When Scents Help Me Remember My Password

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Current authentication processes overwhelmingly rely on audiovisual data, comprising images, text or audio. However, the use of olfactory data (scents) has remained unexploited in the authentication process, notwithstanding their verified potential to act as cues for information recall. Accordingly, in this paper, a new authentication process is proposed in which olfactory media are used as cues in the login phase. To this end, PassSmell, a proof of concept authentication application, is developed in which words and olfactory media act as passwords and olfactory passwords, respectively. In order to evaluate the potential of PassSmell, two different versions were developed, namely one which was olfactory-enhanced and another which did not employ olfactory media. Forty-two participants were invited to take part in the experiment, evenly split into a control and experimental group. For assessment purposes, we recorded the time taken to logon as well as the number of failed/successful login attempts; we also asked users to complete a Quality of Experience (QoE) questionnaire. In terms of time taken, a significant difference was found between the experimental and the control groups, as determined by an independent sample t-test. Similar results were found with respect to average scores and the number of successful attempts. Regarding user QoE, having olfactory media with words influenced the users positively, emphasizing the potential of using this kind of authentication application in the future.

Keywords: olfactory media, authentication, olfactory passwords, information recall, QoE.

1 INTRODUCTION

Traditionally, multimedia involves mainly the auditory and visual modalities of a person. Unsurprisingly then, authentication processes currently involve predominantly audiovisual data, usually consisting of text, audio, or images. Whilst text-based authentication systems are the norm, biometric-based security mechanisms involving fingerprint, iris [22] or voice-based recognition [29] are increasingly being used for added security. In the quest to make authentication systems even more secure, increasingly innovative approaches, such as the incorporation of a user's emotional dimensions, have also been pursued [49]. Notwithstanding the levels of innovation and ingenuity involved in such systems, the fact remains that only three senses are used in the associated authentication process: touch, sight, and hearing. However, other senses, such as olfaction (smell), could also be deployed in the authentication process in parallel in order to enhance it. In fact, olfaction and gustation (taste) [30,41] are insufficiently used modalities in multimedia systems, notwithstanding that there is a proliferation of increasingly affordable multi-sensory devices which make the possibility of having mulsemedia (multiple sensory media) systems a reality. As such, research in the area of mulsemedia has focused on issues pertaining to synchronisation [1,36,46], metrics [26], cross-modal correspondences [12], and how the use of different modalities can enhance perception and sense of immersion, conveying data [39] and Virtual Reality systems [5,6,10,11,19–21,28,37,38]. Given the importance of Quality of Experience (QoE) in multimedia, this concern has ported across to the mulsemedia arena, with studies focusing on assessment and modeling [13,23,35,40] as well as delivery [48].

Of the non-traditional modalities in multimedia, olfaction is of special interest given the demonstrated capability of scents to act as cues and aid users in information retrieval and recall. Indeed, olfactory media has already been employed alongside traditional media in a range of applications, adding olfactory media to which could enhance their realism and entertainment factor. For example, whilst the majority of alarm apps use sounds as an event reminder notification, Kaye [24] designed a seminal scent reminder that used olfactory media as notifications. Other studies [17,43], have evidenced the ability of using olfactory media to aid users in information retrieval and recall, as well as to enhance their Quality of Experience (QoE). In particular, olfactory media (scents) were found to be able to stimulate the users' ability to recall or retrieve words related to the emitted scent. In other work [8] relevant to the study reported here, a model incorporating scents to enhance image content was shown to be an effective way for senders and receivers to communicate over the Internet.

The study which forms the focus of the current article incorporates olfactory media into the authentication process. Specifically, olfactory media are used as cues to help a user retrieve a set of words. These words could be related or unrelated to the selected scents, and are integrated in PassSmell, a proof-of-concept olfaction-enhanced authentication application. Accordingly, we investigate the impact that employing olfactory media in the authentication process has on user performance and QoE.

The structure of this paper is as follows. Section II reviews related work, after which Section III describes the PassSmell authentication application used to examine this model, whilst Section IV details the experimental methodology employed. Results are then analyzed and discussed in Section V. Lastly, conclusion are drawn in Section VI.

2 RELATED WORK

Whilst there have been a fair number of studies exploring how best to integrate olfactory media in a digital context and what implications this might entail, studies looking at how to use olfactory media as cues in digital applications have been few and far between. This is somewhat surprising, as the ability of scents to act not only as cues, but also enablers of information recall is well documented in the physical world. However, this has not (yet) been ported across to the digital realm.

Accordingly, work has been undertaken exploring the use of olfactory media in a Virtual Reality (VR) setting [14,45], as well as to enhance user QoE in both traditional 2D videos [33,34,46,47] as well as more novel 3D video content [31]. It is to be remarked that most of these studies considered the semantic congruence between the audiovisual media content and the olfactory media. In work-related to ours [2,16,18,44,50] the authors examined the influence of using olfactory-enhanced video on users' information retrieval performance, with encouraging results.

2.1 Olfactory media and words

There is a paucity of studies examining the use of olfactory media as cues for word recall in a digital context. One is that described in. [8], in which, in the first part of their work, experimenters asked participants to rate scents as to their closeness to particular words. An initial pool of 45 words was whittled down to 16 words, thus obtaining so called sense-descriptive adjectives (SDAs) associated with a set comprising 11 scents (grapefruit, rosemary, rose, jasmine, peppermint, vanilla, ylang-ylang, lavender, sandalwood, chamomile, bergamot). Scents were categorised as suitable, relative and irrelative and were then associated with four video excerpts, based on their semantic congruence with the respective video scenes. Based on the most appropriate scent as chosen by users, the authors then propose a scent-based communication model incorporating SDAs, as their results underlined the fact that scents can be used as effective reinforcers of video content in digitally-mediated communication.

Another related research endeavour [43] explored the potential of olfactory media to aid a user in recalling words associated with particular scents. Researchers here ran two separate experiments in a between subjects design, the first of which employed three conditions (jasmine, rosemary, no scent), as did the second (peppermint, bergamot, no scent). A set of words were presented to participants in random order on the screen, being displayed there for three seconds, whilst participants were experiencing one of the aforementioned olfactory conditions. The results of the first experiment highlighted that participants in the rosemary group recalled statistically significant more associated words than users in the other two groups, whilst in the second experiment this was true of participants from the peppermint group, which lends further credence to the observation that certain olfactory media can be used as memory cues for odour-associated words.

Last but not least [17] describes an experiment in which olfactory media are used in a word search game. Accordingly, twelve words were hidden in a 15X15 letter matrix. The hidden words could be found in the matrix written top-down, bottom up, left-to-right, right-to left, as well as diagonally. The twelve words comprised 4 groups of three words, each group related to a particular scent (e.g. the strawberry scent was associated with the words Fruity, Strawberry, Sweet. whilst the curry scent was associated with the words Spicy, Curry, Aromatic).36 participants split into a control and experimental group, had three minutes to spots as many of the 12 words as possible. Whilst participants in the control group did the task without any olfactory media being emitted, those in the experimental group had the four scents being emitted cyclically (strawberry, burning wood, curry, rancid) by an olfactory dispensing device. The findings showed that participants in the experimental condition recognized statistically significant more words than those in the control condition. Thus, olfactory cues whilst performing a word search increases the number of correct words found, compared to the case when olfactory media cues are absent, a finding consistent with that of [43].

Despite such studies highlighting the potential of olfactory media in information recall, their use in a digital context remains limited. In particular, to the best of our knowledge, the use of olfaction for authentication has not been undertaken thus far. Hence, in a recent publication [3], we proposed PassSmell, an olfactory-enhanced authentication application based on olfactory media and words. Whilst the initial study reported in [3] had a reduced sample size and only reported on a reduced sample of users and on a single performance metric, the study reported here was done with the participation of a considerably extended sample of users, and reports on additional issues such as user QoE as well as PassSmell's robustness to attack. Accordingly, we now proceed to describe PassSmell.

3 PASSSMELL – OLFACTORY ENHANCED AUTHENTICATION

Most authentication systems follow the send/receive protocol. Consequently, as illustrated in Figure 1, a set of send/receive requests have to be done between users and the authenticating system to authenticate users. However, in such traditional systems, users only receive text, pictures or audio. PassSmell is a novel authentication application relying on olfactory media and associated words for authentication. For experimental purposes, two different versions of PassSmell were developed in Java, the first of which incorporated olfactory media in the authentication process, whilst the second was a word-only counterpart.

The first step that potential users have to do in order to use PassSmell is to create a profile; these can be based on scents and related words, or groups of words only. Firstly, users would select a username and supply demographic information such as age and gender, as can be seen in Figure 2. Users would then, in a dropdown list, be asked to choose two scents from a total of four (mint, orange, lavender, rosemary). Once a particular scent is selected, the user has to indicate a set of four words that s/he wishes to associate with that scent. These can be chosen from two lists - one is a set of seven semantically- related words, with a second list comprising 27 words unrelated to the scent (Table 1). The semantically-related words used had been the subject of a study reported in [8] and were shown to score a high percentage rating in terms of users associating them with a particular scent.

The last phase in the profile setup is profile confirmation. In this phase, users can preview their profiles, receive their used scents, and preview the words in both groups while they were receiving the olfactory media. This stage helps the user to build a relationship between words and congruent scent. Users can also preview words randomly or make changes to their profiles should they wish.

Once a profile had been created, users could then use PassSmell to authenticate themselves. Accordingly, as illustrated in Figure 1, the user has to send a request to receive a scent. This would then be emitted; concurrently a 4X4 word matrix containing two words associated with the scent (as detailed in the user profile) would be generated. Once the user correctly matches two associated words with the received scent, they will be able to login and authenticate themselves successfully. This process is shown in Figure 4 – here, two words were selected from the user's profile - juice and fruity - and embedded in a 4X4 matrix. In this matrix, the user received 14 other words which are not associated with the scent. After three failed attempts, users are unable to login further without resetting their credentials, a principle applied in the majority of authentication systems to prevent successful attacks.

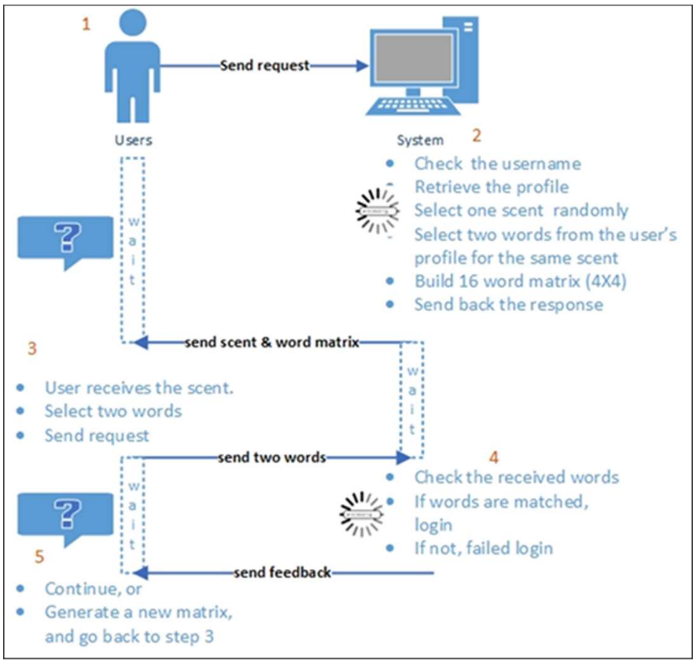

Figure 1: Olfactory-enhanced authentication process [3]

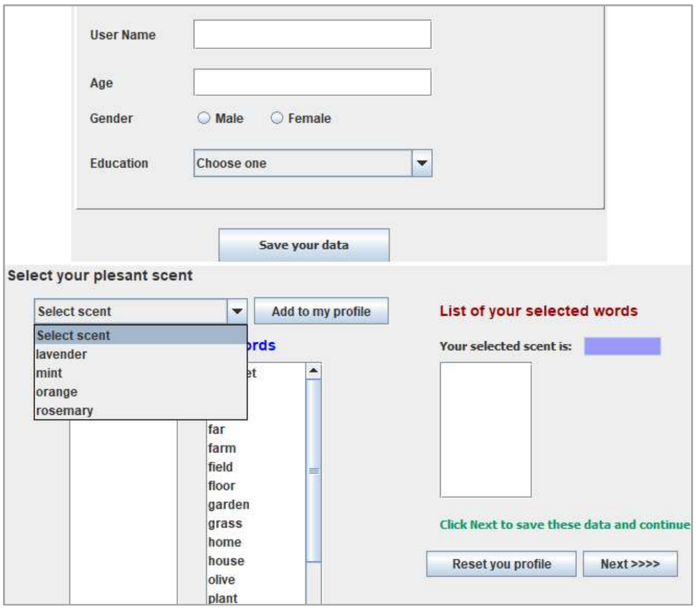

Figure 2: Profile setup

Table 1: PassSmell Word Database [3]

Mint	**Orange**	**Lavender**	**Rosemary**
Active	Cocktail	Blossom	Aromatic
Candy	Dynamic	Colourful	Exciting
Clean	Fresh	Ascinating	Herb
green	Fruity	Flower	Natural
refresh	Juice	Love	Shrub
relaxed	Vitamin	Romantic	Simulative
tea	Vivid	superfine	Thrill
General words (unrelated)			
Bouquet	Grass	Screen	
Bus	Home	Soft	
Car	House	Sour	
Far	Olive	Spray	
Farm	Plant	Table	
Field	Road	Teacher	
Floor	Room	Watch	
Garden	Warm	Water	
Tree	School	Window	

Of course, attackers might try to identify commonalities between the matrices to find redundant or common words and use these as login credentials. PassSmell counteracts such hacking behavior through a four-pronged strategy. Firstly, the pair of words needed to be recognized for a successful login are extracted from the combination of selecting 2 out of 4 words, 6 combinations overall, and, a different pair of words is generated on each login attempt. Secondly, incorrect words are intentionally repeated in order to distract hackers/attackers. Thirdly, if the user wrongly chooses the first word, s/he is not informed about this, but instructed to go and recognize the second word too, and only then is s/he informed that the overall login attempt was unsuccessful (but not told which word(s) –first, second, or both - were incorrect). This prevents attackers from eliminating incorrect words in any subsequent login attempt. Lastly, as mentioned, the number of allowed login attempts was restricted to three, after which the user would be locked out of the system.

In terms of attacks, we allocated the third part of our experiment to address these. We created six profiles that involved all available scents combinations, as shown in Table 2. Then, we asked participants in the experimental group to login to the profile that was similar to theirs with respect to the scents. For example, if the user selected mint and lavender in his/her profile, we asked him/her to login using Profile 2. Regarding the words used for these profiles, we used the same words' database in the pre-created profiles. For example, 'tea', 'garden', 'home' and 'school' were selected with the mint scent. All words were drawn from our database (Table 1).

Regarding the word-based version (not employing olfactory media for authentication) of PassSmell, users here follow the same process, but have to build their profiles based on two groups of words. Thus, users could use a database of words containing 55 words to choose eight words in their profiles. The process followed in the word-based version (control condition) is similar to what was applied in the experimental version, but in the word-based version, no olfactory media were used as a clue. In this version, we designed a screen similar to the one for the olfactory- enhanced application, as shown in Figure 3 , where users had to add two groups of words to their profiles, which can be selected from a database that contains 55 words (Figure 3, part 1). Thus, users have 341,055 choices (combination (55, 4)) to select the first group, and 249,900 (combination (51, 4)) choices to select the second. People who tried this version had no idea about the olfactory-enhanced version. For this reason, we labeled their words using Group1 and Group 2. The same set of words were used in both versions.

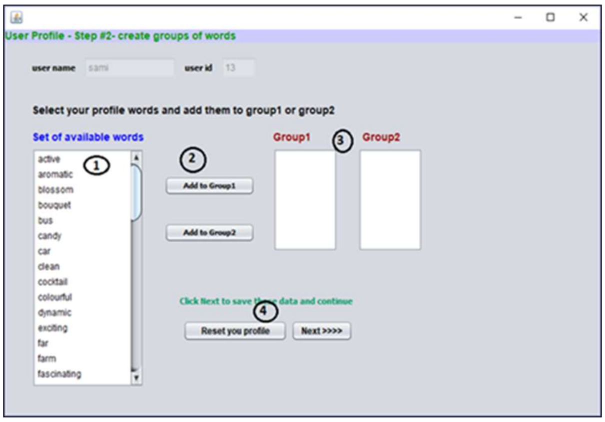

Figure 3: Profile creation using non-olfactory application

Figure 4: First user attempt at PassSmell authentication

Table 2: Pre-created profiles

Profile	Scent 1	Scent 2
Profile 1	Mint	Orange
Profile 2	Mint	Lavender
Profile 3	Mint	Rosemary
Profile 4	Orange	Lavender
Profile 5	Orange	Rosemary
Profile 6	Lavender	Rosemary

4 METHODOLOGY

4.1 Participants

Forty-two participants were recruited in this experiment. They were randomly allocated in two equal-sized groups (control and an experimental group). Experimental group participants employed the olfaction-enhanced version of PassSmell, whilst control group participants used its non-olfactory variant. The ages of participants ranged between 18 to 39 years. None self-reported as having any relevant health problems, such as anosmia (inability to smell), breathing difficulties or allergies. In addition, all participants were volunteers. They were invited to participate either directly (face-to-face), through invitational emails or by phone. Finally, none of the subjects in the experimental or control groups had participated previously in similar experiments incorporating olfactory media.

4.2 Experimental materials

Olfactory Display: An Exhalia Diffuser SBi4, as shown in Figure 5, was used in this experiment to send the required scents toward the user when needed. Using four different fans and with replaceable scent cartridges,

up to four scents can emitted by this device. The Exhalia device was connected to the computer through a USB and Java package.
Olfactory media: Four scents were used as an olfactory media in these experiments: mint, orange, lavender and rosemary. The scent cartridges could be replaced with other scents depending on the user's preference.
PassSmell: two versions of the application were utilized to test our model, which have already been described above. The first version (Figure 5), was enhanced with olfactory media in which scents were used with words (Table 1) in the login process, whilst the second only involved words. Both were built using Java and the data needed were retrieved from a MySQL database, with user responses being recorded there too.

Figure 5: Exhalia Diffuser (1) and PassSmell on laptop (2)

4.3 Procedure

The experimental study was held at Brunel University, London, in a room with windows and air conditioning, considered appropriate for experiments with olfactory stimuli [32]. On arrival, users were asked to read the experiment's aims and description as well as fill in a consent form. The set-up such of the Exhalia SBi4 device was adjusted in respect of direction, angle, and distance, for each user, as recommended by [32].
Participants then proceeded to create their profiles. The profiles comprised three parts: demographic information, words and olfactory media. Regarding words, in both versions, users were restricted to choosing eight distinct words. This aims to protect users' profiles from attacking attempts. The last stage was to preview and confirm the words and olfactory media chosen in the user's profile.
Participants were then asked to log in three separate times in order to verify the effectiveness of PassSmell. For each particular login, participant had a maximum of three attempts to authenticate themselves. Each login round was considered to be completed either when the user had successfully authenticated him/herself or had a succession of three failed attempts to do so.
Finally, each participant filled in a 5-point Likert scale questionnaire containing ten items about PassSmell's usability, and, for experimental group participants only, questions regarding the scents employed, the user experience and future trends, as detailed in Table 3.

4.4 Assessment

To assess our system and track the users' performance in both versions, we recorded all the necessary information about the login process. Firstly, we reported the time taken per attempt. Secondly, we recorded the first response time which is the time elapsed starting from receiving the words and scent to selecting the first word - this to calculate the time required to receive/recognise the olfactory media and take action. Thirdly, we reported the number of successful and failed attempts per user. Words selected by users, irrespective of whether they ultimately corresponded to a correct or failed login attempt, were also logged. In addition, we calculated a score for each login attempt: 0 was given for a fail, 1 for a first-time success, 0.66 for a second time one, and 0.33 if it they were successful on the third and final attempt. Lastly, in terms of users' QoE, as mentioned in the previous section, users were asked to fill in a questionnaire involves 23 items.

Table 3: post-questionnaire items

Items
System Usability Items:
Q1 - I think that I would like to use this system frequently
Q2 - I found the system unnecessarily complex
Q3 - I thought the system was easy to use
Q4 - I think that I would need the support of a technical person to be able to use this system
Q5 - I found the various functions in this system were well-integrated
Q6 - I thought there was too much inconsistency in this system
Q7 - I would imagine that most people would learn to use this system very quickly
Q8 - I found the system very cumbersome to use
Q9 - I felt very confident using the system
Q10 - I needed to learn a lot of things before I could get going with this system
Scents and words:
Q11 - The scent was pleasant
Q12 - The scent was annoying
Q13 - The scent intensity was appropriate
Q14 - The scent was distracting
Q15 - The scent was emitted for a suitable duration
Q16 - The scent was emitted at the appropriate time
Q17 - The scent helped me retrieve my words
Q18 - There was a set of related words for each scent
Q19 - The system has an adequate database of words when I created my profile
Q20 - Most words were unrelated for the available scents
Q21 - It is unlikely I can guess the targeted words without receiving a related scent
Q22 - I think no one can attack my profile that uses word-scent pattern
Q23 - I would like to use the word-scent pattern for authentication in the future

5 RESULTS AND DISCUSSION

As illustrated in the previous sections, in the study reported here, we explored the impact of employing olfactory media in the authentication process. Our main metrics are given by the time taken for authentication (first_action_dur, Total_dur) and the scores achieved by participants, which reflect the number of attempts needed for a successful login. Accordingly, we shall now proceed to analyse the results obtained in the following subsections.

5.1 Impact of olfactory media in the authentication process

Login phase one duration (first_action_dur): To determine whether the olfactory media improve the speed with which the user retrieves the first of the two words needed for authentication, an independent sample t-test was conducted on data collected between experimental and control groups. This highlighted a statistically significant difference between the control group (M=9.35s, SD=1.78s) and experimental group (M=7.14s, SD=2.65s); $t(164)=-6.375$, $p<0.05$. This can be noticed in Figure 6, where the average first_action_dur time in the experimental and control groups was 7.14s and 9.35s, respectively, across all attempts (failures and success). In respect of successful attempts, the average was 6.49s and 8.99s, respectively. Moreover, the minimum first-response time was 3.13s and 6.71s for experimental and control groups, respectively. This means having the olfactory media as a cue to aid in word retrieval had a significant effect on user performance in regard to the time taken to select the first word. Not to mention, for the experimental group, these numbers involve the time needed for receiving, recognizing and responding to the olfactory media – yet numbers are smaller than those for the control group, in which no olfactory detection/recognition was required.

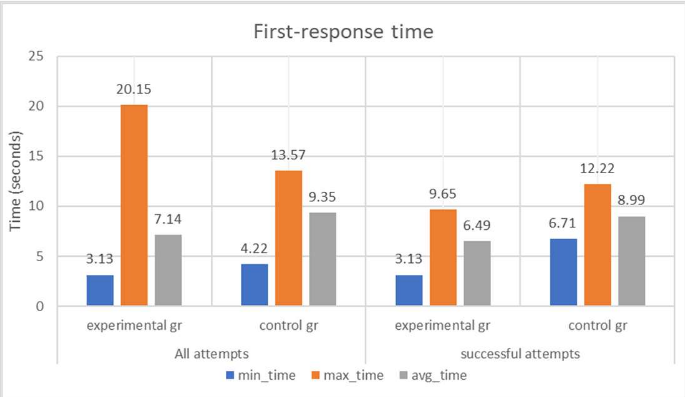

Figure 6: Comparison of the first-response time across the groups

Login phase two duration: The times needed for detecting the second (and final) word in our authentication protocol were quite close to those of detecting the first. Specifically, as regards the experimental group, they were in fact uniformly lower as users did not need to spend the roughly 2.5s needed to detect and recognise the emitted scent [25], which had already taken part in the previous login phase. An independent sample t-test was conducted to compare the effect of using the olfactory media on user performance between experimental and control. Results show a significant influence, $t(164)=-8.528$, $p<0.05$. The average time taken to retrieve the second word for the experimental and control groups is 3.88s and 6.48s, respectively. In respect of the successful attempts, the average is 3.71s and 6.42s, respectively.

Overall login duration (Total_dur): applying an independent sample t-test on the overall time-taken in the whole process confirmed the significant influence of having olfactory media as a cue to retrieve the words from the users' profiles ($t(164) = -9.862$, $p<0.05$) compared with the non-olfactory method in which users must know which group of words has been selected in the matrix. As shown in Figure 7, in the experimental group, the users spent between 6.73s and 15.3s to complete the whole process successfully, at an average of 10.2s. On the other hand, as far as the control group is concerned, participants consumed between 8.25s and 22.12s to pass the attempts successfully, at an average of 15.4s. Moreover, the maximum taken time for the failed attempts was 23.1s and 21s in the control and experimental groups, respectively.

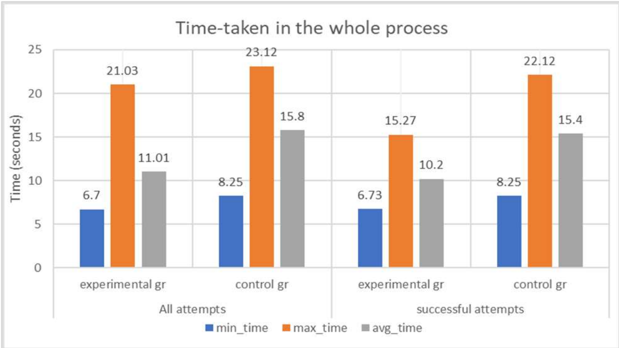

Figure 7: Comparison across groups of the overall time-taken for authentication

Robustness: to test PassSmell's robustness to attacks, experimental group participants were asked to try logging using a similar profile. These profiles have the same scents as those selected by the participants, pre-created profiles (see Table 2) or users' profiles. For example, if the users chose the mint and orange scents in their profiles, we asked them to login to profile that has a 'profile 1' as a user ID, or login to similar participants' profiles, if any. For example, participants 2,10,12 and 14 chose the mint and orange scents in their profiles. As shown in Figure 8, for pre-created profiles, 156 tries were given to attack the available profiles. For example, 45 attempts were done to attack profile 1, the maximum time that spent was 59.6s. None of these attack attempts were successful.

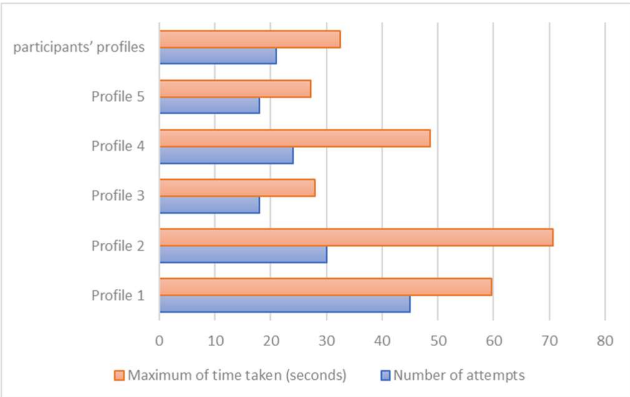

Figure 8: Comparison of number of attacking attempts and time-taken

Moreover, while each attempt has 16 words to choose from, an attacker needs to try 120 combinations, i.e. (16,2) to check each pair of words. Accordingly, the probability of choosing a pair of correct words is '8.E-03', if the words are not shuffled and randomly generated. This was considered in our four-pronged approach. Further, our proposed system can be easily customised to be a 5X5 instead of a 4X4, which makes any attacking attempt more difficult. This can be further strengthened if we widen the word database in Table 1. In the case we choose to expand our system to be a 5X5, the probability of choosing a pair of correct words will be '7.E-03', if words are not shuffled or generated randomly.

Login attempts: As mentioned, participants were asked to login 3 times. For each login, they were allowed 3 attempts. The number of attempts needed to successfully login varied between participants because some of them could do so on the first attempt, whilst others needed two or three attempts. For the experimental group, it was found that the average time needed to recognise the first word (first_action_dur) for the last successful attempt fell by 17.5% compared with the corresponding time needed for the first successful attempt, as shown in Figure 9. Moreover, a paired sample test confirmed that these differences were statistically significant, $t(20)=4.288$, $p< 0.05$. Regarding the control group, the variance between the two averages was only 3.5%. Concerning the experimental group - where olfactory media was deployed - we conclude that the more training the users have, the lower time will be needed for users to response.

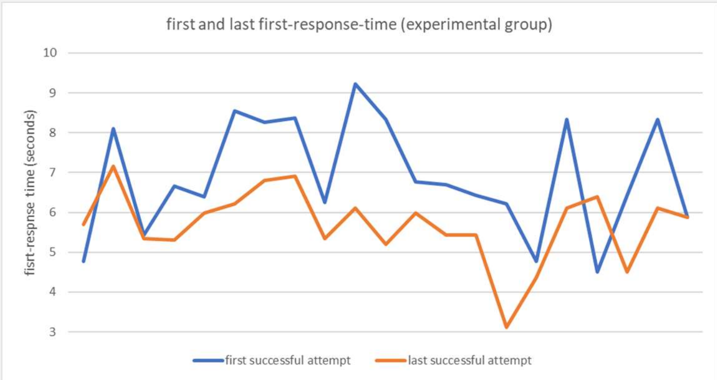

Figure 9: Recognizing the first word: attempt comparison

Last but not least, usage of olfactory media as a cue for word recall had a significant influence on the users in terms of the number of successful attempts (accuracy) and their scores. In the experimental group, out of 78 attempts, 86% of them were successful. In contrast, regarding the 88 attempts made by the control group, only 60% were successful. Finally, it is worth mentioning that the average success score in the experimental and control groups for those attempts was 0.94 and 0.81, respectively; moreover, t-test analysis confirms that this difference is statistically significant, $t(164)=4.968$, $p<0.05$.

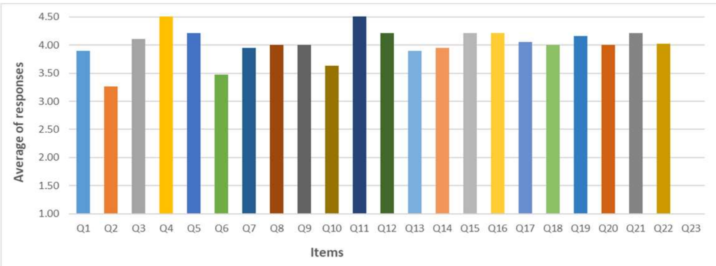

Figure 10: Average of responses for the QoE questionnaire

5.2 Impact of olfactory-enhanced authentication on QoE

Investigating user QoE was done through a questionnaire of 23 items given to experimental group participants, as described in Section 3. Cronbach's alpha reliability analysis for responses to this questionnaire yielded a Cronbach alpha value of 0.81, which is considered very good [15]. As shown in Figure 10, after mirroring the negatively worded items, the average of all responses was 4.02, which means they are located between agree and neutral, being a positive indication. Moreover, as can be seen, item 11 (scent was pleasant) had the highest average responses of 4.58. On the other hand, item 2 (the system unnecessarily complex) had the lowest average, 3.26 among all items in our questionnaire.

System Usability Scale: We followed guidelines detailed in [9,42] to calculate an overall SUS score between 0 and 100 for each individual participant in our study. On the whole, the average SUS score for all participants was 74.76, with a standard deviation of 7.94. This average is considered to be acceptable according to guidelines for interpreting SUS scores [7]. As shown in Figure 11, the SUS score for most of our participants was acceptable or excellent, (>=70), and the rest was marginal acceptable (50-60). Importantly, none of these scores was not acceptable.

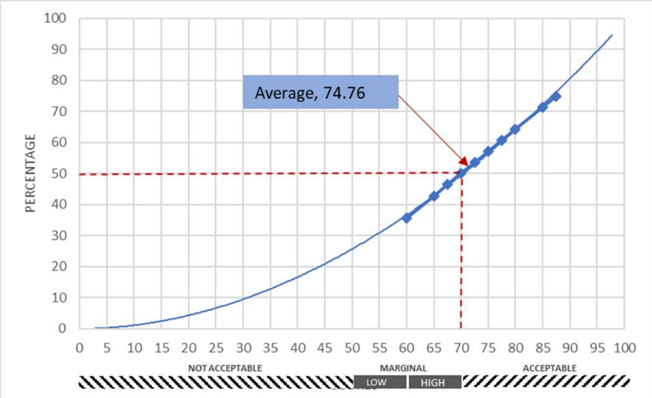

Figure 11: Acceptability of the overall SUS score.

Reponses to SUS items are summarized in Figure 12 (overall agree, neutral or overall disagree). In the following bullet points, the responses are discussed in more detail for each item:

Q1: The results show that 76% of users reported that they would like to use this application in their daily life, whilst the rest did not decide in this regard.

Q2: We asked users whether they found this application unnecessarily complex. According to their responses, about 76% disagreed or strongly disagreed, whilst just 5% agreed or strongly agreed and the rest did not respond in this regard.

Q3: Users were asked to whether this application was easy to use. 86% reported that the application was easy to use, and 10% were neutral, with only one participant claiming that the system was not easy to operate.

Q4: As came across in participants' responses: 76% of them agreed or strongly agreed that they do not need a technical person to support them and the rest were neutral regarding this matter.

Q5: Different screens were used that allow for users to create their profiles and login smoothly. These screens were well arranged and integrated so it was easy to work promptly and effectively on them. The users supported these claims, with 76% agreeing/strongly agreeing, whilst the others were neutral.

Q6: the responses were consistent with item 5, whereby the users found the application well integrated. 90% of users stated that they found no inconsistency in this application, with 10% being neutral.

Q7: learnability is a crucial aspect that should be considered in every newly developed application. For this reason, we took great care when developing the application to make it smooth in its operation and easy to use. This appeared to have been achieved as 90% of participants found our application easy to learn quickly, with the rest being neutral on the matter**.**

Q8: users needed to follow the instructions that clearly told them what should do in each step during creating profiles and executing the login process. Hence, they should have been able to navigate in this system easily. We asked participants whether they found this application cumbersome or not. 10% of users claimed that it was so, whilst 67% disagreed or strongly disagreed. 23% of users were neutral in this regard.

Q9: 91% of the participants stated that they were confident when using the application, and all the rest were neutral.

Q10: only 14% of participants reporting that they needed to learn a lot of things to start using this application. 67% stated that they did not need to learn much to be able to use it and 19% were not sure on this matter.

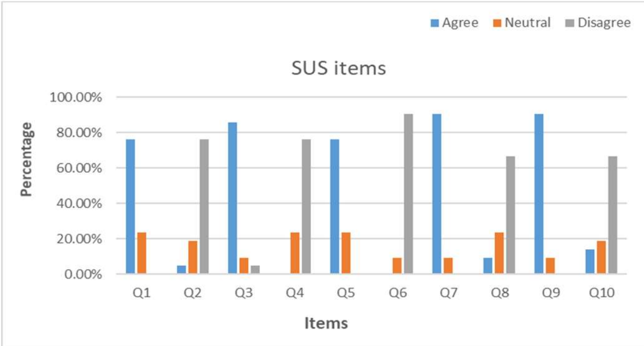

Figure 12: Responses to SUS questions

QoE impact of olfactory media characteristics: The particular characteristics of olfactory media might impact user QoE and user performance. For this reason, we allocated a section of six items to study this particular aspect (Q11-Q16, see Figure 13).

Q11 (pleasantness): as aforementioned, four scents were used in this study as olfactory media: mint, orange, lavender, and rosemary. All of these are known to be pleasant smells. Users could select two out of these four scents in this work and they were able to choose them depending on their mood. Despite this, we asked participants whether the available scents were pleasant. As shown in Figure 14, 91% found the used scents were pleasant, whilst 10% were neutral. In fact, we dwelt long on this issue, because the type of olfactory media (pleasant or unpleasant) can impact on user performance, as found by Martin and Chaudry [27]. That is, these authors found that pleasant olfactory media is associated with better performance; should it be unpleasant, then this is associated with poorer performance in terms of working memory.

Q12 (annoying): Olfactory media might cause annoyance when synchronised with other traditional media, like audio or images, especially, if is it used secondarily. In our case, 95% of subjects disagreed or strongly disagreed that the used scent was annoying.

Q13 (intensity): the intensity level was customised using the Exhalia Diffuser employed to emit the olfactory media. According to our results, 95% of users found the scent intensity was appropriate, and the rest were neutral regarding this issue.

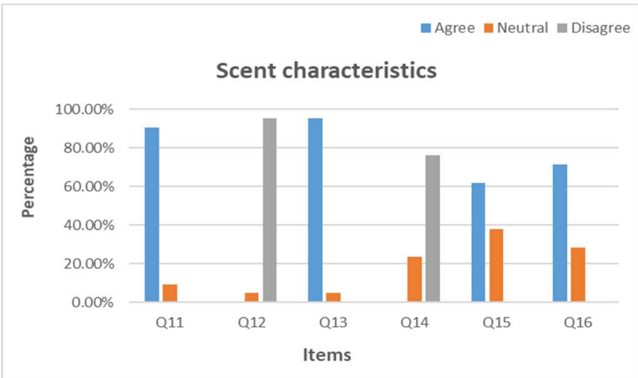

Figure 13: Olfactory media characteristics impact on QoE

Q14 (distraction): Users had to wait, receive and recognize the olfactory media in order to recollect their chosen words in PassSmell – if the scents were found to be distracting, this would be a major downside to PassSmell. In this respect, a strong majority (76%) disagreed or strongly disagreed that the scents were distracting; also noteworthy is that not a single person agreed that the olfactory media was distracting.
Q15 (scent duration): it has been estimated that users need between 2 and 2.5s to receive and recognize the emitted scent [16,25]. For this reason, in this work, the scent was emitted for 10s to give users enough time to receive and recognize it. 62% of the subjects reported that this time was suitable, whilst the rest were neutral on this matter. For successful attempts, users spent, on average, 6.49s to react after receiving the olfactory media. Some users reacted after 3.13s, which is considered as good evidence that the duration (in this experiment) of emitting the olfactory media was sufficient. Furthermore, no significant difference was found when these responses were compared with a previous study in which the olfactory media was emitted for 20s [4].
Q16 (emitting time): the selected olfactory media was synchronised with words. At the time of building the matrix that contained two related words, the scent would be emitted (at zero seconds). 71% of users stated that the time of the release of the olfactory media was appropriate, whilst the rest were neutral.

<u>QoE impact of employing olfactory media with words for authentication</u>: Our olfactory-enhanced authentication process relies on a combination of olfactory media and words. Participants were asked to answer six items about this particular aspect of PassSmell in order to gauge the impact on QoE and user performance (Q17 – Q22, Figure 14):
Q17 (scent and retrieving words): in the olfactory-enhanced version, the users had only one choice. It is the scent as a source of information to get their words. Otherwise, users had to spend a long time to find the words targeted. For this reason, we asked participants whether the scent acted as a source of information and helped them to recall the words needed, and an impressive 81% of users reported that the olfactory media helped them to choose the correct words.

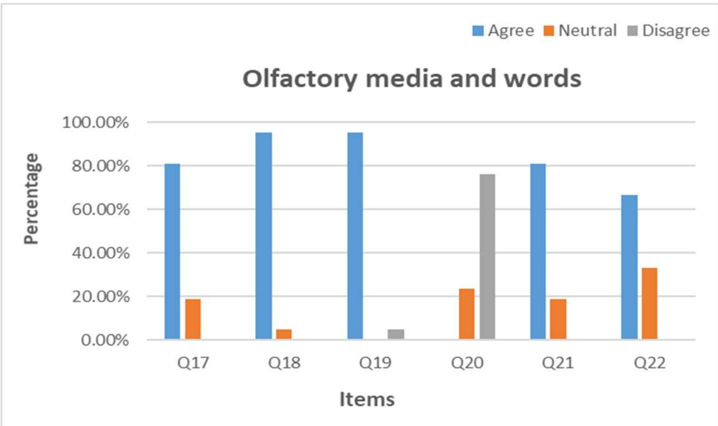

Figure 14: Responses for olfactory media and words questions

Q18 (availability of associated words): our expectations were that participants tend to choose their words from the associated lists. For this reason, we supported our database with seven words per each scent and an overwhelming 93% of users expressed their satisfaction with the associated words provided.
Q19 (adequate database of words): in addition to the related words, we used a general list. This included words unrelated to the scents in order to broaden those available to, and reduce the probability of attacks, as explained above. Only 5% of users found this list of words in the database was not enough, with the rest

reporting that it was adequate. It should be noted, furthermore, that the database of words could be updated to include a potentially much larger number of words.

Q20 (words were unrelated): the words that used in our study were extracted from the literature [8] and synonyms. Most of these words were rated in mentioned study as a relative to the corresponded scents, and these words got the highest rank. Nevertheless, we asked the participants whether those words or some of them were unrelated. 76% of them disagreed or strongly disagreed, whilst all the rest were neutral on this issue.

Q21 (difficulty of guessing words without receiving scents): we wanted to if users thought that olfactory media used by PassSmell acts as cues to aid in recollecting their chosen words. Most participants (81%) supported us in this regard, and 19% were neutral. Impressively, none of the participants believed in the possibility of guessing the words without receiving a scent.

Q22 (probability of attacking): in our view, there is a very slim possibility of successfully attacking this application, as PassSmell adopts a four-pronged approach to prevent this, as described in Section III. However, we wished to know what was our participants perspective on the issue. Accordingly, 67% of them reported that there was no possibility of attacking their profiles when utilizing the word-scent pattern, whilst the rest of the users were neutral on the matter.

Using olfactory-enhanced authentication in the future: In the last item in our questionnaire Q23, we asked participants whether they would employ this type of authentication application frequently in the future. Regarding this item, 86% were willing to use these systems that use olfactory data and words, with the rest being neutral on this matter (Figure 15).

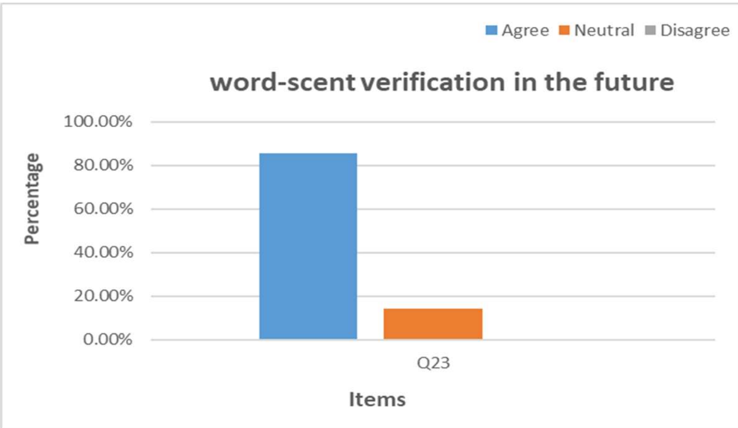

Figure 15: Responses for user's trends in the future

6 CONCLUSIONS

The study reported in this paper explores the impact of using olfactory media as cues to aid users during the authentication process. Results highlight that using olfactory media significantly improves user performance regarding overall login time, time needed to retrieve words necessary for authentication, as well as login accuracy (number of successful attempts). Moreover, users' performance gets better the longer they try to login using an olfactory-enhanced system deploying olfactory media. Furthermore, PassSmell, the proof-of-concept application developed to test our proposed olfaction-enhanced authentication process, incorporates a four-pronged approach to deter attacks, thus significantly reducing their success probability. Lastly, user QoE evaluation highlighted positive user evaluations and experiences with PassSmell.

Whilst more investigation is required to reduce the time needed to recognize scents (and this is acknowledged as a limitation of our study), our results nonetheless would appear to be encouraging in providing evidence that olfactory media can be used as a data channel. This is reinforced by our study's results highlighting the enthusiasm of users to use olfactory-enhanced authentication systems in the future. Moreover, further investigation is required in technology needed (such as olfactory devices) to utilise olfactory-enhanced authentication systems in real life. Last but not least, it is to be remarked that the vast majority of the users in the experiment were willing to adopt future systems that use olfactory data and words in combination.

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