On-Face Olfactory Interfaces

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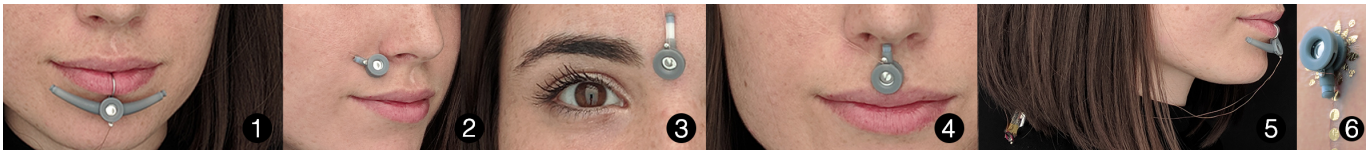

Figure 1. We explored different form factors that can be used as a nose-ring (4), mouth piercing (1) for olfactory-gustatory interfaces as well as jewelry-like accessories placed directly on the skin (2) (3), integrated with tattoos or clipped on glasses, hats or sewn into fabrics. The cable that connects to the PCB is merged with the metallic tattoo (6) and can be hidden behind the ear, in the back part of the neck (5), or as a hair clip.

ABSTRACT

On-face wearables are currently limited to piercings, tattoos, or interactive makeup that aesthetically enhances the user, and have been minimally used for scent-delivery methods. However, on-face scent interfaces could provide an advantage for personal scent delivery in comparison with other modalities or body locations since they are closer to the nose. In this paper, we present the mechanical and industrial design details of a series of form factors for on-face olfactory wearables that are lightweight and can be adhered to the skin or attached to glasses or piercings. We assessed the usability of three prototypes by testing with 12 participants in a within-subject study design while they were interacting in pairs at a close personal distance. We compare two of these designs with an "off-face" olfactory necklace and evaluate their social acceptance, comfort as well as perceived odor intensity for both the wearer and observer.

Author Keywords

Olfaction; Olfactory Interfaces; Wearable Device; Scent Display; On-Face Interfaces; On-Face Wearables; Wearability; Jewelry; Fashion.

CCS Concepts

•**Human-centered computing** → **Interaction devices;**

*Both authors contributed equally to this work

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INTRODUCTION

Scientists have studied and shown how the sense of smell influences memory [33, 17], emotion, and behavior [1]. In the field of HCI, olfaction as a promising medium has gained more and more attention [28, 40, 20]. Researchers have created smell-enhanced technologies for toolkit design [26], gaming and immersive environments [29], augmented flavors [30, 38], notifications [12, 25], car-driving [11], well-being, emotion regulation, and sleep [2, 3]. More recently, researchers and designers have begun to create compact olfactory wearable devices for everyday use [3, 12, 35]. Unlike the other human senses, such as vision and hearing, scent is difficult to prototype with because of its unique characteristics (volatile, lingering, invisible).

Moreover, people have significantly variable scent perception and sensitivity [21]. An extra challenge is added when releasing scent at a large distance from the nose, since more fragrance is lingering in the air, causing potential habituation and desensitization [8]. Therefore, it is hard to control the amount of scent that is effectively inhaled by the target user and the scent may also affect other people in the vicinity.

In this paper, we aim to create a personal, close-to-the-nose olfactory display, which can release scent directly to the wearer's nose by shortening the scent delivery distance through a lightweight and fashionable wearable for everyday use.

RELATED WORK

Perfume is commonly worn in everyday life, however, the design of wearable, smell-enhanced technologies is still underexplored. Most of the olfactory displays in Human-Computer Interaction (HCI) are stationary [29, 11, 20]. Some researchers have developed head-mounted displays with wearable scent delivery [39, 30, 22], as well as neck-based wearables [4, 12]. A few researchers and designers have tried to create face-located scent delivery wearables. For instance, Choi et al. developed a pair of 3D-printed glasses embedded with a heating module for releasing the scent at the end of the frames[10, 9], while

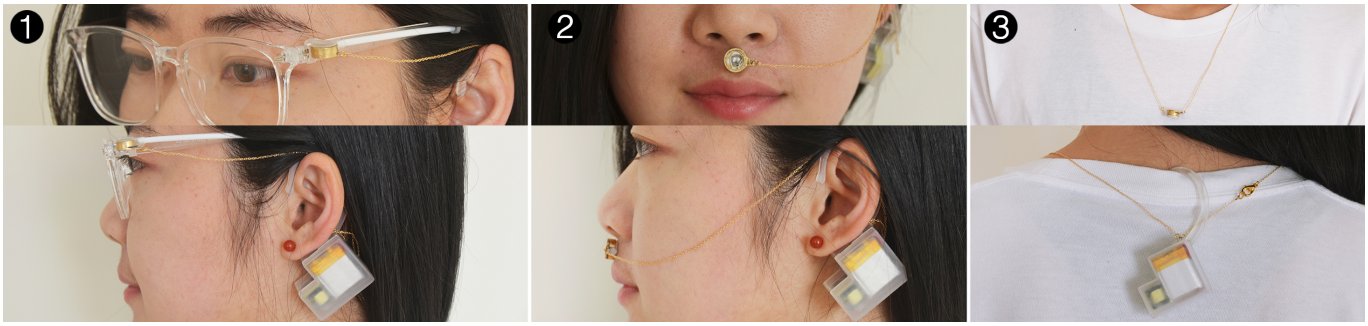

Figure 2. Prototypes that we used for the user study. 1) "Glasses" prototype, 2) "Nose" prototype, and 3) Olfactory necklace. Participants wear the PCB board and battery on their left ear for both on-face designs while hooking the holder at the back part of the cloth for the necklace.

Simun designed a non-digitized and artistic olfactory project [32]. However, although these devices are targeted to the user's nose, they are relatively far away from it. Therefore, when the devices are being used in public spaces or during social interactions, others might be able to notice it. In some cases, this can be beneficial, but in our research, we focus on specific scenarios where the user prefers to release scent in a personal and private way. The impact of scent in a social context has been explored in the past [7]. Researchers have shown how ambient scents can significantly increase the number of social interactions [43, 44] and encourage pro-social behavior like helping someone [16], increasing cleaning behavior [18], or subliminally guiding social likeability judgments [24]. Dunne et al. [13] presented a theoretical framework to understand how wearable products are perceived and evaluated in a social context. The social aspects of wearability are especially relevant when designing devices that are worn on the face. The social impact of non-traditional form factors such as on-skin interfaces located at the collarbone, ears, back of the neck, arms, forearms, and hands have been explored in the past [41].

Researchers and designers have, for decades, explored how digital technologies can be worn, minimizing weight and size, and experimenting with a variety of form factors [15]. Where to wear the device might be the very first question to be answered [42]. We focus on the face, as it is the closest body part to the nose and worthy of exploring when designing olfactory interfaces. Researchers have developed various interactive technologies and sensors that are attached or worn on the face, such as head-mounted displays (HMD), wearable electroencephalograms (EEG), or nose interfaces for nostril temperature recording [23]. Through the perspective of beauty technology, Kao et al. designed on-face dynamic color-changing eye shadow to create interactive body decorations [19]. As far as we are aware, little work in the area of on-face olfactory interfaces has been done so far, but we hope our work can be the start of more researchers looking into this promising area, building up a body of knowledge.

Our main contributions are the following: 1) Design of various forms for face-located olfactory displays; 2) Implementation of these prototypes, including mechanical and industrial design, explorations of form factor, aesthetics, face locations, as well as the technical test of lasting time; 3) User study comparing the usability, social acceptance and personal scent experience of on-face olfactory wearables in comparison with an off-face one; 4) Discussion and design considerations for future on-face olfactory interfaces.

DESIGN CHALLENGES AND RECOMMENDATIONS

The face is one of the most visible parts of the human body, providing important clues about our emotions, and being key to our identity. Therefore, it plays a significant role in social interactions. It also has three of the sense organs, including the nose, which is crucial for olfactory perception. By investigating existing face-located olfactory displays and jewelry-like olfactory wearable projects [10, 9, 32, 22, 35, 34], as well as our findings, we consider that the main challenges and considerations when designing on-face olfactory interfaces are the following:

1. **Miniaturization** The scent delivery device should be small and light to be minimally obtrusive and maximize comfort when being worn on the face. We recommend placing the PCB board and battery away from the face area, while the scent release mechanism stays on-face to minimize weight and distribute the dimensions of the prototype.

2. **Social acceptance and prototype placement** To maximize social acceptance, we recommend placing the prototype in a location that has been previously used for jewelry and piercings [36]. We located the prototypes along the lower lip, close to the nostril, and in the middle of the eyebrow with either piercings or skin-friendly stickers (see Figure 1). We recommend avoiding areas that are close to the eyes and ears to prevent irritation.

3. **Aesthetics** We recommend using materials, textures, and colors based on established adornment practices and social acceptance for specific demographics, gender, and cultures [36]. We fabricated our prototypes with off-the-shelf materials that are common in jewelry and the maker/DIY community (e.g., jewelry findings, golden leaf). These materials are accessible and cheap for prototyping. We chose them based on their aesthetic appearance, practicality, social acceptability, and skin-friendliness properties. Moreover, we also recommend choosing the material and aesthetics while taking into account the type of interactions that the users are going to perform when using the device [6].

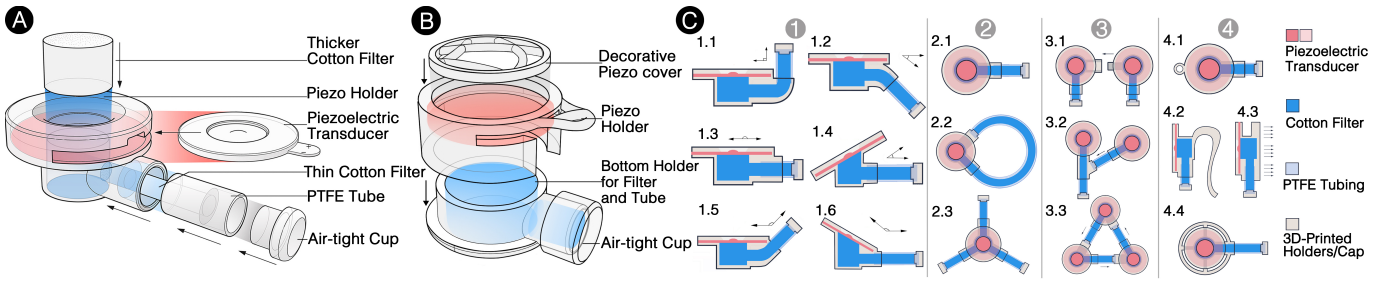

Figure 3. We designed two modular scent delivery holders, A) one-piece structure, and B) multi-part decorative structure. C) Design explorations of the scent release mechanism based on 1) Angle between the piezo and the tube. 2) Length and shape of the tube, 3) Assembly of multiple scent release, 4) Clip-on accessories or embeddings in jewelry and piercings. We adjusted these parameters based on the part of the face the prototype was designed to be placed on, ranging angles from 0 to 180 degrees. For example, if the scent release was placed along the lower lip, then we recommend using design 1.4. This design has an angle of 30 degrees, which will direct the scent towards the nose. In contrast, if the scent delivery is placed on the forehead, we used design 1.6.

In our prototypes, electronic wires are very thin and made with materials that resemble gold or bronze. They can be twisted and braided in chains, embedded in tattoos or piercings (see Figures 1, 2). We used enameled copper wire (D = 0.08mm) to connect the piezoelectrics to the PCB board and Polydimethylsiloxane (PDMS) protective layers for the tattoos (see Figure 1: image 6). Although the materials and colors we suggest are common in jewelry, further research is encouraged with other non-traditional materials such as flexible and biocompatible composites. We also recommend creating designs that are modular and that the user can customize depending on their preferences. In our prototypes, the scent container and the top part that covers the piezoelectric (scent delivery mechanism) can be replaced so users can select their preferred material. We used gold, rose, and silver leaf sheets used in art and gilding crafting as well as leafing pens to decorate the containers (see the right image in Figure 4).

Aesthetics is much more than just materials, textures, and colors. We also recommend engaging the culture-value orientations of participants as another aspect of aesthetics into design considerations when interacting and communicating with our devices as well as social and ethical dimensions and people's physical, cognitive, emotional, and social skills [31]. In our designs we aimed at designing for an inclusive and diverse pool of users with different cultures and genders.

4. **Olfactory perception** To ensure that the fragrance is only smelled by the wearer and not by people nearby, it is vital to direct the bursts towards the nostrils. However, if the prototype is too close to the nose, and the user is sensitive, they might be able to smell it before it is released due to lingering. Therefore, it is crucial to create an air-tight design that is clean before using it. On the other hand, due to the large variability in how each person perceives odors, it is also essential to let the user choose their preferred intensity and frequency of burst release (which is why we use a smartphone app to control these preferences).

5. **Skin-friendly** The 3D printed material, cable insulation, and fragrances should be skin-friendly due to their direct contact with the face. We recommend hydrosols, very diluted perfumes, or natural oils as well as digestible fragrances. The scent delivery part needs to be very well insulated and away from the principal electronic components to prevent lingering and potentially causing electrical short circuits. Piezoelectric transducers for scent delivery require high voltage, therefore, the cable that transmits power to the piezo must be insulated due to its direct contact with skin.

ON-FACE OLFACTORY INTERFACES

Industrial Design and Assembly

We explored 16 different form factors for on-face olfactory wearables (see Figures 1, 3 and 2). We made five final prototypes that were tested in a pilot study: an on-skin/nose piercing inspired design (placed in between nostrils and next to the nose), a mouth piercing, a tilaka-inspired design, a decorative piece in a tattoo and a pair of glasses. We then studied the usability of the glasses and nose prototypes in comparison to an olfactory wearable that we created based on previous work [4] (see Figure 2). All the designs have very similar structures that were reused in our design exploration. We propose two modular structures that both include a PTFE tube as a container of the fragrances, a 3D printed holder, a customized cotton filter, and a piezoelectric transducer to release scent.

Container

Previous work in the medical field and in HCI has used Teflon tubes made out of Polytetrafluoroethylene (PTFE) to transport the liquid or scented-air from the primary container, which is commonly made out of glass [39, 30]. Using a Teflon tube as the primary container can be beneficial for on-face interfaces since it is lightweight, thin, flexible, and easy to fabricate and mold. PTFE is a distinguished plastic that has a low coefficient of friction, making it resistant to a wide range of chemicals. PTFE has been widely used in the field of scientific research and medical products used in hospitals. We customized the tubes with various lengths. We experimented with sizes ranging from 1cm to 10cm and an inner diameter of 2.5mm. The tubes are flexible and can bend up to 45 degrees. The length of the tube is probably one of the most critical parameters that influences how much liquid can be contained and, therefore, what the lasting time of the scent release system

is before it depletes. Users can either use a linear design (see Figure 3, drawing 2.1) with a longer tube or a multi-channel design (see Figure 3, drawing 2.3) which will be able to hold the same amount of liquid but with a shorter length. The closed-loop design (see Figure 3, drawing 2.2) is an extended design of the linear one that can be used to simulate piercings or embed in circular accessories.

Scent Delivery Holder

We created two different designs to hold the cotton filter and protect the piezoelectric. They are both air-tight 3D printed structures built using Rhinoceros 3D, and 3D printed using the Formlabs 2 with a 0.025mm resolution and clear resin and were curated in the alcohol tank for less than 10 minutes to prevent deformations. Both designs consist of a PTFE tube and cotton filter that are inserted tightly into the holders. The user can inject the scented liquid using a 1ml syringe while an air-tight cap on the other end prevents leakage. Finally, a 10mm diameter piezo is inserted through the holders from the side and above the cotton filter.

The first design consists of a one-piece structure that holds the piezo, tubes, and cotton filters (see Figure 3, A). The second design (see Figure 3, B) consists of 1) a piezo holder, 2) a cotton and tube holder, 3) a decorative and removable piece that covers the piezo and can be cleaned or used for customization purposes. We chose the latest design for our user study due to its convenience and versatility.

Cotton Filter

The cotton filter absorbs the scented liquid from the container, transferring and supplying liquid for atomizing by being placed underneath the piezo. All the prototypes consist of 2 cotton filters; one is a commercial cotton (D = 7.5mm) that we cut to 3.6cm and placed underneath the piezo. The second is inserted into the tube and was customized to have a diameter of 1.5mm. The length of the filter should be the same as the tube to maximize the scent release.

Scent Release

We based our scent delivery mechanism on previous work [4, 3] and adapted the smartphone app as well as the microcontroller program to use a different piezoelectric that was smaller and that had different frequency (10mm and 108Khz). In comparison to previous work that used a 12mm and 110Khz piezo, our prototype uses a smaller one that releases less scent but is more than enough for on-face olfactory interfaces. We modified the Android app with different duration and intensity of the smell ranging from 1ms to 90ms. These values were chosen to release shorter bursts that could reach the user's nose but were not too intense.

Smell Distance and Lasting Time

The lasting time depends on the amount of liquid that the tube carries and how often the scent is released. We tested the linear design (see Figure 3, drawing 2.1) with a variety of lengths and amounts of liquid. The total number of bursts was recorded by setting the app for an automatic scent release of 30ms every second (starting when the tube was full until no scent was released). Our test shows that the final number of bursts given such a small container was large (ranging from 112 to 524; 2 to 8 hours) with an average burst height of 12.5cm. These results show how our designs can provide both short term and long term use even with a minimal amount of liquid (see Table 1 for details of the prototypes used in our study).

Prototype	*Tube Length*	*Liquid Amount*	*Number of bursts*
Glasses	70mm	0.45ml	372
Nose/Necklace	4.2mm	0.16ml	55

Table 1. The number of bursts generated with different amounts of liquid for all prototypes until depletion. We found that the results are not linearly correlated with the tube length and liquid amount. The cause might be the handmade cotton filters and the orientation of the prototype.

Potential Applications

Millions of people around the world suffer from stress, anxiety, and loss of attention, affecting their personal and professional lives. One of the most common sources of stress in the United States is work [5]. Stress and anxiety impact workplace performance, the quality of the work as well as the relationship with superiors and coworkers. Thus, a growing number of technologies aim to bring more calmness in people's daily life, and help them be more mindful and present in the moment. We believe that on-face olfactory interfaces could provide subtle cues for breathing exercises and support mindfulness practices in public settings, while working in an open office, library, or driving a vehicle, without disturbing others. We also envision that a close-to-nose interface could be used as a drug delivery device instead of using nasal cannulas or masks, to deliver a small amount of liquid medicine or hormones such as oxytocin directly to the nostrils throughout the day and night. On-face olfactory devices can be coupled with board or Virtual Reality games by transferring hidden information only to the wearer. We also envision that people could customize the aesthetics of the device and match it to their fashion, cultural believes, jewelry, or piercings. Finally, these devices could be used to augment culinary experiences by releasing bursts of scent very close to the mouth and nose.

USER STUDY

Previous researchers have explored the use of a scent-delivery necklace for notifications in public [12, 4], but the effects on people nearby have not been thoroughly studied. Dobbelstein et al. wrote that in their study, "bystanders did not show indication for perceiving scents". Unfortunately, the distance from participants and their perception of the odor was not reported in the paper. Therefore, in this study, we aimed at understanding if on-face olfactory interfaces such as glasses or on-skin prototypes could provide an advantage for personal scent delivery in contrast to off-face designs such as a scent-delivery necklace. We conducted a usability study to understand how participants felt while wearing the prototypes as well as to evaluate if these devices were private enough that a person in a close distance could not perceive the scent.

Prototypes and Scent Selection

After several tests in different face locations, we chose to study the "Nose" prototype due to its proximity to the nostrils, and

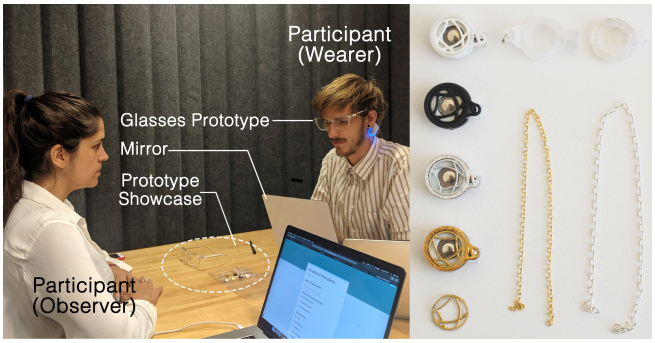

Figure 4. ***On the right image:*** **showcase of the prototypes with different materials and aesthetics. The asymmetrical pattern of the piezo cover is designed to move the attention away of the central circle and make it more aesthetically pleasing.** ***Left image:*** **A pair of participants during the user study. The "wearer" has a mirror to evaluate the aesthetics of the device (glasses) as well as its social acceptance. The observer was instructed to pay attention to the prototype to later asses the same.**

the "Glasses" based on its social acceptance (see Figure 2). We chose two different types of odors that intended to be similar in intensity and different in hedonic tones (one pleasant and one unpleasant). One fragrance was "Strawberry Ice Cream" from Demeter as the sweet and pleasant scent while P&J "Dirt" fragrance oil as the unpleasant, sour or bitter fragrance. The dilution was 15ml of filtered water in 5 drops of strawberry ice cream using a 3ml pipette, and eight drops of dirt oil. The burst duration was selected during a set of tests conducted before the study, and we found that 30-millisecond burst was enough to be smelled using the three designs and was not too strong (see Table 1 for more details).

Procedure

We conducted a user study with 12 participants (6 females with a mean age of 26). Five participants identified as Asian, three as Hispanic/Latino, three as white and one as middle eastern. 5 out of 12 participants had beard w/o mustache. We recruited pairs of people that did not know each other and excluded those that had odor allergies, anosmia, or were smokers.

The duration of the study was ≈1 hour and it was conducted in an open office space. After participants signed the consent form, they proceeded to evaluate the prototype (with randomized order). Participants were sat in front of each other at a distance of 46 cm/1.5 feet (see the left image in Figure 4), which is considered a "close phase" personal distance for interactions among good friends or family based on Edward T. Hall's proxemics.

Participants were told to minimize their facial expressions and to avoid commenting on their perceived sensations (they knew the prototype could release a burst of a pleasant or unpleasant scent, water, or no burst at all). All participants had bursts of smell with a randomized order.

The experimenter controlled the scent release via a smartphone app and instructed them to inhale at the count of three (at that time, a burst was released). This action was repeated with a 30-second break in between scents to avoid habituation. Participants filled out a computer-based survey and repeated the steps above for all three prototypes and then switched from wearer to observer, filling out a total of 6 surveys (three for their perception wearing each prototype) and an informal debrief about their user experience.

Results

Social Acceptance

Participants found the necklace most socially acceptable, followed by the glasses and, finally, the nose prototype (see Figure 5). The nose design was the most controversial and had very different ratings; while some participants found it interesting and worthy to use in public, others found it funny and not appropriate: *"It looks really cool, very steampunk. A statement piece that will stand out. I can see it being worn at a burning man as opposed to a dinner party, unless the wearer clearly wants to stand out at said dinner party."*, another participant mentioned: *"I felt a bit embarrassed and funny wearing it under my nose. Like if I had a mustache. It was pretty big and I didn't feel like I looked nice with it. I liked the chain to the ear. I think I would prefer to have it as a ring on my nose rather than something attached above my lip."* Some other comments were: *"Looks pretty cool, somehow like a rapper, even a gangster"*. Other comments were: *"I think cultural context should be taken into account here. For example, in my culture (middle eastern) face piercings (which this prototype looks very similar to) is not culturally "acceptable" because it is associated with delinquents or trouble makers."*. Other participants mentioned *"If I saw someone wearing this device in public, I would assume that the face decoration had religious or cultural significance."*

Some participants wearing the nose prototype reported that they felt they were invading the social space of the other when a burst of scent was being released and that the other person could smell it, although this was not the case for the person viewing the wearer. Interestingly, male participants ranked more positively the nose prototype than females, and some were excited about it and found it provocative. Other participants mentioned that: *"There could be an earring, bracelet, or a ring (on finger) as a prototype design for more social acceptability."*

We also found different results for the glasses and necklace prototype, depending on how familiar they were with these form factors. For example, one participant mentioned: *"I wear a headscarf (...) it seemed like I was only wearing glasses, and I do wear prescription glasses, so it's as if not much changed in terms of appearance for me."*, another participant mentioned *"I don't wear glasses thus it was a little unfamiliar and not natural for me to see myself in glasses."*. Some other comments: *"I liked how I looked with the glasses and the part attached to the glasses didn't feel uncomfortable at all. It felt like a regular chain. But the part on the ear feels a bit too big."*

The necklace prototype was higher-ranked for both social and comfort ratings (see Figure 5). However, there were some comments in regards to the gender and culture of the wearer and the viewer. For example, a female rating a male wearing the necklace mentioned: *"I couldn't perceive any scent or mist coming from the device. The aesthetic looked out of place*

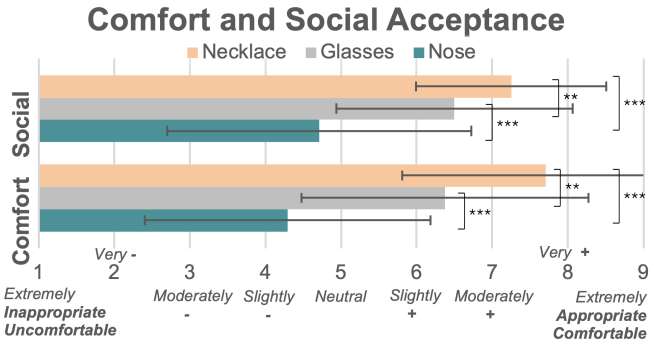

Figure 5. Likert Scale for 1 = Extremely Inappropriate or Extremely Uncomfortable and 9 = Extremely Appropriate or Extremely Comfortable. Orange for the olfactory necklace, grey for the glasses, and blue for the nose prototype. Error bars correspond to ±1 S.D. On the top, social acceptance for the necklace (M = 7.25, S.D = 2.75), glasses (M = 6.5, S.D = 1.56), nose (M = 4.7, S.D = 2.01). Comfort while wearing the nose prototype (M = 4.29, S.D = 1.88), necklace (M = 7.7, S.D=1.9), glasses (M = 6.37, S.D = 1.78). ***P-value <0.001, **P-value <0.01.

on the user testing it - maybe a cord or option for different aesthetic instead of the metal chain would suit a variety of people.", and rated it as "Slightly Inappropriate". However, the person wearing it mentioned that: *"I wouldn't wear this at home because I would have more domain of the scents in my home. But outside my home, I could see it being used as a way to control the scents of my environment if I find those scents unpleasant. Dispensing medicine would be a good use for it as it is discrete and unless someone is looking at the pendant, I don't know if anyone would notice."*

Male participants were more likely to rank the necklace prototype lower than the females, and a male participant added: *"I would think that it (the gold version) generally appeals (within our certain gender stereotypes) to females more than males. Thus I gave it a low rating in aesthetic appeal on that assumption."*

Another participant mentioned: *"The reason why I said "moderately" appropriate is because culturally (at least in my culture), necklaces for women are deemed appropriate but men who wear necklaces are usually delinquents."*. Another very important feedback a participant gave was: *"Maybe for the tests I would try to have the necklace closer to the chin. So that people don't have to be staring at other's chest/breasts. It would also help to feel the scent more."*

Comfort and Perceived Sensations

Participants found the necklace the most comfortable to wear, followed by the glasses. Overall, they found equally comfortable the frontal part of the prototype and the one held by the ear. However, this was not the case for the nose form factor. We found that participants were slightly uncomfortable while wearing the nose prototype as seen in Figure 5 due to its sticky part and the location of the device. For example, one participant mentioned that: *"The most uncomfortable element of the attachment above the mouth was that the sticky pad was fairly large and I didn't feel I could move my mouth normally (smile, etc). A smaller attachment point, even with device the same size, might make this feel more normal. I could also imagine getting more accustomed to normal motion and facial expression with the device over time, if I can train myself to feel that it won't fall off."* Multiple users reported that it could have been more comfortable and socially acceptable if integrated in a nose ring as a septum piercing. Most of the wearers reported not feeling any moist/humidity on their skin -no matter what prototype they were wearing (see Figure 6, "Moist" bars). There were significant differences between how much the burst of scent was observed when comparing the nose prototype with the necklace (see Figure 6, "Burst " bars). Several participants found the LEDs distracting, and the bursts were more visible with the nose prototype rather than with the necklace or glasses: *"I could see an obvious puff of mist when the scent released, which would also catch my attention if someone was wearing this in public."* Some other comments: *"I could imagine wearing the glasses form factor for something like watching TV if the scent was related to the program or an emotional augmentation, because I'm already used to wearing glasses for vision. The component behind the ear looks a bit like a large hearing aid and I would be less likely to wear it in public. The most distracting / eye catching part of the behind-ear component was the blinking lights - if the device was not glowing or was made of a darker color, it might be more socially acceptable for me."*

Some comments from a person wearing the necklace was: *"I didn't see as much visual effect with this device, maybe because it wasn't as close to my face, but I also would feel more comfortable wearing it for a public setting or public speaking if there aren't visible mist clouds."* Nevertheless, most of the viewers did not report seeing the bursts (see Figure 6). For example, one of the viewers said: *"I'm not sure if I would have noticed the bursts of liquid coming from the device if I had not heard the count down for the release or known more about the device - it was very faint but could have easily missed it if I hadn't been looking."* Some other relevant comments: *"The scent seemed stronger and lingered for longer than in the on-face prototype device. The device was definitely more comfortable to wear and I could imagine wearing it in public settings. I also didn't see as much visual effect with this device, maybe because it wasn't as close to my face, but I also would feel more comfortable wearing it for a public setting or public speaking if there aren't visible mist clouds."* Some other comments to take into account are the material of the chain: *"I think the chain of the necklace could be made of a braided plastic or other synthetic material so it is less abrasive against the skin of my chest and neck as well as be somewhat more aesthetically pleasing and in line with integrating the look of the components at the front and back of the neck."* as well as *"I would think that it (the gold version) generally appeals (within our certain gender stereotypes) to females more than males. Thus I gave it low rating in aesthetic appeal on that assumption."*

Finally, participants were mostly unaware of the burst sound, both for the observer and wearer for all the prototypes; please see Figure 6, "Sound " bars.

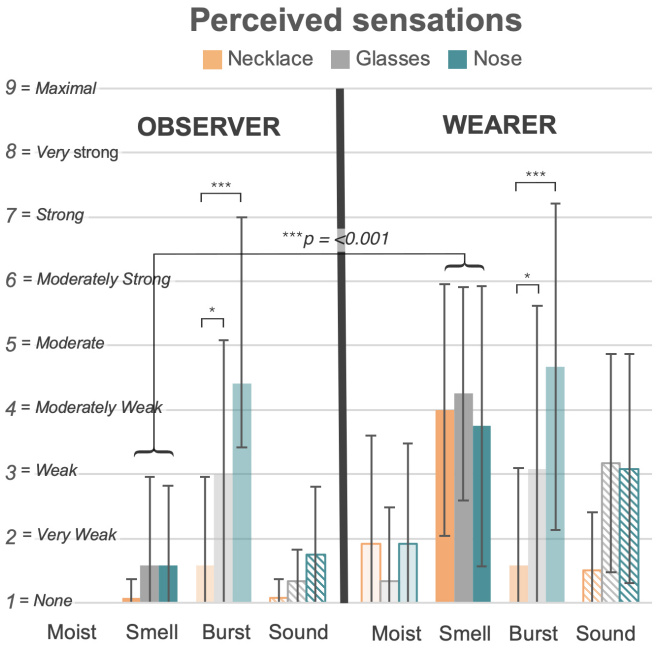

Figure 6. "Moist" - humidity felt on the face, "Smell" - intensity of the smell, "Burst" - visual spray, "Sound" - emitted when a burst is released. Error bars correspond to ±1 S.D. The wearers smelled the fragrance significantly more than the observers for all the prototypes (*P-value <0.001). The bursts were significantly more visible for the nose prototype than for the necklace (***P-value <0.001) and for the glasses *P<0.05 (both the wearer and viewer).**

Odor Intensity and Hedonics

Contrary to what was expected, most participants found both odors to be pleasant. The "Strawberry" scent was on average rated between very and moderately pleasant (M = 7.5, S.D = 0.8, where 9 = Extremely Pleasant and 1 = Extremely Unpleasant) and "Dirt" ranged from "moderately unpleasant" to "very pleasant" (M = 5.9, S.D = 1.6). The smelled scent intensity varied from person to person, ranging from "moderately strong" to "very weak", no matter which one of the three prototypes they were wearing (see Figure 6, "Smell" bars). Scent was always smelled by the wearer and was barely noticed by their peers. In the case of the nose and glasses prototypes; the ratings ranged from "none at all" to "weak". While for the necklace, participants rated from "none at all" to "very weak". We performed an F-Test to determine if the variances of the two populations were equal. F>F Critical one-tail, therefore we rejected the null hypothesis and ran a Welch's test for unequal variances and found that there was a highly significant difference between the odor intensity perceived by the wearer and the observer in all three designs P-value <0.001 but there was no significant odor intensity difference within the three designs. We also evaluated the ratings of friendliness that the wearer gave to the observer to understand if the odor pleasantness might affect the ratings of friendliness (e.g., more sweet smell could yield to more positive results or other related work [37, 14, 27]). Nevertheless, due to its similarities in the pleasantness ratings and the limited number of participants, we can not draw any conclusions.

DISCUSSION AND KEY FINDINGS

We found that participants had very different opinions in regards to the comfort, social acceptability, and overall perceived sensations while wearing the prototypes and while seeing their peers. Our study was gender-balanced, and although we had a variety of participants with different ethnicity, age, and cultural background, the sample size was small; therefore we suspect that this might be one of the reasons why our results show so much scattered data and large standard deviations as seen in Figures 6 and 5. Against our hypothesis, there was no significant difference between the odor intensity perceived while wearing an off-face and on-face prototype, but there was a highly significant difference between the odor smelled by the wearers and the observers. Therefore, the data suggest that all three designs might be suitable for personal scent delivery without it being perceived by people nearby.

Further research should address how to increase comfort and social acceptance, especially for the prototypes that are attached to the skin and are more visible, like the nose prototype. The sticky part can be replaced by a ring to make it more socially acceptable and comfortable to wear in the street as well as for those that have a beard or mustache. Although relying on the double-sided tape to stick the device under the nose does not seem to be the best option for day-to-day interactions, it might be worthy of exploring for clinical purposes and drug-delivery settings, as well as physical tasks or environments that have more airflow. On the other hand, targeting user groups that wear piercings or focusing on applications that could use this device as an ice-breaker for social interactions should be further explored.

Although the scent was almost imperceptible by the observers, visual bursts were more noticeable for the nose prototype than the glasses or necklace. The bursts seen by the wearer were significantly higher when using the glasses versus the necklace P-value <0.05 and even more significantly higher for the nose prototype P-value <0.001. These results might vary amongst those that had long hair, beard or mustache, or that were wearing a dark shirt. The bursts are more noticeable in black background and we also suspect that the visual LED lights might have affected the social acceptance ratings for those prototypes that had the LEDs facing the observer (nose and glasses). We, therefore, recommend avoiding the use of LEDs and transparent materials that expose the electronic components. Lastly, we expected participants to feel more humidity/moisture on their skin when they were wearing the glasses and nose prototypes than with the necklace due to their proximity to the face. Nevertheless, the data shows no significant difference between the three designs, and overall, participants did not perceive moisture on their skin. Another unexpected result was that 1 participant out of 12 reported that although he did not feel any moisture on his skin, he got a burst of scent in his eye. We, therefore, advise olfaction researchers to change the angle of the scent release to avoid discomfort (if the form factor chosen is the glasses and the scent delivery method is atomization).

Further studies should address how much these results can change depending on the scent delivery mechanism chosen,

the environment where the study is conducted as well as the task. All the prototypes evaluated in this study use ultrasonic atomization, and other types of scent delivery mechanisms might show very different results. We chose this scent delivery method because it has been explored in the past due to its reduced size, silent delivery, and compatibility with skin-friendly fragrances. We suspect that if the method chosen was in the form of heat, participants might have felt warmth on their skin. In the case of fans, the noise would be significantly higher. However, these are hypotheses that have never been validated for on-face olfactory interfaces and that are worthy of exploring.

Other parameters that should be further explored and taken into consideration are the direction of the burst and its orientation towards the nose. The bursts emitted by the necklace face upwards, while the ones by the glasses are downwards, and the nose one is towards the front. If the nose prototype was facing towards the nostrils, we might have seen an increase of moisture and scent intensity with a potential decrease of burst visibility.

Conclusion

Although the presented results do not show a definite advantage of using on-face prototypes for personal and private scent delivery in comparison to an olfactory necklace, further research should be conducted. Increasing the sample size, recruiting subjects that already wear on-face decorations/piercings as well as conducting experiments in places with increased airflow are some of the many potential investigations that could be done. The results obtained in this study could diverge if we take into account different demographics, culture, and previous memory associations, environment, face size as well as what scent delivery mechanism is chosen. We aimed at recruiting a diverse pool of participants with different demographics. This may be one of the reasons why our results are diverging from the speculated outcomes.

We hope that these preliminary findings can help olfactory researchers to understand better the benefits and limitations of using on-face olfactory interfaces in comparison to an olfactory necklace.

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