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That Scent Evokes an Image—On the Impact of Olfactory Cues on User Image Recall in Digital Multisensory Environments

Anas Ali Alkasasbeh[a] and Gheorghita Ghinea[b]

[a]Department of Computer Science, Faculty of Information Technology, Mutah University, Mutah, Jordan; [b]Department of Computer Science, Brunel University London, London, UK

ABSTRACT
In traditional digital filing systems, people mostly use text as a key to categorise images, and retrieve them in the future. The use of other media as keys for image retrieval is rarely used, notwithstanding that multisensory digital media – mulsemedia – can be harnessed to improve users' performance and help them to retrieve their images. In this respect, olfactory media (engaging the sense of smell) is an example, as people can categorise their images by using congruent olfactory media. Accordingly, we investigated the impact of employing olfactory media as a key for retrieving a set of images. Moreover, we also studied the impact of the usage of olfactory media in this context on a user's performance and Quality of Experience (QoE). To this end, we developed an olfactory-enhanced application (SCENT2IMAGE) in which olfactory media was emitted alongside a 5X5 matrix of images, of which users had to recognize 4 images congruent with the emitted scents. Furthermore, we developed a word-only version of the application (WORD2IMAGE) in which words alone were used as an equivalent key instead of olfactory media. Forty-four participants were invited and took part in our experiment, evenly split into a control and experimental group. Results highlight that using olfactory media does have a significant impact on user performance by helping them find related images. Moreover, using olfactory effects in this context was also found to enhance user QoE. Lastly, our findings underscore that users were willing to use olfactory-enhanced applications for categorizing/retrieving their albums and images.

KEYWORDS
Olfactory media; olfactory cues; mulsemedia; images; recall; QoE

1. Introduction

Technologies and applications used in image browsing tools ("browsers") are based on traditional (audiovisual) multimedia such as JetPhoto Studio 5 and Picasa, in which users use only a single modality to interact with the browsers. Accordingly, users could name or categorise their images using text. In the same way, they can retrieve these images when needed. Remarkably, visual content is still the dominant key employed in image browsers; this means that only two senses are used (hearing and sight), although other senses such as tactile (sense of touch) and olfaction (sense of smell) could also potentially be employed.

Mulsemedia, or multiple sensorial media (Ghinea et al., 2011; Mesfin et al., 2020), involves the use of media beyond the audio-visual to enhance current digital applications. One such possibility involves olfactory media, engaging the sense of olfaction. According to recent studies (Alkasasbeh & Ghinea, 2020; Murray et al., 2013; Yuan et al., 2015), olfactory integration with other traditional media could enhance user perception (Garcia-Ruiz et al., 2021; Murray et al., 2014), performance (Caro-Alvaro et al., 2022; Ghinea & Ademoye, 2015; Maggioni et al., 2018), recall (Ademoye & Ghinea, 2013; Alkasasbeh et al., 2021; Garcia-Ruiz et al., 2021), the ability to convey information (Batch et al., 2020; Patnaik et al., 2018), as well as user Quality of Experience (QoE) (Covaci et al., 2018; Liu et al., 2022; Monks et al., 2017; Murray, Lee, et al. 2016). Furthermore, olfactory media has been employed in Virtual/Augmented Reality (VR/AR) not only to enhance QoE, but also to add a new dimension of realism (Caro-Alvaro et al., 2021; Comsa et al., 2019; Covaci et al., 2019; Doukakis et al., 2019; Harley et al., 2018; Moore et al., 2015; Ramic-Brkic & Chalmers, 2014). Despite these studies and their vital findings, the relationship between images and olfactory media remains a relatively unexplored domain.

In this study, we have investigated the potential of employing olfactory media as a key to retrieve or categorise images, and to explore the relationship between images and olfactory media. We hypothesize that users can widen choices and utilise the olfactory media to categorize, match, and retrieve images. Hence, the purpose of the research described in this paper is to explore the feasibility of having an olfactory-enhanced tool in which olfactory media is used as a key to match a set of images with a related scent. In this context, we studied the impact of having congruent

CONTACT Gheorghita Ghinea george.ghinea@brunel.ac.uk Department of Computer Science, Brunel University London, London, UK

olfactory media as a key on the user's performance and QoE.

The current paper expands on initial work reported in (Alkasasbeh et al., 2019). Specifically, and in addition to the work described in this paper, here we present a pre-study conducted to choose olfactory media and images; we also evaluate the characteristics of olfactory media used in terms of intensity, relevance, duration, and starting time. Moreover, we increase the number of participants who took part in this study. Also, we investigate additional factors that could impact user performance and QoE. Accordingly, the structure of the paper is as follows: we first review background, and related work for mulsemedia and olfactory media, after which we present the pre-study procedures and results. In the subsequent section, we present the experimental work and producers. Lastly, we discuss the results that reveal that olfactory media (compared with using words as a key) significantly influenced users' performance in respect of all three metrics employed: first response time, score, and time consumed. Moreover, our results revealed the positive and statistically significant impact that olfactory media characteristics have in respect of QoE. However, the main contribution of this study is that it describes exploratory work showcasing the potential of olfactory media in a digital context through its integration with other media such as images, investigating the impact of having olfactory media on users' recall performance and QoE. By reviewing the previous research in the literature, we concluded that these issues need further investigation, which motivates us to proceed in this direction.

2. Related work

Identification or matching has attracted the interest of researchers to investigate the impact of multisensory digital media to help users, such as using olfactory and tactile forms (Alkasasbeh & Ghinea, 2020; Garcia-Ruiz et al., 2008; Ghinea & Ademoye, 2012; Ghinea & Chen, 2006, 2008; Murray et al., 2013, 2016; Yuan et al., 2014, 2015; Zou et al., 2017). This work extends to VR, where olfactory, haptic and auditory media have been used to identify and detect 3D objects (Sithu & Ishibashi, 2017). In this study, 16 participants were asked to identify 16 objects including a building block, peach, banana, and a softball. Sets of attributes were used to identify these objects. For example, some of these objects were identified by their softness and sounds, while others were detected by both sounds and olfactory media (associated scents). In addition, they used visible and invisible modes to hide or reveal objects when this option was needed in their experiment. According to Sithu and Ishibashi's results, the object identification process was enhanced greatly with the presence of olfaction and sounds.

In an earlier study, Barfield and Danas (1996) investigated how olfactory displays might improve virtual environments. According to the authors, scent can play a significant part in making a virtual experience more authentic and immersive by appealing to the sense of smell, which is intimately related to memory and emotion. In related work, Dinh et al. (1999) suggested that multi-sensory integration contributes to a more immersive and realistic virtual experience. Their findings support the notion that multi-sensory integration is crucial for creating more immersive and engaging virtual experiences. Subsequently, Radvansky and Dombeck (2018) presented an innovative olfactory VR system tailored for mice. Their work revealed the successful integration of head-mounted imaging and controlled odor delivery, enabling precise study of olfactory stimuli on behavior and neural activity. The system's potential to further our understanding of olfactory processing is highlighted in the study, along with its implications for understanding olfaction in mice and maybe other species. Furthermore, in Pizzoli et al. (2022), the researchers aimed to assess the impact of scent-induced relaxation on participants' subjective well-being, stress reduction, and emotional state. The findings suggest that incorporating olfactory cues in virtual environments enhances the relaxation experience.

The impact of olfactory cues in training was highlighted by Washburn et al. (2003), who discussed their practical and beneficial effects in various contexts, such as flight simulators, medical training, and hazardous environment simulations, where the incorporation of olfactory inputs may be advantageous. They concluded by underlining the fact that olfactory signals can offer extra information and sensory feedback, making training sessions more fruitful and interesting.

Accordingly, retrieving content based on images has been investigated in recent work and significant results were achieved for content-based image retrieval (CBIR) (Cai et al., 2020; Choe et al., 2022; Hameed et al., 2021; Latif et al., 2019; Li et al., 2021; Shahabi et al., 2021; Tena et al., 2021; Wang et al., 2014; Zhou et al., 2022). These studies and other paid attention the gap between image-feature representation abn human visualization/understanding, and authors in this area aimed to reduce the gap between those issues. As opposed to other approaches which are based on AI/ML methods our is based on using the olfactory modality – a more natural and underused modality – to help the user retrieve images. Moreover, as to the uniqueness of our approach. CBIR proposed systems aim to categories the images retrieved from their directories using their classified features with minimum human interventions.

In related work, olfactory displays (diffusers) have been used in the identification process between scents and specific positions. To this end, Matsukura et al. (2013) designed a new olfactory-enhanced system, known as the smelling screen, in which a diffuser was used to distribute the emitted olfactory media onto LCD screens at several positions using USB fans. They executed several experiments to evaluate this system. In the first, they asked participants to determine three positions in which they received a scent; they used a peach scent as an olfactory media in this experiment. In the second evaluation, they used five peach pictures, with only one of them having the scent source. Also, they asked participants to evaluate the degree of fit between the peach pictures and scent source. In their experiments, the authors used high or low airflow and different screen corners as a scent source. The authors found it was rare for participants to select the wrong position of olfactory media source. Their answers were either correct or close to the correct answer because the positions were limited to a few millimeters. The authors acknowledged that the maximum distance was a limitation and insufficient for large LCD screens.

In this same regard, namely that of matching between olfactory media and locations (positions), Olofsson et al. (2017) designed a one-back test as a digital game-based test to examine participants' ability to make matching between two scents positions. They used a grid that contained 32 squares, with every four squares in this grid having the same scent. They asked 15 subjects to run this game and try several times to match scent pairs. This game depended on the user's ability to memorise the scent locations. Moreover, with respect to matching, object identification using their attributes like size, shape, and smell seemed to be easily compared with identification using objects' colours, especially for blind people. Li et al. (2017), on the other hand, designed a new system to help blind people recognize colors using olfactory media. In their work, participants were asked to identify seven different colours, by receiving related scents. For example, they used a lemon smell to identify the yellow colour, and the smell of a lily to indicate that clothes were fresh and clean.

Relatively few studies have explored the relationship between digital images and olfactory media in a digital context. Moreover, to the best of our knowledge, none of these studies investigated the olfactory media as a key to retrieve or match a related image. With respect of images matching, Nambu et al. (2010) utilised their evaluation's results on a visual-olfactory display and olfactory sensory map to examine the assessor's ability to deliver a match between a set of presented images and associated olfactory media. In their study, they divided 18 pictures into four groups and in each and used a specific generalised scent as an index. They concluded that one scent in each group is enough to identify the related pictures. This claim is very similar to the pre-study undertaken by Stafford et al. (2009). Here subjects were asked to write a set of words that they considered related to the emitted olfactory media. They found the rate of picture identification was 44%, which was considered insignificant.

Similarly, Sakai et al. (2005) experienced the interactions between visual images and olfactory media. They hypothesized that a user's perception of objects' scents could be affected by the visual systems being experienced. Users in this study were asked to rate the least and most appropriate images for each presented scent. Depending on the most appropriate images, participants were asked to evaluate the intensity of each scent. In the same regard, Seo et al. (2010) synchronised a set of scents with four images in photographic slides, with only one of these images being considered congruent to the presented scents. Moreover, the experimenters used eye-tracking technology to follow the users' visual attention. Their results show that the presence of congruent scents influenced the users' attention towards the related images. Errajaa et al. (2020) explored the impact of synchronization of congruent olfactory media with that of brand images on consumer behavior in terms of perception, pleasure, spending, attitude and arousal. Similarly, Morrin and Ratneshwar (2003) explored whether an ambient scent released in an experimental room enhanced user recognition and recall of digital images of goods. Participants were examined 24 hours later and it was found that ambient scents do indeed improve the recall and recognition of brands.

Byun et al. (2012) also investigated the parameters that should be considered whenever olfactory media is synchronised with related images. They presented a model for interaction between images and smells. In their model, they defined the request information that has to be synchronised with moving images such as scent time, speed, intensity and scent description. In a recent study, Wu et al. (2018) presented an olfactory display system in which image processing techniques were used to present the predefined scents with video content.

In work related to ours, Brewster et al. (2006) developed a new tool, written in Java, to help users by using text and scent tags. The first stage in this study was to build the scent and text categories in order to use them in tagging and the recall study. They asked participants to describe their own images using one word and a related scent. The output from this stage was 16 scent and 12 text categories. In the next step (tagging study), they asked the participants to tag their own pictures using the available scent and text groups. The available scents in this stage were not labelled, and the participants were asked to describe them in words. The number of pictures that were used in the tagging study was over 6,000 from 12 participants. Tens of words were extracted from both studies: categorization and tagging. The final process was the recall study, in which the participants were asked to match one proposed scent or text tag with the correct picture, or match one proposed image with the proper tag. Also, they were requested to use the search options to retrieve the pictures from the galleries. This process depended on the output from the tagging study. Their results showed that the smell tag helped the participants find their pictures, although the text tag was better regarding recall information. These findings match those of Stafford et al. (2009), which indicated the possibility of using one scent as an index to an image group.

The main issue stemming from the above review is the lack of a related image-olfactory dataset, as well as that of an accepted mapping between olfactory media and images. Moreover, as we state in the conclusion section, the time needed for users to receive the olfactory media still needs further investigation in order to optimize it. In our study, we undertook a comparison between using related words and related scents as indicators on a matrix of images. This study aimed at investigating the impact of deploying olfactory media on user performance in terms of retrieving a set of congruent images from SCENT2IMAGE. To this end, two tools were built, SCENT2IMAGE and a worded-image counterpart, WORD2IMAGE. Also, we sought to test the impact of having olfactory media on user performance, and the time needed for them to take action after receiving olfactory media or words.

3. Pre-study

Eight participants were recruited in this study, all of whom were students at Brunel University. This study aimed at selecting and rating four images for each scent that will be used in the following study, and assessing the scent characteristics. We chose eight images that were considered to be related to each scent used. To this end, we developed an application, in which users could select a scent from the list, as shown in Figure 1. Once the scent was selected, users would receive the scent for 10 s using a diffuser. Concurrently, eight images would be presented to users in a 2×4 set-up, out of which users were expected to choose only four images they considered to be most related to the experienced scent. Figure 1 shows an example of eight such images presented once the coffee scent was selected from the list. The scents used in this study were mint, orange, lavender and coffee.

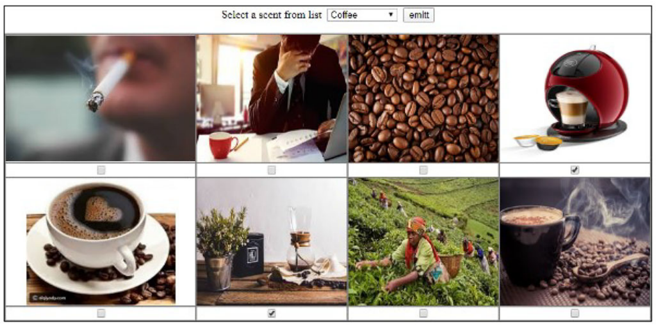


Figure 1. Rating of related images.

The second issue investigated in this study was to evaluate the characteristics of scents used. Accordingly, participants were asked to select a scent from the list from the screen (Figure 1) and fill in a Likert-scale questionnaire that included the following items:

- The scent was annoying
- The scent intensity was appropriate
- The scent was distracting
- The scent was emitted for a suitable duration
- The scent was started at the appropriate time
- The emitted scent was recognizable

The last issue was that of the image presentation dimensions. Thus, we asked participants to preview a number of images of randomly selected images displayed in three different matrices of (6×6) – Figure 2(a), (4×4) – Figure 2(b), and (5×5) – Figure 2(c). After that, we asked users to

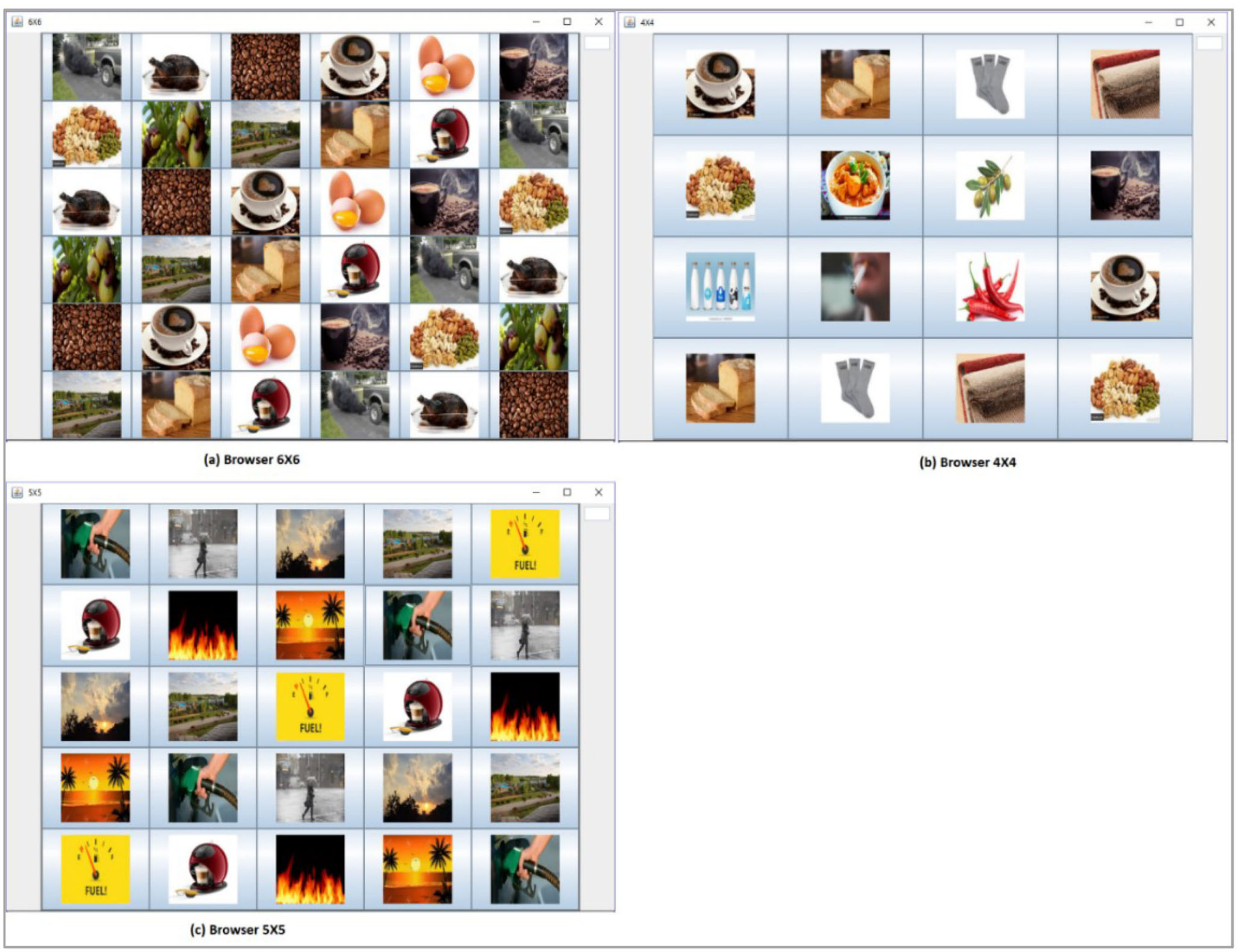


Figure 2. Different image layout presentations. (a) Browser 6×6. (b) Browser 4×4. (c) Browser 5×5.

let us know which of the three they preferred, bearing in mind the need for an image to be recognizable as well as having a satisfactory resolution.

3.1. Pre-study results

Table 1 shows the results of users' choices in respect of most suitable images to be associated with specific scents (a score of 0.125 signifies that the particular image was chosen by one out of the eight participants). Accordingly, for each scent, we selected the topmost 4 rated images, as chosen by users.

According to users' responses to the questionnaire regarding the characteristics of scents, scents used in this study were not found to be distracting or annoying by participants of the pre-study. Furthermore, participants also considered the duration and starting time of scents to be suitable, and no changes were required. Regarding scent intensity, users found it to be appropriate for all scents with the exception of the mint scent, which was perceived by some users as having a high intensity. For this reason, we reduced the mint intensity employed in the main study. Finally, in terms of scent characteristics, all users were able to recognize the scents used. Last but not least, most of the users in the pre-study preferred the 5 × 5 set-up, which we thus decided to use in the next stage of our study.

4. SCENT2IMAGE

Based on our results in the pre-study, we developed SCENT2IMAGE, an olfactory-enhanced tool. This displayed 25 images (in a 5 × 5 matrix), of which only four would be related to the emitted scent (Table 1). This was done with the aim of investigating the ability of users to recognize the scent received and to match it with the targeted images. Accordingly, once a user opens SCENT2IMAGE, s/he would receive an associated scent and a matrix containing 25 images, as shown in Figure 3. In this particular case, the emitted scent was coffee and the four correct images that should have been chosen by the user are circled in green. Current user choices are displayed underneath the image matrix.

In order to investigate the impact of having olfactory media as a key in SCENT2IMAGE, a counterpart, non-olfactory, version was adapted, in which users would receive one or more words instead of scents (henceforth referred to as WORD2IMAGE). As shown in Figure 4, here users were asked to select four images related to the two provided words (vivid and cocktail). Participants with this version did not receive olfactory media, with these words being considered as being equivalent keys to the olfactory media in the olfactory-enhanced version.

Table 2 shows the scents used in our experiment and the corresponding words used in the non-olfactory version (WORD2IMAGE), with the related images used with these scents or words. With respect to words used in this experiment, they emanate from a study of Bannai et al. (2006), in which participants were asked to rate a set of words as related or not to a particular scent. In our experiment, we selected the two topmost ranked words for each scent used in our study.

Table 1. Results of rating of congruence between images and scents.

	pic1	pic2	pic3	pic4	pic5	pic6	pic7	pic8
Scent1 (orange)	0.125	**0.875**	0	**0.875**	**0.875**	0.125	**0.875**	0.25
Scent2 (lavender)	0.25	**0.75**	**0.875**	0.125	**0.625**	**0.875**	0.25	0.25
Scent3 (mint)	**0.75**	**0.75**	0.25	**0.875**	**0.75**	0.375	0.125	0.125
Scent4 (coffee)	**0.625**	0.125	**1**	0.375	**0.875**	0.75	0	0.25

Boldface shows the images that were selected for each scent (scoring above 0.5).

5. Experimental study

5.1. Participants

A total of 44 participants aged between 21 and 43 were recruited in our experiment as shown in Table 3. Participants were randomly allocated and split evenly into two groups, a control and experimental group, with 22 subjects in each.

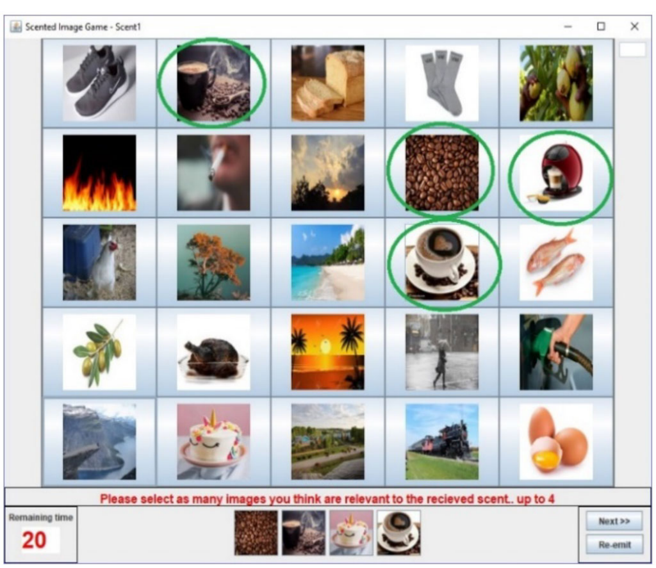


Figure 3. Example of olfactory-enhanced images.

Figure 4. Example of non-olfactory images.

Table 2. List of olfactory media, words and examples of used images.

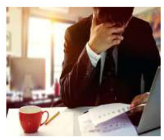
Scents	Images	Words
Mint	   	Refresh Relaxed
Orange	   	Vivid Cocktail
Lavender	   	Romantic Fascinating
Coffee	   	Aroma Mood

Table 3. Breakdown of participants.

	18–24	25–30	31–36	37–42	
Female	8	7	7	2	24
Male	8	5	6	1	20
Total	16	12	13	3	44

The control group used the WORD2IMAGE tool in accomplishing the experimental task (congruent image retrieval), whilst the experimental group employed SCENT2IMAGE towards the same end.

None of the participants had previously taken part in any experiment employing olfactory-enhanced applications. Furthermore, none of the participants reported any condition that might have prevented them to take part in the experiment such as anosmia, infected sinuses, headaches or other issues that might affect user health or user performance. The study had obtained formal, prospective approval from the Brunel Research Ethics Committee (ref 15038).

5.2. Experimental material

Olfactory display: The Exhalia Diffuser SBi4 was used in this study to emit and synchronise scents. As shown in Figure 5, this device can be connected to a computer through a USB cable. In order to emit and synchronise the scents with traditional digital media, a Java package has been used to control the main scent characteristics such as starting time, intensity, and duration. Moreover, this package was also used to activate and deactivate the scents and control order of their emission. Finally, scents contained in cartridges (Figure 5) are emitted in the surrounding atmosphere using one of four independent fans.

Java application and MySQL: Both SCENT2IMAGE and WORD2IMAGE were developed using NetBeans IDE. All data required in these applications were stored in a MySQL database. The database contains a set of tables to record all the participants' responses, such as images selected in each round and task times. On the other hand, all images, words and scents information needed to build the two tools are stored in particular tables in the database. For example, the table depicted in Figure 6 was used to record participants' responses such as starting time, reaction time and scents received for each participant

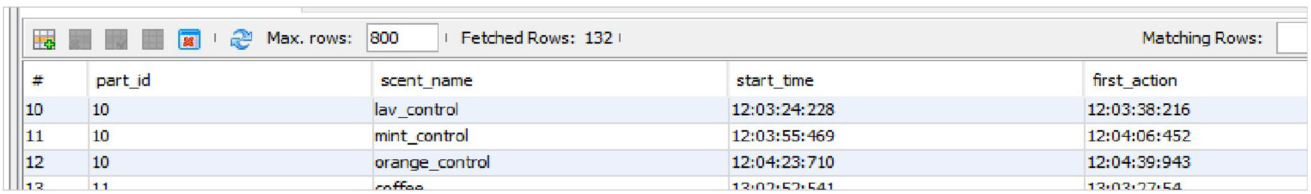
Words, scents and images: As mentioned above, we used four scents (mint, orange, lavender and coffee) in SCENT2IMAGE. As detailed in Table 2, for each scent, four related images were used. As regards WORD2IMAGE, two corresponding words were used instead of scents (Table 2).

5.3. Experimental procedure

On arrival, participants were received in the experimental room. This was a 5 × 4 metres air-conditioned room. After sitting themselves comfortably at the experimental table, participants were explained the experiment's procedure and aims. They were then asked to read an information sheet containing more details on the study. On completion they were asked if they had any questions, and, if applicable, these questions were answered by the researchers. If participants were happy to proceed with the experiment, they were asked to sign a consent form.

Experiment set-up: Before starting, participants were asked to sit in front of the laptop and adjust its screen till they were comfortable with the viewing angle. Then, we adjusted the olfactory display according to the participant's height, as the angle and distance should be considered and adjusted. It has been recommended by Murray et al. (2017) that the distance between participants' noses should be

Figure 5. The Exhalia Diffuser (SBi4) and scent cartridges (Murray et al., 2017).



Max. rows: 800 | Fetched Rows: 132 | Matching Rows:

#	part_id	scent_name	start_time	first_action
10	10	lav_control	12:03:24:228	12:03:38:216
11	10	mint_control	12:03:55:469	12:04:06:452
12	10	orange_control	12:04:23:710	12:04:39:943
13	11	coffee	13:02:52:541	13:03:27:54

Figure 6. Example of a database table in SCENT2IMAGE.

Table 4. A questionnaire of scent characteristics and matching of images.

Part1 (scent affects, characteristics and relevance)	Part2 (olfactory-enhanced application)
Scent affects	**SUS items**
QS1: The scent was pleasant	QA1: I think the browser was easy to use
QS2: The scent was distracting	QA2: I found the browser unnecessarily complex
QS3: The scent was annoying	QA3: I felt very confident using the browser
Scent characteristics	QA4: I found the browser very cumbersome to use
QS4: The scent intensity was appropriate	QA5: I needed to learn a lot of things before I could get going with this browser
QS5: The scent was emitted for a suitable duration	QA6: I think that I would need the support of a technical person to be able to use this browser.
QS6: The scent was started at the appropriate time	QA7: I found the various functions in this browser were well integrated
Scent relevance (used for the experimental group)	QA8: I thought there was too much inconsistency in this browser
QS7: The scent helped me to recognise the targeted image	QA9: I would imagine that most people would learn to use this browser very quickly
QS8: The scent was relevant to more than one image.	QA10: I think that I would like to use this browser frequently.
Word relevance (used for the control group)	**Future trends**
QW7: The words helped me to recognise the targeted image	QA11: It is unlikely I could have completed the task without receiving a related scent.
QW8: The words were related to more than one image.	QA12: I would like to use the olfactory-enhanced browser to retrieve my images.

adjusted between 30 and 40 cm in order to receive the scents. Also, as per the recommendations, the angle for receiving the scents was adjusted to be between 30° and 45°, depending on the participant's characteristics. Finally, all the scents were readied previously, before participants arrived in the experimental room, and kept in a corner of the room to maintain the room atmosphere fresh.

SCENT2IMAGE: upon completion of the experiment set-up, users were asked to start using the tool. Firstly, users had to fill-in a form containing demographical information such as username, age range, and educational background. Once users finished this, they were issued with an ID and were asked to click on a "Start" button when ready. When this happened, they received a 5×5 matrix of 25 images, as explained in Figure 3. At the same time, a related olfactory media was emitted for 10 s. Users were then expected to select up to four images that they considered related to the emitted olfactory media. When users were satisfied with the choices made, they submitted them by pressing a "Next" button, upon which experimental group participants were asked to fill in a QoE questionnaire containing 8 questions (QS1-QS8) regarding the scent used. As shown in Table 4 (part 1), some items were used to evaluate scent characteristics such as starting time and duration, whilst the rest were used to assess the perceived nature of the olfactory media employed. Participants repeated this process four-fold, once for each particular scent (the presentation order of each scent was randomized so as to avoid order effects; in between scents, participants waited 60 s to avoid potential scent cross-contamination) and its set of congruent images.

WORD2IMAGE: the process for control group participants mirrored that of their experimental group counterparts which used SCENT2IMAGE, with the exception that words were used as cues instead of olfactory media, and that participants here only answered QW7 and QW8 from Table 4.

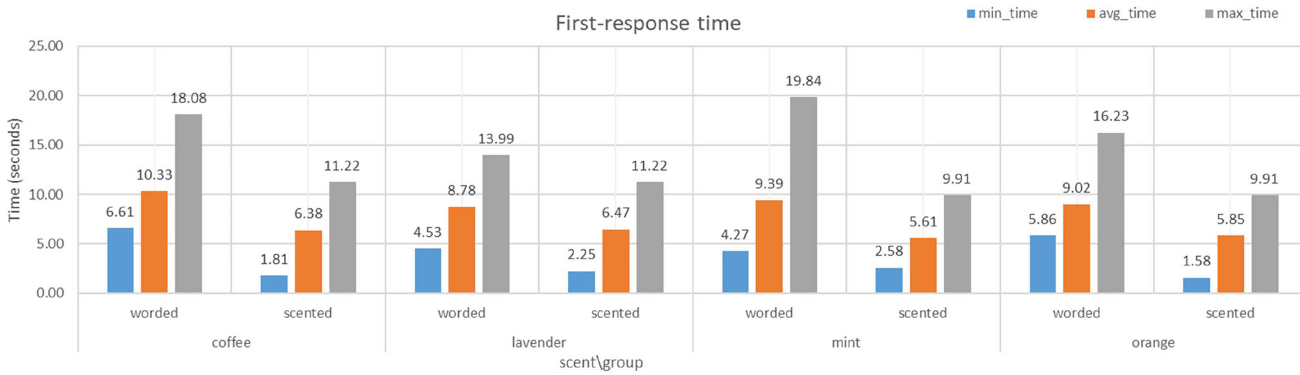


Figure 7. Comparison across groups of the first-response time.

Post-questionnaire: At the end of the experiment, each participant was asked to fill in a general questionnaire (5-point Likert scale) about the olfactory-enhanced application (SCENT2IMAGE) as shown in Table 4 (part 2). The first 10 items in part 2 were drawn from the System Usability Questionnaire (Brooke, 1996).

The experiment procedure lasted for 40 min in average. Regarding control group participants, the experiment followed the same process but participants did not have to fill in this questionnaire. For this reason, the experimental duration was between 25 and 30 min approximately for this cohort.

5.4. Assessment

To measure the impact of having olfactory media on user performance, the first-response time was reported for both SCENT2IMAGE and WORD2IMAGE. The first-response time is the time elapsed from receiving the images matrix and associated cues (either olfactory media or related words) to selecting the first correct image. 6., which comprises the length of time spanning from the user receiving the images matrix and associated cues till s/he selects all images perceived to be congruent with the cues and presses the "Next" button. Lastly, a user score was calculated as being, for a particular key (olfactory or word) the number of correctly selected images by participants; as at most four such images could be selected, this was a number between 0 and 4.

6. Results and discussion

6.1. Olfactory media impact on user performance

As mentioned above, we reported the first-response time in both scented and worded versions of the image retrieval tool, SCENT2IMAGE and WORD2IMAGE, respectively. Figure 7 shows the maximum, minimum and average for the first-response time recorded for all participants in both versions. For example, in the case of the orange scent, users in the experimental group spent an average of 5.85 s to choose an image that was considered to be associated with this particular scent, whilst the control group took 9.02 s on average to choose an image from the same matrix, when related words listed in Table 2 were used as cues. Across all scents and word cues used in the study, the average first-response time in SCENT2IMAGE was 5.96 s compared with 9.38 s spent by those who used the WORD2IMAGE to choose congruent images from the displayed matrix.

Table 5. Results of an independent sample *t*-test for *first response* time.

Worded-scented	*F*	*t*	df	Sig. (2-tailed)
Coffee	0.654	4.857	42	0.000
Lavender	0.318	3.283	42	0.002
Mint	5.143	4.102	42	0.000
Orange	0.019	4.089	42	0.000

An independent sample *t*-test was conducted to confirm the significance of having olfactory media as a key to retrieve related images compared with using related words in terms of first-response time. The results suggest that using olfactory media does have a significant impact on user performance. Table 5 shows the results of the test for each pair of scents and words.

Furthermore, regarding the second measurement of user performance, a score, ranging between 0 and 4, was recorded for each participant of both control and experimental groups, as explained in section 5.5 As shown in Figure 8, the results show the average scores achieved by the participants in the experimental group is 3.2 out of 4, whilst it is 2.19 for participants in the control group. Moreover, this sizeable difference between the two cohorts is statistically significant ($p < 0.05$), as confirmed by an independent sample test on the scores for both groups (Table 6).

Last but not least, an independent sample test was conducted on the time consumed in the whole process for each participant and round. Apart from the lavender scent, the results show a significant difference between the control and experimental groups in terms of coffee, orange and mint scents (Table 7).

6.2. Olfactory media impact user QoE in image recall task

As discussed above, we divided the questionnaire into two parts. The first part was eight questions regarding the scents employed and words effects on user quality of experience, while the second part was ten questions concerning system usability. To check the reliability of the responses, the Cronbach's Alpha coefficient was calculated. Accordingly, the Cronbach's alpha value was shown to be 0.7221, which is considered good (George & Mallery, 2003).

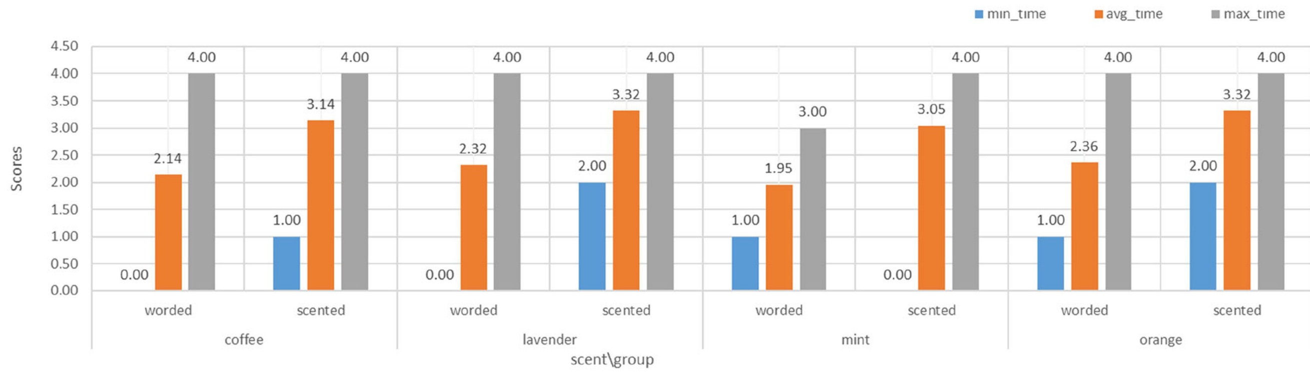


Figure 8. Comparison across groups of the scores achieved by the participants.

Table 6. Results of an independent sample test for *scores* achieved by participants.

Worded-scented	F	T	df	Sig. (2-tailed)
Coffee	0.005	−3.849	42	0.000
Lavender	2.115	−3.954	42	0.000
Mint	0.202	−3.913	42	0.000
Orange	0.824	−3.887	42	0.000

Table 7. Results of an independent sample test for the *time consumed.*

Worded-scented	F	T	Df	Sig. (2-tailed)
Coffee	0.071	2.2253	42	0.03
Lavender	0.476	2.048	42	0.47
Mint	0.405	2.826	42	0.007
Orange	0.001	3.946	42	0.000

6.2.1. Scent effects and characteristics

As detailed above, experimental group users were asked to answer 8 items after each round of using SCENT2IMAGE (QS1- QS8). In respect of the control group, users answered only two items (QW7-QW8) after each round. These two items were used to compare the impact of having words as cues (Figure 9).

As we mentioned above, four scents were used in this study. And the items QS1-QS8 were used to assess the impact of using the scents on the user QoE. For this reason, we conducted the one-way ANOVA to test whether there is a statistically significant difference between our group means.

Table 8 shows the output of the ANOVA analysis. The results of the test show there is no significant difference between groups (used scents). Based on this, we will deal with responses from all groups as one group in the detailed analysis.

Detailed analysis in respect of the different questionnaire items reveals that:

QS1-The scent was pleasant: As was found in previous research (Alkasasbeh et al., 2021; Caro-Alvaro et al., 2022; Martin & Chaudry, 2014), pleasant scents had a positive impact on user performance. Twenty-two responses were received for each scent used in this study, corresponding to participants in the experimental group (88 in total). According to these responses, as can be seen in Figure 9, roughly 79.5% of participants found the scents used were pleasant, 15% were neutral, while only 5.5% found the scents were unpleasant (mean = 4.02, SD = 0.816). Moreover, these positive results were found to be statistically significant, as evidenced by a one-sample test ($t(87) = 11.755$, $p < 0.05$).

QS2-The scent was annoying: 78% of users did not perceive the scents used in the study to be annoying, confirming the trend noted in the pre-study; in contrast, a minority of 7% of users found the scents used annoying. Moreover, it was confirmed using a one-sample test that this distribution of responses (M = 1.95, SD = 0.946) is also statistically significant ($t(87) = -10.370$, $p < 0.05$).

QS3-The scent intensity was appropriate: Murray et al. (2017) refereed to a potential relationship between the intensity and users QoE. Based on that, we considered this issue in the pre-study, and the intensity of scents used was adjusted using the Java application. As can be seen in Figure 10, about 75% of experimental group participants found that the intensity of scents was appropriate, 19.5% of them were neutral, and only 5.5% claimed that the intensity was not appropriate. This was due to using the same level of intensity for all scents in this study, apart from mint which was adjusted down based on the feedback from the pre-study. Regarding participants' responses, the positive user attitudes in respect of intensity (mean = 3.88, SD = 0.77) are also revealed by a one-sample test to be statistically significant ($t(87) = 10.744$, $p < 0.05$).

QS4-The scent was distracting: according to participants' responses, 74% of participants found the scents not to be distracting, 17% were neutral, whilst only 9% found the scents distracting. Again, conducting a one sample t-test found the positive attitude of users in respect of scents not being distracting (mean = 2.13, SD = 0.945) to be statistically significant ($t(87) = -8.69$, $p < 0.05$) that match with previous studies (Saleme et al., 2021) Indeed, it is worthy of mention that scents such as coffee and orange did not cause a single user to state that they were to any degree distracting.

QS5-The scent was emitted for a suitable duration: All scents were emitted for 10 s which is supposed to be a long enough duration for users to receive and recognise scents given that users need about 2 s to receive, recognise and take action to the scent received (Alkasasbeh et al., 2021; Ghinea & Ademoye, 2012; Kim et al., 2015). According to participants, 75% of them reported that the scents were emitted for a suitable duration, 19% were neutral, and a

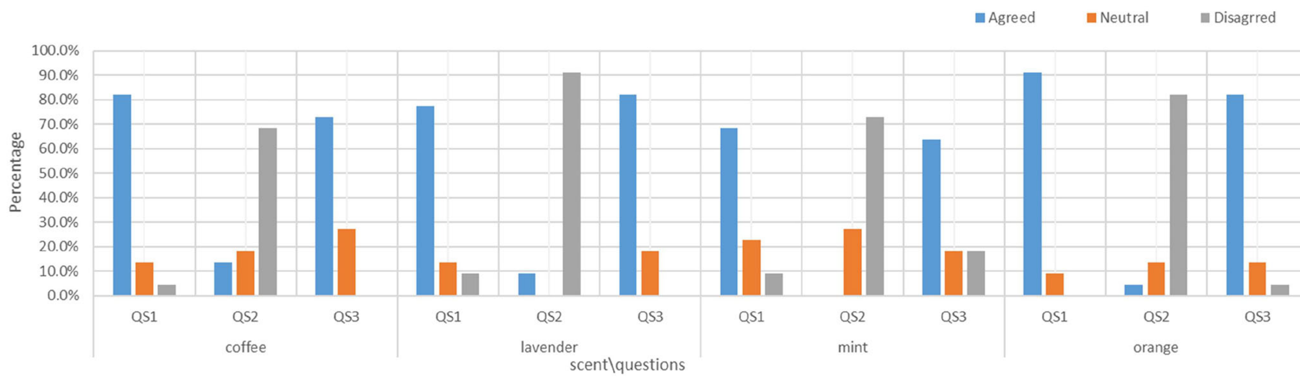


Figure 9. Responses to scent effects questions (pleasantness, distracting and intensity).

Table 8. Results of one-way ANOVA between scents.

Item	df	Mean Square	F	Sig.
The scent was pleasant.	3	1.045	1.602	.195
The scent was annoying	3	.606	.670	.573
The scent intensity was appropriate	3	1.193	2.086	.108
The scent was distracting	3	1.496	1.718	.169
The scent was emitted for a suitable duration	3	.769	1.087	.359
The scent was started at the appropriate time	3	1.894	3.065	.032
The words helped me to recognise the targeted image	3	1.379	1.646	.185
The scent helped me to recognise the targeted image	3	1.375	2.409	.073
There was only one image that related to the listed words	3	1.636	1.382	.254
There was only one image that related to the emitted scent	3	.636	.637	.593

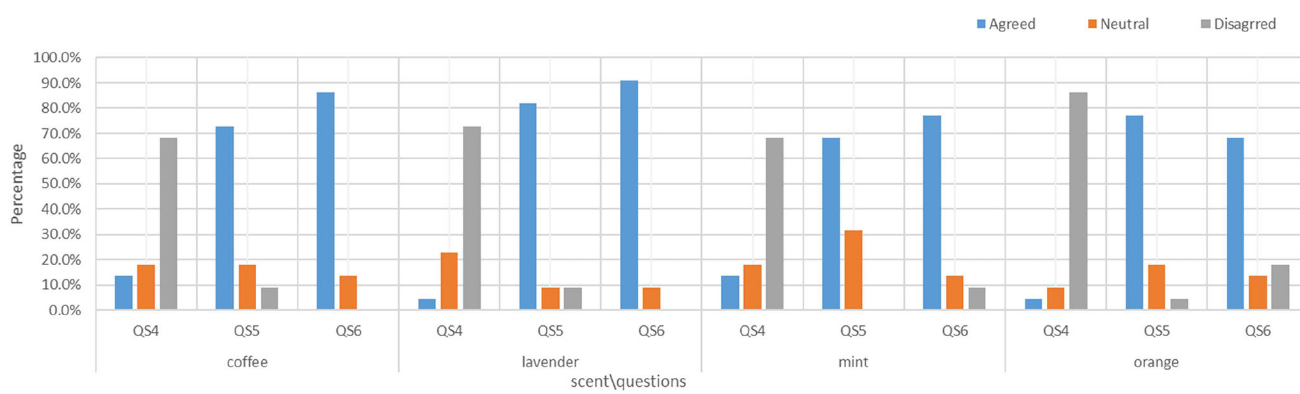


Figure 10. Responses to scent characteristics questions (distracting, duration and starting time).

small minority of roughly 6% disagreed. Moreover, it was confirmed using a one-sample test that this distribution of responses (3.81, SD = 0.842) is also statistically significant ($t(87) = 8.986$, $p < 0.05$).

QS6-The scent was started at the appropriate time: regarding SCENT2IMAGE, scents were synchronised with and emitted for 10 s when the 5×5 image matrix corresponding to a particular scent first appeared on users' screens. In this respect, about 80.7% of participants found the scents were started at the appropriate time, 12.5% were neutral, with only 6.5% reporting that the starting time was not appropriate. Although a sizeable minority of 21% of participants claimed that the starting time for the coffee scent was not appropriate, in contrast, none of the participants reported the same about mint and orange. Unsurprisingly, this distribution of positive user opinions (mean = 3.9, SD = 0.814) is shown to be statistically significant by one sample *t*-test ($t(87) = 10.744$, $p < 0.05$).

6.2.2. Scents and words relevance

QS7-The scent helped me to recognise the targeted image: in this study, we explored the impact of having olfactory media as a key to match a set of related images. To this end, the current question asked users whether the scents helped them to find the most relevant images. As can be seen in Figure 11, about 82% of participants reported that the scents helped them to find the related images, 11.5% were neutral, and 6.5% claimed that the scents did not help them. Moreover, a one-sample test reveals that there was a significant difference ($t(87) = 10.885$, $p < 0.05$) regarding participants' responses (mean = 3.9, SD = 0.774), highlighting that users perceived all scents employed to have a positive effect on their ability to recognise the congruent images contained in the matrix displayed.

QW7-The words helped me to recognise the targeted image: in the counterpart version (non-olfactory), instead of each scent, we used two words that were considered to be

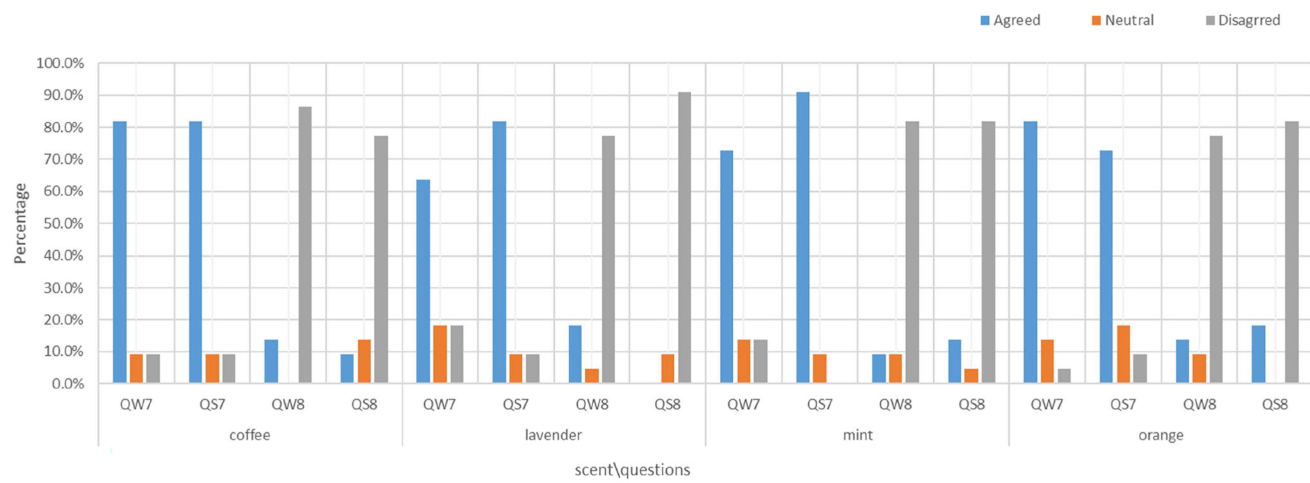


Figure 11. Responses to Scents and words relevance questions.

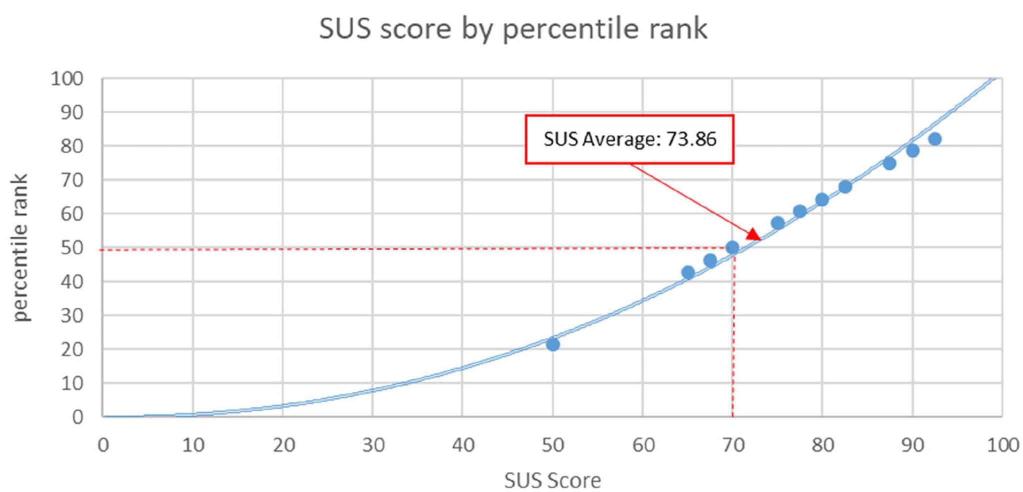


Figure 12. SUS items scoring.

related, as found by according to previous studies (Alkasasbeh et al., 2019, 2021; Bannai et al., 2006). Participants in the control group were asked whether these words helped them to find the related images. As can be noticed in Figure 11, about 75% of participants in the control group found that the words used instead of scents helped them to match the images targeted, 13.5% were neutral, and 10.5% did not agree with this issue. Whilst a one-sample t-test confirms the statistically significant ($t(87) = 7.603$, $p < 0.05$) nature of participants' positive attitudes (mean $= 3.75$, SD $= 0.925$) to having word cues, what is noteworthy is that user scores, first response times and time consumed are significantly better in the case when olfactory cues were employed.

QS8-The scent was relevant to more than one image: in SCENT2IMAGE, participants were asked whether they found the scent emitted to be congruent to one or more images displayed-. This question aimed to see if the scent can be perceived in a different context rather than the intended one. For example, when people receive a whiff of coffee, some might match it with an image of coffee beans, however others might choose an image of cigarettes or one related to love. Nonetheless, 83% of participants reported that scents emitted were related to more than one images, 10% of subjects disagreed with that, and the rest were neutral (Figure 11). It was confirmed using a one-sample test that this distribution of responses (M $= 3.95$, SD $= 0.993$) is also statistically significant ($t(87) = 9.016$, $p < 0.05$).

QW8-The words were relevant to more than one image: this question was asked of participants in the control group who used words instead of scents as a key to retrieve images. The aim is the same as in QS8 (how words can be interpreted). As shown in Figure 11, results show 81% reported that words were related to more than images, 5.5% were neutral, and 13.5% claimed that words were related to only one image. Furthermore, the participants' opinions did not vary regarding the number of related when scents or words were used as a key. The results of conducting a one-sample test confirm the statistically significant (M $= 3.86$, SD $= 1.095$), $t(87) = 7.397$, $p < 0.05$.

6.2.3. SUS items

The second part of our questionnaire assessed the olfactory-enhanced application using the system usability scale, as

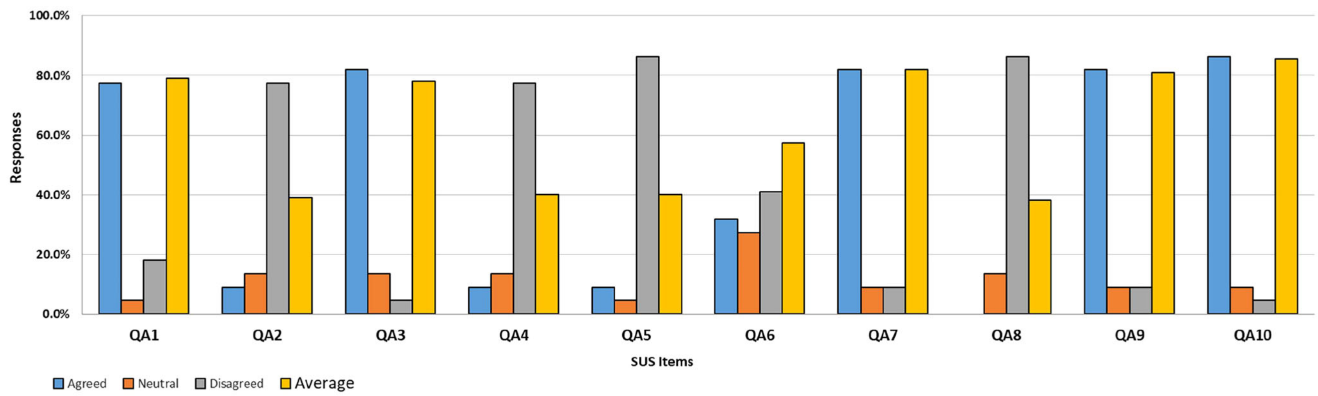


Figure 13. Participants' responses to SUS questions.

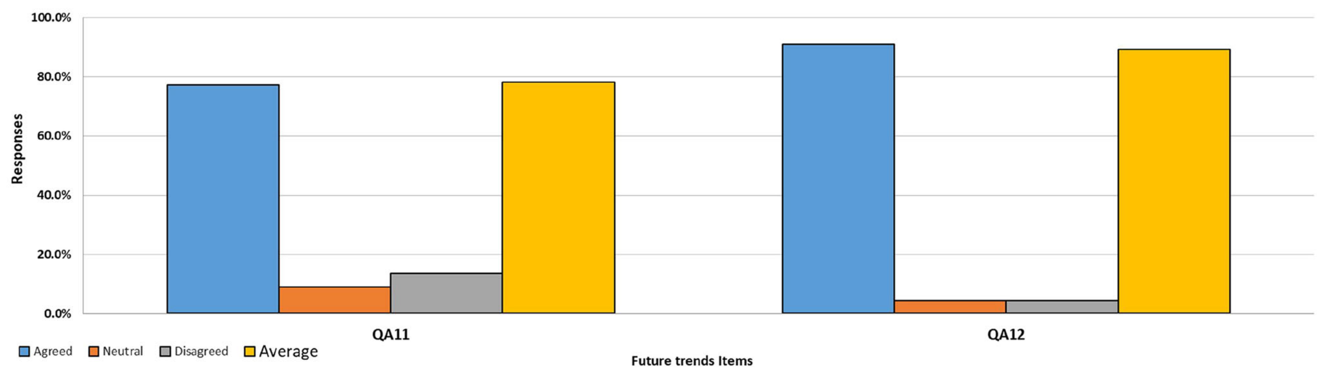


Figure 14. Participants' responses to future trends questions.

presented in Table 4. Some of these items were presented negatively (QA2, QA4, QA5, QA6 and QA8) while the rest were worded positively (QA1, QA3, QA7, QA9 and QA10). SUS scores, out of 100, were calculated for each participant. For the negatively worded items, each value was subtracted from 5. Regarding the positively worded items, 1 was subtracted from each response. Therefore, all responses are expected to be between 0 and 4 (Brooke, 2013; Sauro, 2015). As can be seen in Figure 12, the average score for all participants was 73.86. According to Bangor et al. (2008), this average is situated in the acceptable region (> =70) as is the case for most participants' scores. Moreover, as can be seen in Figure 12, the participants' scores that below the SUS average are situated marginally acceptable region (50–70).

Figure 13 shows the responses of participants for the SUS items and the average of these responses. In the following, participants' responses for SUS items are discussed in more detail:

QA1-I think the system was easy to use: 77.3% of participants found the olfactory-enhanced system was easy to use, whilst 18.2% claimed that the system was not.

QA2-I found the system unnecessarily complex: out of 22 participants, 77.3% found no unnecessary complexity in SCENT2IMAGE, 13.6% were neutral, and 9.1% of participants found the system unnecessarily complex.

QA3-I felt very confident using the system: 81.8% of subjects felt confident while they used SCENT2IMAGE, and only 4.5% claimed otherwise, with the same percentage being neutral.

QA4-The system was not cumbersome to use: according to 77.3% of participants in the experimental group, while 9.1% claimed that the system was very cumbersome to deal with, with 13.6% being neutral on the issue.

QA5-I needed to learn a lot of things before I could get going with this system: 86.4% of subjects reported that they did not need to learn a lot to be familiar with the system. In contrast, 9% responded they need to learn a lot of things before starting with the application.

QA6-I think that I would need the support of a technical person to be able to use this system: There was a convergence of views among participants regarding this issue, with 31.8% of them reporting that they would need support to use SCENT2IMAGE (presumably because of the perceived complexities of operating the Exahalia device). 40.9% opposed this argument, and 27.3% were neutral.

QA7-I found the various functions in this system were well integrated: 81.8% of users agreed that all the components and functions in the application were well integrated compared with 9.1% who disagreed, and 9.1% who were neutral.

QA8-I thought there was too much inconsistency in this system: regarding consistency in the application, 86.4% of participants found no inconsistency in our system. Remarkably, none of the participants agreed with the statement, whilst 13.6% were neutral on the issue.

QA9-I would imagine that most people would learn to use this system very quickly: 81.8% of subjects believed that people would learn to use this system very quickly, 9.1% disagreed, and 9.1% were neutral.

QA10-I think that I would like to use this system frequently: about using this system frequently in the future, 86.4% of participants agreed that people would like that, only 4.5% didn't, whilst 9.1% were neutral.

6.2.4. Future trends

At the end of the experiment, we asked participants to respond to the following questions regarding SCENT2IMAGE, the olfactory-enhanced application employed in our study:

QA11-It is unlikely I could have completed the task without receiving a related scent: As can be seen in Figure 14, 80% of the participants agreed that they might not be able to retrieve the targeted images without having a key such as olfactory media; 5% of them were neutral, whilst 15% believed that they can retrieve those images without receiving the olfactory media. Moreover, these positive attitudes are reinforced by the statistically significant better user performance of users in the experimental group compared to their control group counterparts.

QA12-I would like to use the olfactory-enhanced browser to retrieve my images: in this respect, an overwhelming 89.5% of participants responded that they would like to use SCENT2IMAGE in the future, 5% were neutral, and a similar percentage were not willing this type of tools (Figure 14). This set of responses underlies the positive attitudes of users towards olfactory-enhanced digital technologies in general and SCENT2IMAGE in particular. Whist such attitudes could be impacted by the relative novelty of the experienced technology; they nonetheless point to encouraging user attitudes towards its potential.

7. Conclusions

The study reported in this paper investigated the use of olfactory media as cues/keys for retrieving a congruent set of images. To this end, we developed SCENT2IMAGE, an olfactory-enhanced application, in which users can employ olfactory media to retrieve images. We also designed a counterpart version in which words were used as keys for image retrieval instead of olfactory media.

Our results reveal that olfactory media significantly influenced users' performance compared with using words as a key in respect of all three metrics employed: first response time (time taken to identify a first correct image), score (number of images correctly retrieved for each cue), and time consumed (time taken to retrieve a set of up to four congruent images). For example, users spent about 5.7 s on average as the first response time in the olfactory-enhanced version compared with an average of 9.5 s in the counterpart version. Moreover, a significant difference was found regarding the average score, where a sizeable performance gap was highlighted between the experimental group (average score of 3.18 out of 4) and the control one (average score of 2.14).

Furthermore, we explored the impact of olfactory media characteristics on users' QoE and results revealed the positive and statistically significant impact that olfactory media has in this respect. User responses also highlighted that most were willing to use SCENT2IMAGE in the future. Moreover, they overwhelmingly believed that olfactory media could be used as a key to help them to recognize the related images and that without olfactory media, it would have been difficult for them to complete this task. However, despite the significant difference in terms of first response time between versions, the time needed for users to receive the olfactory media still needs further investigation in order to reduce it. Further investigation and enhancement are needed on SCENT2IMAGE to more comprehensively examine the ability of scents to be used as cues for image retrieval, even in cases when the image is not semantically congruent to the emitted scents. All are valuable future pursuits.

A few limitations of our work have to be noted; relatively few studies have been conducted to investigate the relationship between olfactory media and images; for this reason, the lack of pre-studied images and congruent olfactory media, and the number and range of scents are deemed to be limitations in this study, which can be addressed in future investigation. Moreover, whilst our study did not focus on culture, we do recognise that it may be a factor (along with age) affecting scent-based recall in digital multisensory environments – both represent valuable channels for future work. Last but not least, whilst the exploratory study described herein has highlight the promise of scents for image recall in a controlled experimental setting, additional experiments and analysis are needed to determine its potential in a variety of real-world contexts, with e-learning, virtual tourism, and online dramatic arts performances being application domains worthy of future exploration.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Anas Ali Alkasasbeh http://orcid.org/0009-0004-8586-4461
Gheorghita Ghinea http://orcid.org/0000-0003-2578-5580

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About the authors

Anas Ali Alkasasbeh is currently an assistant Professor of Computer Vision with the Department of Computer Science, Mutah University, Jordan. Anas earned his PhD in Computer Science at Brunel University, UK, in 2020. His areas of research encompass computer vision, network security, as well as the application of machine learning.

Gheorghita Ghinea is currently a Professor of Mulsemedia Computing with the Department of Computer Science, Brunel University, London, U.K. His research interests lie at the confluence of Computer Science, Media and Psychology, focusing on building adaptable cross-layer end-to end communication systems incorporating user multisensorial and perceptual requirements.