and our thoughts and behavior are frequently biased by our senses [21, 26, 25].

Among the so-called "five senses", olfactory perception takes an exceptional position in the neurological processing of sensory stimuli. The olfactory bulb has direct connections to the two brain areas that control emotions and memories: the amygdala and hippocampus [37]. Interestingly the sense of sound, sight and touch do not pass through these brain areas, they are routed through the thalamus which is the reason why sound, sight and touch interrupt sleep [27]. This makes smell an especially interesting modality to use in human-machine interaction during sleep as well as wake states because it is processed by the brain but does not disrupt the ongoing brain processes as easily.

Scent has a hidden power in our behavior and the unconscious. Positive and negative emotions not only transfer between individuals through mimicry of vision and hearing but also through smell [11, 32, 12]. Other studies show that stress and anxiety can be reduced with the use of essential oils [36, 29]. Recent findings found that a single night of olfactory aversive conditioning during sleep, significantly reduced cigarette-smoking behavior in the wakefulness state and persisted for several days [5]. Such functional studies continue to remain in the realms of research laboratories. The main aim of Essence was to fabricate a technology that people could use in their daily life, without the need for medical assistance nor burdensome devices. In this paper we describe the design and implementation of the prototype and describe potential applications for HCI.

RELATED WORK

While scent has been widely explored in Psychology, Neuroscience, Chemistry and Art, the olfactory system has been less appreciated in the world of personal technologies. Current personal, wearable devices that promote wellbeing, such as fitness and sleep trackers, mostly make use of visual, auditory and the haptic stimuli. The HCI research community has formerly looked into some of the challenges and possibilities for smell-based technology [33, 24, 23]. Most recent HCI research and product development efforts have focused on enabling scent to become part of digital communications [4, 38, 34, 42, 9, 10]. Most systems use off the shelf aromas in their prototypes, focusing research efforts on the device itself. Ranasinghe et al. [35] explored the use of smell for digital communication, enabling the sharing of smell over the Internet. By recreating smell though form, Clayodor [22] explores the possibility of form as a user-controlled navigator for smell.

The state of the art in smell-enhanced technologies is mostly limited to non-portable and non-fashionable devices that cannot be comfortably used in everyday life situations. Some artists have explored the use of scent in fashion or using the body as an atomizer [41, 28]. ICT Scent Collar [20] it is a scent delivery device in the form factor of a collar or bib that is meant to be used in a virtual environment. The "Smoke Dress" by artist Anouk Wipprecht [44] releases a cloud of smoke when it detects a person approaching. "Climate Dress" has an array of LEDs that light up depending on the CO2 levels in the air [13].

We propose Essence, a wearable olfactory display that was designed to be lightweight, fashionable and comfortable enough for people to be used in daily life. The main contributions that are distinct from previous work are the design of a fashionable olfactory necklace that is wirelessly-controlled and can be used in every-day life situations as well as the automated control of that device based on contextual and physiological data of the user. We also propose a set of novel applications for this type of technology that make use of biometric and contextual information in order to intervene with scent in particular instances.

SYSTEM DESCRIPTION

In order to make the prototype aesthetically appealing and as light as possible, most of the electronic components and the battery of the necklace are placed at the back of the neck so as to be hidden (see Figure 1).

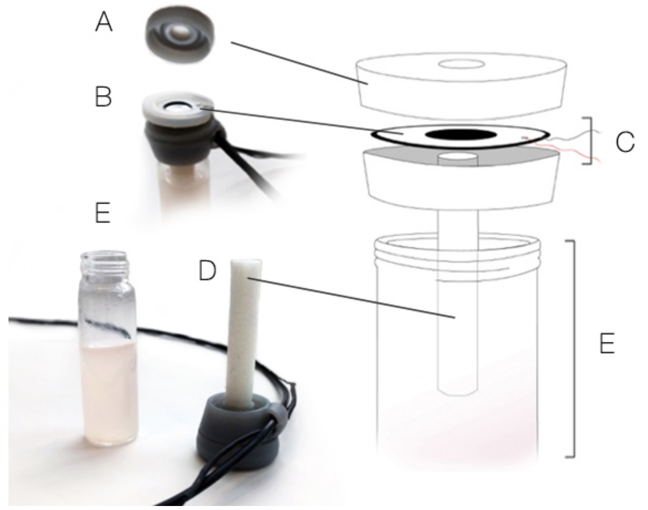

Figure 2. (A) 3D printed cover that protects and holds (B) a piezoelectric transducer with a small metal plate that vibrates at high frequency to release the fragrance. The piezo is connected to the rest of the electronics through the thread. (C) are the GND and Vcc cables. (D) is the cotton stick filter that soaks the liquid from the container (E).

A variety of form factors and materials were considered to make the prototype pretty, functional and comfortable (see Figure 3). One of our goals was to make the necklace as small and lightweight as possible so as to be comfortable enough to be worn on the neck all day and potentially all night, so that ideally the back part of the necklace would be flexible and neck-adaptable (see Figure 3 C).

Scent Release

The front part of the necklace holds a container with an encapsulated piezoelectric transducer that controls the release of the scent (see Figure 2). In order to make the piezoelectric vibrate, it needs a frequency of 100KHz, 10VAC (20Vpp). Alternating current (AC) voltage makes the plate oscillate at the same frequency and produce ultrasonic sound. These ultrasonic sounds are inaudible to the user, but they are capable of breaking the water into small particles that look like vapor. Therefore, the device transforms the fragrance/essential oil from the container into a fine mist, instantaneously distributing the scent all around the necklace. Essence has 7ml capacity that can operate for 27-28 hours with continuous 1-20-sec release. The default duty cycle frequency of 1 second of scent every 20 seconds was chosen to assure there was enough time in between burst for the smell to fade, while being enough noticeable for the average user (avoiding habituation and desensitization [8]).

Scent Selection

We used 3 different types of scents. One is natural essential oil commonly used in Aromatherapy (like lavender, peppermint, eucalyptus, etc.), the second type are fragrances, perfumes and diluted oils. Finally, we tried some experimental odor-less scents and pheromone perfumes that claim to use a patented blend of "human pheromones" including Androstadienone,

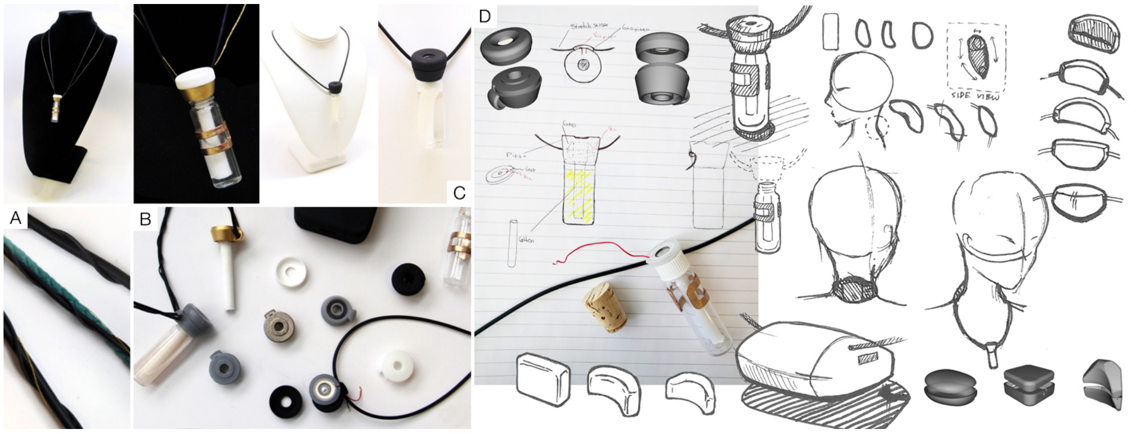

Figure 3. A) Close up of the different braided cables and cords of the Essence necklace (including conductive cord and Vcc/GND cables). The cord is 2mm diameter made of carbon-black impregnated conductive rubber. B) 3D printed results from Shapeways and Formlabs. C) Final design with small decorative gold/bronze-style accessories. The necklace is approximately located 7 inches from the nose (enough to reach the nose and not be too noticeable by the user). D) Design and fabrication of the Essence necklace.

Androstenol, Androstenone and Androsterone [2, 1]. Aside from pheromone perfumes, Essence can also be used with liquid forms of hormones or other types of medicines such as Oxytocin nasal sprays.

Conductive Thread

Usually jewelry string serves only as a decorative element, the materials used for necklaces or other wearable jewelry do not include electronic components or cables. In this prototype we braided two cables (Vcc and GND) with a conductive rubber cord stretch sensor (see Figure 3.A). Therefore, the thread not only serves as a decorative component but also as a connector between the microcontroller and the piezoelectric. The necklace thread is a key element in the design of the wearable since it transfers power and data from the back part of the necklace to the piezoelectric (front part). The sensor measures stretch forces: as you pull on it, the resistance increases. When these values go over a certain threshold the scent is released. The necklace can also release the scent without manual activation and can be controlled to release scent automatically without user involvement, for example based on physiological sensor data.

Wireless Communication

To endow the necklace with communication capabilities to be remotely controlled through the smartphone Android application, we used a microprocessor that controls the whole system and a Bluetooth Low Energy (BTLE) board that implements the wireless communication with the smartphone. When activated, the default values are 1 second of burst of scent every 20 seconds, additionally the user can manually release extra bursts of scent by pulling the necklace down. The system is powered with a 3.7V Lithium Battery. The user can easily charge the necklace through a small USB micro connector and additionally there is a turn on/off button. The microprocessor is an ATmega32u4, the hardware interface to transfer the commands is UART.

Physiological Data and Context Awareness

The system is capable of releasing scent based on context data from the smartphone such as location (GPS), date and current time. We also experimented with releasing scent based on physiological data such as Heart Rate, Electrodermal Activity and brain activity. For the HR and EDA we used the E4 Wristband [16]. In the case of brain activity we used the EEG MUSE Headband [31] to detect the concentration levels accordingly to the brainwave frequency. We detect when the user is emitting Gamma brainwaves - usually seen in states of peak performance, high focus and concentration. These values increase when the user is focused and directs his/her attention with intensity. We mapped the values from 0 to 1 and synchronized them with the burst of scent.

APPLICATIONS

Sleep and Memory

Sleep has been identified as a state that optimizes the consolidation of memories [40, 14]. Neuroscientists conducted laboratory studies that cued new memories in humans during sleep by presenting an odor that had been presented as context during a prior learning episode, and showed that reactivation indeed causes memory consolidation during sleep [14, 6]. These medical studies suggest that the optimal learning point occurs when memories are processed in SWS (Slow Wave Sleep) and REM sleep (Rapid Eye Movement). Work on [5] supports the need for detecting biometric information of the user to ensure that scent are released at a specific point in time.

Using Essence users could benefit from these studies and experiment outside of laboratories, for example while they are sleeping at their homes. The convenience of having a portable device that can be used anywhere will help to deploy the device for larger number of users and make it possible to analyze the biometric data and contextual information collected by the smartphone.

Learning and Cognitive Performance

It has been proved that peppermint scent promotes a general arousal of attention, and that it causes people to stay focused on their task and increases their concentration [39]. It has also been proven that memory recall can be improved by presenting contextual stimuli that were present at the time memories were recorded [7, 17]. Essence can release a specific scent while a user is studying and then help them retrieve the learned facts by releasing the same scent again. Other use cases could potentially help a person concentrate or focus, like when meditating or doing yoga.

Social Interactions and Immersive Environments

When coupled with Virtual Reality or Mixed Reality, the addition of smell significantly enhances the sense of immersion to augment digital experiences and creates a more complete sensorial experience [45]. Beyond immersive systems we could also use Essence as a subtle way of communication among remote users.

In a physical social interaction, people are constantly using their sense of smell. Even though we are not very aware of doing so, our brain is responding to odors [37, 15]. Odor-less scents like pheromones or hormones can be used to remotely intersect users' realities and perceptions [43, 30, 19]. As previously mentioned in this paper, chemical signals communicate human emotions [11, 12, 32]. We secrete different odors depending on the emotional state that we are in, such as the "smell of fear" or "aggression". We may induce pleasurable scents, mask body odors, or may put subjects into a state of high suggestibility. Using olfactory devices like Essence, the user can have complete control over the secreted scent signals that could potentially trigger stronger social responses between subjects.

As mentioned in the "Physiological Data and Context Awareness" section, Essence is capable of using date, location and time information. A remote user could remotely control the necklace and release the scent at a certain location or time of the day as a means of subliminal messaging and notifications as if "I am thinking of you" or "I am worried". For example, if the user goes to the doctor and stress levels go beyond a certain threshold, the remote wearer could sense the "scent of fear", increasing empathy between them. The remote person could then trigger a nice scent to calm the stressed person down, or the system itself could automatically release a burst of scent when the doctor's location is detected.

Wellbeing

There are a variety of application scenarios related to health purposes ranging from using Essence for mindfulness and meditation or as a personal, wearable device for cold and flu treatment, allergies, asthma or other respiratory problems to beauty treatments like face moisturizer for dry skin. In the same way, we could potentially release the scent of lavender or vanilla to reduce stress levels or pain for diseases like cancer. Studies have already shown that stress and anxiety can be reduced with the use of essential oils. Researchers administrated Heliotropin (a vanilla fragrance) to patients undergoing cancer treatment [36]. The results reported that the administration of fragrance was associated with 63% less anxiety versus placebo effect.

TESTS

We conducted a set of tests to evaluate Essence in a mobile, everyday life context. We were mainly interested in testing the robustness and usability of the prototype for long periods of time in multiple scenarios.

4 participants (men, with a mean of 29 years old) were asked to use the necklace during 3 days in 6 different campus locations (3 indoor and 3 outdoor). The participants reported not using accessories or necklaces in their daily life (a drawback that might bias against the study).

The type of scents used were tea tree, peppermint and rose. The smell selection was based on previous studies that examined how "positive" fragrances induce feelings of relaxation, reduced anxiety and alertness [29, 36, 39].

Evaluation

We used computer-based surveys, questionnaires and in-person final interview to gain an understanding of the participants' perception of the system.

Users were asked to fill out a questionnaire and a survey about their experience wearing the necklace for each one of the environments. The questionnaires asked to rank ease of use, satisfaction and comfort of the necklace.

The questions of the surveys were related to the feel of the necklace and the intensity and frequency of the scent to identify opportunities for improvement. Some of the questions related to the olfactory experiences included awareness of the scent and the necklace, intensity, pleasantness, distraction or to what extent the scent helped them relax or focus.

Results

The results of the initial testing of the prototype show that the Essence prototype is robust and usable enough to be used for long periods of time in multiple environments. The necklace successfully worked during all the tests and participants ranked the experience of wearing the Essence necklace very positively Figure 4. The results suggest that users generally found easy and effortless to wear the necklace.

User Experience

When asked to describe the experience of wearing the necklace in different environments, participants mentioned: "Effortless, it was nice to feel the good smell from time to time", "Most of the time I completely forgot it was there, except for some moments when the scent suddenly became more noticeable, either stronger or just different. However even when it was noticeable it was pleasant, it never became an inconvenience." "The scents were pleasant and relaxing and otherwise I hardly noticed it was there." "It was very seamless, and enhanced the environment nicely." "The necklace wasn't too invasive. I did feel some weight of the device in the back of my neck, but quickly forgot about it".

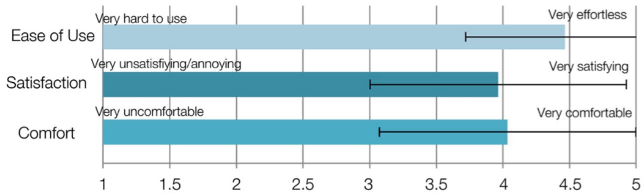

Figure 4. The chart show user feedback (P=4) where 5 = very effortless, very satisfying and very comfortable, suggesting that users found the system easy to use and were satisfied overall with the experience of wearing the necklace. Ease of use (mean = 4.464, std = 0.744), satisfaction (mean = 3.964, std = 0.961), and overall comfort (mean = 4.035, std = 0.961).

Awareness

When asked to rank how aware they were of the necklace, most of the users mentioned that they were not aware (mean of 2, were 1 is "not at all", and 5 is "very much"). However, although the mean was 2, one of the participants ranked negatively the necklace and mentioned he was aware of it all time because the scent was too strong for him, especially the Peppermint (mean of 3.4). Another interesting thing happened with P11, he ranked awareness in all situations "1" - as if he was not aware of the necklace, however in day 2, he ranked the necklace as "5" - very aware, because the scent was "too strong" for him. Interestingly, the type of scent and intensity were exactly the same in day 1, but then he ranked it as "1" - not aware of the necklace. That day, in the report he wrote, "I am almost not aware of the necklace. However, I could smell the scent much less at the beginning. Seems like I need some time to get used to the smell. Maybe it's because I was biking right before doing the study."

Intensity and Frequency of Scent

The prototype released a burst of scent every 20 seconds (1 second per burst). As mentioned in the System Description section of this paper, this is a default duty cycle that can be changed by the user. In the surveys we asked if they would increase or decrease the intensity or timing of every burst of scent. The results were completely different for each person. For example, P10 would increase the intensity of scent in all conditions, whereas for P12 the scents were too strong so he wanted to decrease them. In the same condition, P12 ranked as "decrease intensity during this session. Too strong!", while the rest of participants mentioned "just about right" or "increase". Based on that feedback we confirmed how important was for the user to be able to control the intensity and duration of the scent depending on their preferences.

Use cases and Feedback

In the final survey, participants were asked if they would wear the essence necklace in their daily life and in what kind of cases they would use it. Some participants responded they would use the necklace for meditation sessions, relaxing and concentration. Some users mentioned they would prefer to use it in private spaces since they do not usually wear necklaces in public. Potential improvements people mentioned were the ability to control intensity, and make the back part of the necklace smaller and more compact.

Limitations and Findings

We conducted an initial testing of the prototype with a small number of participants that shows a robust prototype that can be used in every-day life situations. The user tests show an overall comfort, ease of use and satisfaction wearing the necklace. Further study is required, including a larger sample size and increased variety in participants' demographics (olfactory perception differs by gender, age and culture [18]).

In the following paragraphs we provide some of the qualitative findings, limitations and recommendations for future designs of olfactory devices based on users experiences'.

Customizable Bursts

In general, during the study and while interviewing people, we corroborated how different people's perceptions are in regard to smell. While for one person the scent was not strong enough, for the other it was too much. While some of them loved the Peppermint scent, others did not like it at all. The preferences even vary from day to day within the same person. The feedback provided through the final interview and surveys show the importance for future designs of olfactory devices of creating systems that can be controlled by the user depending on their preferences (augmenting/decreasing intensity and frequency of the scent like Essence).

Limitations and Potential Improvements

Some potential limitations of the current prototype are the refilling need and the limit of one scent at a time. Although the refilling need depends on the duty-cycle chosen by the user, it is important to take into account for future designs of olfactory interfaces habituation and desensitization and the limits of intensity and frequency of scent (mentioned in the Scent Release section of this paper).

Promising improvements for future designs of olfactory devices include the miniaturization of the back part of the necklace, the use of flexible materials or soft electronics and to have a design that can accommodate multiple scents in one. These improvements are specially relevant for night usage and to enable use of scent for multiple use cases without the need to replace the container (e.g. peppermint to focus while studying, lavender to relax, and rose for sleep).

CONCLUSION AND FUTURE VISION

We presented Essence, a wearable olfactory display that can be controlled manually or automatically to release subtle bursts of scent. We designed a fashionable and comfortable necklace that can be used in daily life. The results of the tests show that it is important for future olfactory devices to let the users change the default duty cycle and to have a customizable system like Essence.

In future work we would like to deploy several of the Essence prototypes so we can conduct user studies in different environments, for longer periods of time and while the person is awake and sleeping. We also want to further develop the smartphone app so the user can configure biosensor-data based release rules similar to https://ifttt.com/. For example, "if X and Y then release scent for Z intensity and W frequency".

The result could be personal, wearable devices that will promote health and wellbeing in very different ways than today's fitness and sleep trackers. We believe that in the future users will be able to use this kind of systems to facilitate memory consolidation for learning purposes, enhance mood and wellbeing. We hope Essence will encourage discussion within the community and open up contributions in the promising area of olfactory devices for HCI systems.

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REFERENCES

1. 2016. Love Scent. (2016). http://love-scent.com/
2. 2016. Raw Chemistry. (2016). https://rawchemistry.com/
3. Judith Amores. 2016. *Essence : Olfactory interfaces for unconscious influence of mood and cognitive performance*. Master's thesis. Massachusetts Institute of Technology. http://hdl.handle.net/1721.1/106061
4. Aromajoin. 2016. AromaShooter. (2016). https://aromajoin.com/
5. A. Arzi, Y. Holtzman, P. Samnon, N. Eshel, E. Harel, and N. Sobel. 2014. Olfactory Aversive Conditioning during Sleep Reduces Cigarette-Smoking Behavior. *Journal of Neuroscience* 34, 46 (2014), 15382–15393. DOI: http://dx.doi.org/10.1523/JNEUROSCI.2291-14.2014
6. Anat Arzi, Limor Shedlesky, Mor Ben-Shaul, Khitam Nasser, Arie Oksenberg, Ilana S Hairston, and Noam Sobel. 2012. Humans can learn new information during sleep. *Nature neuroscience* 15, 10 (2012), 1460–5. DOI: http://dx.doi.org/10.1038/nn.3193
7. Benedict Carey. 2014. *How We Learn: The Surprising Truth About When, Where, and Why It Happens.* Random House, New York, USA.
8. Dipesh et al. Chaudhury. 2010. Olfactory Bulb Habituation to Odor Stimuli. *Behavioral neuroscience* (2010).
9. Parsani R. Pandey A. V. Roman X. Cheok-A. D. Choi, Y. 2013. Light perfume: a fashion accessory for synchronization of nonverbal communication.. In *Leonardo*. 439–444.
10. Yongsoon Choi, Adrian David Cheok, Xavier Roman, The Anh Nguyen, Kenichi Sugimoto, and Veronica Halupka. 2011. Sound Perfume: Designing a Wearable Sound and Fragrance Media for Face-to-face Interpersonal Interaction. In *Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology (ACE '11)*. ACM, New York, NY, USA, Article 4, 8 pages. DOI: http://dx.doi.org/10.1145/2071423.2071428
11. J. H. B. de Groot, M. A. M. Smeets, A. Kaldewaij, M. J. A. Duijndam, and G. R. Semin. 2012. Chemosignals Communicate Human Emotions. *Psychological Science* 23, 11 (2012), 1417–1424. DOI: http://dx.doi.org/10.1177/0956797612445317
12. J. H. B. de Groot, M. A. M. Smeets, M. J. Rowson, P. J. Bulsing, C. G. Blonk, J. E. Wilkinson, and G. R. Semin. 2015. A Sniff of Happiness. *Psychological Science* (2015), 0956797614566318–. DOI: http://dx.doi.org/10.1177/0956797614566318
13. Diffus Design. 2009. Climate Dress. (2009). http://www.diffus.dk/climate-dress/
14. Susanne Diekelmann and Jan Born. 2010. The memory function of sleep. *Nature reviews. Neuroscience* 11, 2 (2010), 114–26. DOI:http://dx.doi.org/10.1038/nrn2762
15. Dina Marie Zemke, Stowe Shoemaker. 2008. A Social Atmosphere: Ambient Scent's Effect on Social Interaction. *Cornell Hospitality Quarterly.* (2008).
16. Empatica. 2016. E4 Wristband. (2016). http://www.smell.dating/
17. Kleinbard Jeff. Erdelyi, Matthew H. 1978. Has Ebbinghaus decayed with time? The growth of recall (hypermnesia) over days . *Journal of Experimental Psychology: Human Learning and Memory* (1978), 275–289.
18. Camille Ferdenzi, S. Craig Roberts, Annett Schirmer, Sylvain Delplanque, Sezen Cekic, Christelle Porcherot, Isabelle Cayeux, David Sander, and Didier Grandjean. 2013. Variability of Affective Responses to Odors: Culture, Gender, and Olfactory Knowledge. *Chemical Senses* 38, 2 (2013), 175–186. DOI: http://dx.doi.org/10.1093/chemse/bjs083
19. Camille et al. Ferdenzi. 2016. Androstadienone's influence on the perception of facial and vocal attractiveness is not sex specific. *Psychoneuroendocrinology* 66 (2016).
20. Inc. with Donat-Pierre Luigi. Jacki Morie. Fabricated by Anthrotronix. 2005. ICT Scent Collar. (2005). http://ict.usc.edu/wp-content/uploads/212/03/ScentCollarBrochure1.pdf
21. Daniel. Kahneman. 2012. *Thinking, Fast and Slow.*
22. E. Amores J. Leigh S. W. Benavides-X. Maes P. Ishii H. Kao, C. Dreshaj. 2015. clayodor : Retrieving Scents through the Manipulation of Malleable Material. *TEI 2015* (2015). DOI: http://dx.doi.org/10.1145/2677199.2688814
23. J. "Jofish." Kaye. 2001. *Symbolic Olfactory Display*. Master's thesis. Massachusetts Institute of Technology, Cambridge, MA.
24. J. "Jofish." Kaye. 2004. Making Scents: Aromatic output for HCI. *Magazine Interactions. Volume 11, Issue 1* (2004), 48–61.

25. Thalma Lobel. 2014. *Sensation: The New Science of Physical Intelligence.*

26. Kevin Lynch. 2015. Subliminal: How Your Unconscious Mind Rules Your Behavior, by Leonard Mlodinow (Vintage Books, 2013). *Journal of Consciousness Studies* 22, 9-10 (2015), 229–234.

27. Rachel S. Herz Mary A. Carskadon. 2004. Minimal olfactory perception during sleep: why odor alarms will not work for humans. *Sleep* (2004).

28. Lucy McRae. 2011. Swallowable Parfum. (2011). http://swallowableparfum.com

29. Tiffany Field Maria Hernandez-reif Saul Schanberg Cynthia Kuhn Mary Galamaga Virginia McAdam Robert Galamaga Miguel A. Diego, Nancy Aaron Jones. 1998. Aromatherapy positively affects mood, EEG patterns of alertness and math computations. *International Journal of Neuroscience* (1998).

30. K Mizuno, N Mizuno, T Shinohara, and M Noda. 2004. Mother-infant skin-to-skin contact after delivery results in early recognition of own mother's milk odour. *Acta Paediatrica* (2004).

31. Muse. 2016. Muse, the brain sensing headband. (2016). http://www.choosemuse.com/

32. Smiljana Mutic, Valentina Parma, Yvonne F. Brünner, and Jessica Freiherr. 2016. You smell dangerous: Communicating fight responses through human chemosignals of aggression. *Chemical Senses* 41, 1 (2016), 35–43. DOI: http://dx.doi.org/10.1093/chemse/bjv058

33. Marianna Obrist, Alexandre N Tuch, and Kasper Hornbaek. 2014. Opportunities for Odor: Experiences with Smell and Implications for Technology. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2014), 2843–2852. DOI: http://dx.doi.org/10.1145/2556288.2557008

34. Onotes. 2015. Ophone. (2015). http://www.onotes.com/ophone2/

35. Nimesha Ranasinghe, Kasun Karunanayaka, Adrian David Cheok, Owen Noel Newton Fernando, Hideaki Nii, and Ponnampalam Gopalakrishnakone. 2011. Digital Taste and Smell Communication. In *Proceedings of the 6th International Conference on Body Area Networks (BodyNets '11)*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), ICST, Brussels, Belgium, Belgium, 78–84. http://dl.acm.org/citation.cfm?id=2318776.2318795

36. William H. Redd, Sharon L. Manne, Bruce Peters, Paul B. Jacobsen, and Hilary Schmidt. 1994. Fragrance administration to reduce anxiety during MR imaging. *Journal of Magnetic Resonance Imaging* 4, 4 (jul 1994), 623–626. DOI: http://dx.doi.org/10.1002/jmri.1880040419

37. Regina M. Sullivan, Donald A. Wilson, Nadine Ravel, Anne-Marie Mouly., and Bryan Raudenbush. 2015. Olfactory memory networks: form emotional learning to social behaviors. *Front. Behav. Neuroscience 17* (2015).

38. Scentee. 2013. (2013). http://www.scentee.com/

39. Shannon Barker, Palema Grayhem, Jerrod Koon, Jessica Perkins, Allison Whalen and Bryan Raudenbush. 2003. Improved Performance on Clerical Tasks Associated with Administration of Peppermint Odor. *Perceptual and Motor Skills* (2003), 1007–1010.

40. Robert Stickgold. 2012. To sleep, perchance to learn. *Nature* 15, 10 (2012), 1322–1323. DOI: http://dx.doi.org/10.1038/384037a0

41. Jenny Tillotson and Adeline. Andre. 2005. Smart Second Skin. University of the arts London. (2005). http://ualresearchonline.arts.ac.uk/5570/

42. R. Strong W. Gaver. 1996. Feather, scent, and shaker: Supporting simple intimacy. *Proceedings of CSCW'96* (1996).

43. Claus Wedekind, Thomas Seebeck, Florence Bettens, and Alexander J. Paepke. 1995. MHC-Dependent Mate Preferences in Humans. *Proceedings of the Royal Society of London B: Biological Sciences* 260, 1359 (1995), 245–249. DOI: http://dx.doi.org/10.1098/rspb.1995.0087

44. Anouk Wipprecht and Niccolo Casas. 2012. Smoke Dress. (2012). http://www.niccolocasas.com/SMOKE-DRESS/

45. Tomoya Yamada, Satoshi Yokoyama, Tomohiro Tanikawa, Koichi Hirota, and Michitaka Hirose. 2006. Wearable Olfactory Display: Using Odor in Outdoor Environment. In *Proceedings of the IEEE Conference on Virtual Reality (VR '06)*. IEEE Computer Society, Washington, DC, USA, 199–206. DOI: http://dx.doi.org/10.1109/VR.2006.147