Investigating the effects of odour integration in reading and learning experiences

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Abstract. Books are the tools used for reading novels and stories, but also for educational purposes. Conventional books have undergone a radical transformation in recent years due to the use of new technologies. However, even today the technological devices used for reading e-books are still poorly exploited, despite the fact that they represent a fundamental tool to make the reading experience more immersive by using a complete multisensory approach. In this perspective, one sense that represents an important element of human perception is the sense of smell. Consequently, authors make the hypothesis that the introduction of odours during reading sessions could increase the user experience and the learning performances. In order to demonstrate these hypotheses, the authors have defined and carried out several experimental testing sessions. The analysis of the collected data proved that the introduction of odour does not disturb the reader during reading activities but, on the contrary, can actually make the experience more immersive. Similarly, odours do not disturb studying activities, but they can instead increase the level of concentration and people's learning performance.

Keywords: multisensory environment, augmented reality, user experience, olfactory technologies

1 Introduction

Books allow us to gain knowledge and to "enter" different worlds, which can be either real or fantastic. Traditionally, books are published in a written format, which is read by the users and then interpreted and used to visualize people, places, situations, stories and so on. In order to do this, writers usually describe colours, sounds, people's traits, landscapes etc. Some books also use illustrations and sometimes they even give the chance to interact with some parts of the book. These *interactive books* require the active involvement of the reader, which can vary to a great extent: the highest level is reached when the interaction is vital to the progression of the story. *Interactive books* engage the reader and pull them into the story, and are usually created for children, in order to capture their attention.

In these books the interaction can be usually based on touch (by using different textures, moving parts, and so on), audio (with musical pages), smell (with the so-called "scratch and sniff" books) and stimuli from these senses being typically integrated with illustrations and text. Consequently, *interactive books* are intrinsically multisensory in nature.

In the case of adult readers, the use of interactive books is quite rare, but often the stimulation of other senses is still a fundamental element for improving concentration and the reading experience. Indeed, some readers use background music or home fragrances while reading, and often pay particular attention to the physical quality of the book (in terms of quality of the paper, etc).

Besides the ones read for pleasure, books are also used for educational purposes, textbooks, scientific books, books about specific topics, such as biographies of historical figures, handbooks etc.. In this case, the main objective of the reader is to keep the level of attention as high as possible (and as long as possible), in order to better understand the meaning of the text and remember all the contents as quickly as possible.

Even in this case, the user interacts with the book through the vision (i.e. reading the text), but also physically (underlining sentences, adding comments etc.). By doing so, mechanisms of human visual memory can be activated, and the user is able to remember some parts of the book (and the corresponding contents) [1].

Nowadays, this scenario is undergoing a radical change due to the introduction of e-books, which are completely modifying the user-book interaction. Indeed, even if e-books are the digital version of traditional books, some fundamental differences are still present.

However, even today technological devices used for reading e-books (tablet, e-readers etc.) are still poorly exploited, and while they represent a fundamental tool to make the reading experience more immersive by using a complete multisensory approach, in which more senses are stimulated in a unique stream, they fall short of the mark. This stimulation can be implemented at conscious level and also at subconscious level, thus avoiding interference with the reading experience, but at the same time improving it. Even more, in the case of textbooks, the multisensory approach has to be focused on the improvement of the attention level, without distracting the reader. With this objective in mind, one sense that represents an important element of human perception and has an impact at both conscious and subconscious levels is the sense of smell. Indeed, the sense of smell is the more irrational sense in humans, and it is linked to visceral emotions in comparison to the other senses. For this, odours can have an impact on the subconscious, thus affecting the feelings, moods, memories and so on.

Consequently, authors make the hypothesis that the introduction of odours during reading sessions could increase the user experience. Specifically, the first hypothesis presented in this paper is that the integration of odours associated with the meaning of a text can contribute to the creation of an engaging multisensory reading experience, thus increasing its pleasantness and engagement.

The second hypothesis concerns the introduction of specific odours during the reading activity for educational purposes, in order to increase the user's level of attention, thus improving the learning performance (if compared to that of a "no-scent" case). In order to demonstrate these hypotheses, the authors have defined and carried out several experimental testing sessions.

2 State of the Art

Reading is a complex cognitive process, which intends to decode meanings from text by relating words with person's existing knowledge and understanding [2]. Traditionally, books are the objects used for reading activities. In recent years the widespread ICT technologies in everyday life has also had an impact in this sector, which has been subjected to a radical transformation. Instead of ink and paper, today digital contents are displayed on different devices, such as e-book readers, computer displays, tablets, and smartphones. This revolution, which has been embraced with scepticism by some "purist" users, is based on a change of the support, from physical to digital. Consequently, readers (especially younger readers) are trying to adapt to these new technologies and change their reading behaviours in order to exploit the digital potential [3].

However, the possibility to use a digital support opened new possibilities such as, from the addition of sounds and audio tracks, or the interaction through touch displays to a transformation into Virtual and Augmented Reality games and applications. Specifically, three trends and directions of book evolution have been identified by Park et al. [4]. These are digitalization, augmentation and hypermediation. Moreover, they suggested three research and business directions: open hypermediation, e-book augmentation, and mobile-device based augmentation [2].

Augmented and multisensory approaches have been proven to be effective both in the case of books for children and young people and in the case of adults. Children and young people can particularly take advantage of augmented multisensory approaches, allowing them to keep their attention high. For instance, Dalim C. [5] developed an Augmented Reality training system, with the aim of providing an interactive learning process for children to enhance their understanding about astronomy. Welch et al. [6] developed an immersive Virtual Reality book for surgical training. Their immersive electronic book (IEBook) environment combines an immersive 3D VR-Cube with a tablet for environment navigation and annotation tasks. Alam et al. [2] presented a multisensory approach of annotation based on hapto-audio-visual interaction with the traditional digital learning materials. Specifically, a prototype in which haptic interfaces (a haptic jacket, a haptic arm band and a haptic sofa) are integrated within a home entertainment system has been developed and tested in order to examine whether the use of this augmented environment can influence the user's learning patterns. Simeone et al. [7] presented the case of a book, released by the Italian publisher FakePress, based on the use of QR codes and fiduciary markers to retrieve and show contents published by authors and readers of the book, in order to foster new educational practices.

Moreover, attempts have been made in order to develop applications for people with special needs as, for instance, in the case of Matosa et al. [8], in which multisensory stimuli (audio, video, tactile and smell) are used to motivate people with intellectual disabilities to assist their learning process.

Mostly, these works have the objective of improving the reading experience, through increased user involvement in the narrated story, and/or improving learning performances. As presented, a common approach is to use a multisensory approach, in which different interaction modalities (usually audio, video, and tactile) are integrated. This is related to the fact that typically the human brain integrates information from different sensory modalities [9] in order to define a univocal final experience of the external world. However, the use of sense of smell is underexplored, especially when its possible application and impact can be quite effective.

2.1 Odours in the Humanities

The sense of smell is one of the main means through which humans investigate and interact with the environment [10]. Smell, indeed, supports humans and animals in recognizing dangerous situations (for instance, fires, predators or deteriorated food), but also in identifying useful opportunities (as in the case of ripe fruits, edible food, etc.).

In human history odours have represented important elements of culture. As example, in the ancient Egypt the use of essences had both mystical and curative values. Also in the ancient Greek culture essences were used during rituals - from birth to death to sacrificial ones -, but also with therapeutic aims. Similarly, in the medieval period, odours were considered to be a cure for illnesses. For instance, the cinnamon and cloves essences were considered as a barrier for plague. However, at the same time, odours were considered as ephemerals and immoral elements, so their use was opposed by the Christian moral. Later, the use of ambient and personal perfumes gradually spread. Thus, in 16th century France, and the city of Grasse in particular, became the world centre for the perfume industry [11].

Also, odours had an important role in religions. As example, in Buddhism, Hinduism, Judaism, Christianity, and Shintoism, men used the aromas emitted by burnt plants (like the incense) to act as intermediaries with the divine.

Nevertheless, in modern cultures, the sense of vision is hegemonic [12], where visual stimuli occupy a greater importance than all the others stimuli. So, Western society has been defined as “the society of olfactory silence” [13] and, up to a few years ago, there was the tendency to remove any unpleasant odour and not to give any importance to the sense of smell. In many European cities, in fact, natural odours are removed: body odours are considered unpleasant and unacceptable and are covered [14], closed environments are deodorized, and open environments are characterized by polluted air and so on.

It is only in recent years that the importance of smell on the rise, especially in regards to its potential to stimulate emotions. This property has been applied in the marketing research area, in which many studies have been carried out on the use of odours for eliciting positive moods in people, and for communicating information about products, for instance, perfumes, household cleaners and food [15, 16].

This pragmatic and commercial use of odours in Western societies contrasts with the poetic-mystical view of aromas in Arabian, Asiatic and Asian societies. In the Arab culture, for example, the wedding implies a very precise aromatic preparation. In particular, hair is scrubbed with aromatic substances, and the bridal gown is macerated for several days with rose, saffron and civet essences. In India the term "mana" means "emanating an odor" or "joining in marriage". In Japan, the Koh-Do incense ceremony is a ritual that is intended to stimulate the subject intellectually and emotionally.

2.2 Physiology of olfaction and the effects of odours on brain activities

Concerning the physiology of olfaction and its effects on brain activities, odours can increase attention level, enhance learning activities, and are deeply evocative [17]. Indeed, studies [18, 19, 20, 21] demonstrated that different brain regions, like the orbitofrontal cortex, can be activated by different odours. More specifically, the activation of different regions of the brain is related to the hedonic value of odours, which can be positive ("pleasant") or negative ("unpleasant") [22–25].

Similarly, odours can also influence moods, emotions [26, 28] and memories [29]: while pleasant odours can induce positive moods, unpleasant odours can induce negative ones [30]. Recent research demonstrated that odours can induce activation or relaxation states in people [31]. Consequently, they can be used for reducing anxiety, as in the case of orange [32] and muguet [33]. Other odours, however, may not have a specific and verified characterization and effect, but may be personal and call up memories related to our past. Concerning the link between odours and memory, many studies have been carried out from different points of view, such as basic science, psychology [34] and marketing [35]. Many studies focused on the ability of scent signals, compared to signals sent to other sensory channels, to evoke autobiographical memories [36]. Also, Herz [37] demonstrated that memories triggered by odours are considered to be more emotional than those evoked by the other types of stimuli. This is related to the fact that, after an odour is experienced and associated in our memory with a specific emotional experience, it is able to evoke the associated emotion when later encountered [38].

This effect could also be obtained through the use of odour-related terms that, as demonstrated by Gonzàlez et al. [39], can elicit activation in some regions of the brain. For this reason, writers often use metaphors that recall odours to make the reader get involved in the text.

Odours do not only stimulate memories and emotions, but they could also stimulate cognitive abilities [40]. Lemon and jasmine [41] are known to increase attention levels, much as peppermint and cinnamon do. Specifically, Raudenbush et al. [42] found that both cinnamon and peppermint, administered either retro nasally or orthonasally, improved subjects' scores on tasks related to attentional processes, virtual recognition memory, working memory, and visual-motor response speed. In addition, subjects rated their mood and level of vigour higher, and their level of fatigue lower, especially when using peppermint. Meamarbashi [43] demonstrated that the use of peppermint improves the physiological and exercise performance. Warm et al. [44] demonstrated that the exposure to air scented with muguet or peppermint can enhance the rate of signal detections in a vigilance task. While operating a motor vehicle, Yoshida et al. [45] found that peppermint enables drivers to be in a fully alert state for 9 minutes on average, and Bordegoni et al. [46] confirmed that the use of odours while driving can be helpful in maintaining the attention level of the driver.

2.3 Integration of odours in Virtual Reality

In the area of Virtual Prototyping, several studies have focused on presenting odours in virtual environments, including the development of both ubiquitous and personal olfactory displays. Olfactory displays are devices controlled by a computer that provide a human user with odours. The two main characteristics of olfaction to take into account for developing an olfactory display is the non-linearity of the olfaction (a change in the intensity of the stimulus can result in a qualitative change in the subjective sensation), and the fact that there is not a consensus on the classification of "primary" odours by which it is possible to achieve an acceptable quality of expressing arbitrary smells. Also, because humans sense odours through the air, the role of an olfactory display is to make scented air from odour materials in a stocked form with the desired components and concentration and to deliver the scented air to the human olfactory organ. There are various technologies, categorized by scent generation methods and scent delivery methods, used to construct an olfactory display [10].

These technologies have been used in several research projects that focused on the development of ubiquitous or personal olfactory display for a specific purpose. For instance, Yoshimura and Sakashita [47] developed an olfactory device for emitting a real perfume into the user's immediate area. Viswadhara Meenakshi and Sowmya [48] developed an olfactory device whose main purpose is to make people experience the sense of smell through an electronic media, such as a personal computer. Yanagida et al. [49] proposed an olfactory display based on an "air cannon" that generates toroidal vortices of scented air. Kim et al. [50] focused their research on developing an olfactory display based on a chemical container of temperature responsive hydrogel and controlled release of aroma by using a Peltier module to control the temperature. Yamada et al. [51] developed two prototypes of wearable olfactory displays to present the spatiality of odour in an outdoor environment. Hirota et al. [52] developed an approach to implement and evaluate odour display to be used in multisensory theatres. Some companies have developed virtual olfactory displays for personal computer use [53] such as ScentAir and TriSenx.

Unfortunately, all these devices are often very technologically limited and not precise or controllable for what concerns the number, the type, the concentration of smells that can be stored and generated, and they have not found commercial success. To date, no commercial product that integrates any kind of olfactory display is known by authors. For this reason, our research group started developing ODs that are fully controllable for different applications [54, 55, 56, 57, 46].

2.4 Measuring the effects of odours on cognitive abilities

In order to measure the cognitive activity and any possible interference of odours to the reading activity, specific physiological measures can be used. Physiological measurements are currently used in different research areas for objectively measuring subjects' reactions to events, situations, stimuli etc. Different methods and measurements are used to assess the changes in autonomic nervous system modulations underlying workload processes [58], and not all the physiological indexes can be used to assess cognitive activity required for a specific performance task[1]. To measure the cognitive impact of odour on the reading cognitive task, the main components of modulations of the Autonomic Nervous Systems can be assessed in order to identify specific contributions of the parasympathetic and sympathetic nervous systems in the cognitive demand related to presence of odour in a task response [59]. Changes in the parasympathetic nervous system relate to mental elaboration effort and can be measured by considering the high frequency (between 0.15 and 0.4 Hz) component of heart rate. At the same time, changes in the sympathetic nervous system that relate to stimuli response and presence/absence of perceived distractors, can be measured by changes in electrodermal activity of the skin. Considering this specific differentiation of the main component of modulations of the Autonomic Nervous Systems, it is possible to provide quantitative measure to quantify the psychological adaptation in response to the presence of odour in a task demand [59], similar to experiments carried out by Bordegoni et al. [46] in which Skin Conductance Response was used to measure effects of olfactory stimuli on drivers during driving tasks. However, to date none of these techniques have been specifically used for the assessment of cognitive activity while reading.

3 Research Hypothesis and Experimental Framework

The first hypothesis presented in this paper is that the integration of odours associated with the meaning of the text can contribute in creating an engaging multisensory reading experience in order to increase its pleasantness and the level of engagement in the narrated story.

The second hypothesis is that the use of specific odours can increase the user's level of attention and, consequently, improve the learning performance in comparison to those of a no-scent situation. In particular, the aims of the present experimental framework are:

- verify if and how the added odours disturb the reading behaviour, and increase the mental workload;
- verify if introducing odours can improve the reading experience;
- verify if introducing odours can increase the learning efficiency.

[1] Several researchers have used Mean Heart Rate to assess the impact of odours, but Using Mean Heart Rate alone would not be enough to understand the cognitive component of workload related to visual attention. Heart Rate can be the result of psycho-physiological processes that can be activated by both parasympathetic and sympathetic nervous systems while reading. The parasympathetic nervous system inhibits the heart through the innervations of the vagus nerve, reducing heart rate during visual and cognitive workload tasks [60]. At the same time, sympathetic activity produces autonomic changes in heart rate, including rapid phasic electrodermal changes, which can add to or subtract from parasympathetic activity on Heart Rate in response to an eliciting stimulus, regardless of workload.

Due to the fact that learning and reading are two different behaviours at the cognitive level, the augmented multisensory environment was divided into two different versions: the reading part and the learning part (Fig.1. Experimental framework). Each part was developed to be used twice in the testing sessions: in one case with the integration of odours, while in the other one in a no-scent control condition. Consequently, each subject was asked to carry out four different testing sessions: a) Reading with odours and b) Reading without odours: c) Learning with odours and d) Learning without odours. In all cases, subjects were not informed about the topic of the research and not aware of the presence of olfactory stimuli in the multisensory virtual environment.

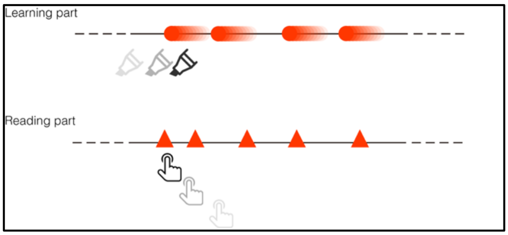
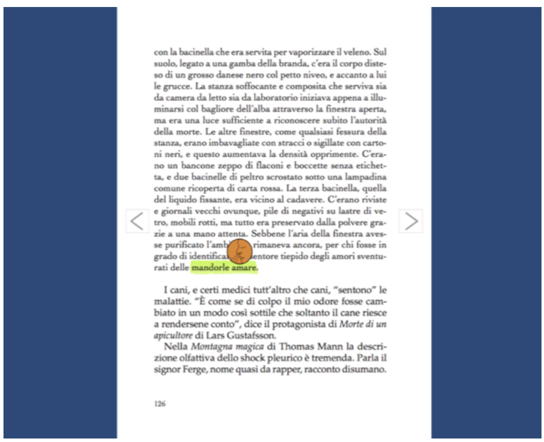


Fig. 1. Experimental framework. The Learning and Reading parts have different interaction modalities. In the Reading part, subjects have to drag and drop the nose icon onto the highlighted words, while in the Learning part subjects have to highlight words and sentences.


con la bacinella che era servita per vaporizzare il veleno. Sul suolo, legato a una gamba della branda, c'era il corpo disteso di un grosso danese nero col petto niveo, e accanto a lui le grucce. La stanza soffocante e composita che serviva sia da camera da letto sia da laboratorio iniziava appena a illuminarsi col bagliore dell'alba attraverso la finestra aperta, ma era una luce sufficiente a riconoscere subito l'autorità della morte. Le altre finestre, come qualsiasi fessura della stanza, erano imbavagliate con stracci o sigillate con cartoni neri, e questo aumentava la densità opprimente. C'erano un bancone zeppo di flaconi e boccette senza etichetta, e due bacinelle di peltro scrostato sotto una lampadina comune ricoperta di carta rossa. La terza bacinella, quella del liquido fissante, era vicino al cadavere. C'erano riviste e giornali vecchi ovunque, pile di negativi su lastre di vetro, mobili rotti, ma tutto era preservato dalla polvere grazie a una mano attenta. Sebbene l'aria della finestra avesse purificato l'amb[illegible] rimaneva ancora, per chi fosse in grado di identifica[illegible]entore tiepido degli amori sventurati delle mandorle amare.

I cani, e certi medici tutt'altro che cani, "sentono" le malattie. "È come se di colpo il mio odore fosse cambiato in un modo così sottile che soltanto il cane riesce a rendersene conto", dice il protagonista di *Morte di un apicultore* di Lars Gustafsson.

Nella *Montagna magica* di Thomas Mann la descrizione olfattiva dello shock pleurico è tremenda. Parla il signor Ferge, nome quasi da rapper, racconto disumano.

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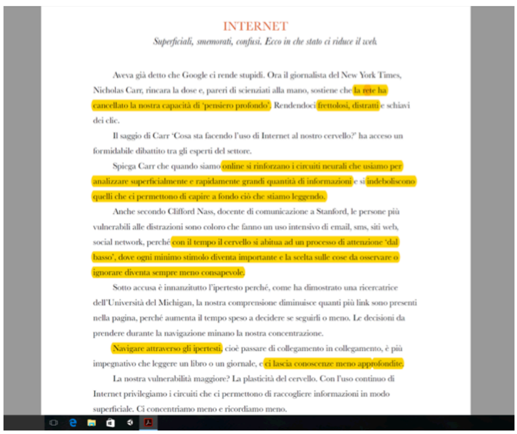
Fig. 2. Reading in a multisensory environment

In the Reading part, a nose icon was integrated into each page of the e-book. Subjects could drag and drop the icon on the highlighted words to trigger the release of the corresponding odour. Subjects could interact with the e-book by using the PC mouse. Two sections of a chapter from the book *La sua voce è profumo*, written by Giovanna Zucconi [61], were provided for testing the Reading augmented multisensory environment. The first section was used for testing sessions with odours and the second one for testing sessions of the no-scent control condition. In the chapter several odour-related terms were presented to the readers. Three of these terms were highlighted before the testing sessions and connected to the corresponding odour diffuser in the olfactory display. In the testing sessions with odours, when subjects dragged and dropped the nose icon onto the highlighted words, a flow of odour was released from the display near her/his nose, while in the no-scent control condition no odours were produced.

In the Learning augmented multisensory environment, odours were released when subjects highlighted words and sentences during reading. The release stopped when subjects ended the highlighting movement. Two short articles from the DALI-C1 test [62] were used in the testing sessions of the Learning environment. The DALI-C1 test is an Italian language ability test with varying levels of difficulty for foreigners whose mother language is not Italian. The two short articles were of equal difficulty and length, and addressed social phenomenon. In the testing sessions with odours, when subjects highlighted a sentence, a flow of odour was released from the display near her/his nose, while in the no-scent control condition no odours were produced. In this case, the peppermint odour was used.



INTERNET

Superficiali, smemorati, confusi. Ecco in che stato ci riduce il web

Aveva già detto che Google ci rende stupidi. Ora il giornalista del New York Times, Nicholas Carr, rincara la dose e, pareri di scienziati alla mano, sostiene che la rete ha cancellato la nostra capacità di 'pensiero profondo'. Rendendoci frettolosi, distratti e schiavi dei clic.

Il saggio di Carr 'Cosa sta facendo l'uso di Internet al nostro cervello?' ha acceso un formidabile dibattito tra gli esperti del settore.

Spiega Carr che quando siamo online si rinforzano i circuiti neurali che usiamo per analizzare superficialmente e rapidamente grandi quantità di informazioni e si indeboliscono quelli che ci permettono di capire a fondo ciò che stiamo leggendo.

Anche secondo Clifford Nass, docente di comunicazione a Stanford, le persone più vulnerabili alle distrazioni sono coloro che fanno un uso intensivo di email, sms, siti web, social network, perché con il tempo il cervello si abitua ad un processo di attenzione 'dal basso', dove ogni minimo stimolo diventa importante e la scelta sulle cose da osservare o ignorare diventa sempre meno consapevole.

Sotto accusa è innanzitutto l'ipertesto perché, come ha dimostrato una ricercatrice dell'Università del Michigan, la nostra comprensione diminuisce quanti più link sono presenti nella pagina, perché aumenta il tempo speso a decidere se seguirli o meno. Le decisioni da prendere durante la navigazione minano la nostra concentrazione.

Navigare attraverso gli ipertesti, cioè passare di collegamento in collegamento, è più impegnativo che leggere un libro o un giornale, e ci lascia conoscenze meno approfondite.

La nostra vulnerabilità maggiore? La plasticità del cervello. Con l'uso continuo di Internet privilegiamo i circuiti che ci permettono di raccogliere informazioni in modo superficiale. Ci concentriamo meno e ricordiamo meno.

Fig. 3. Learning in a multisensory environment

3.1 Experimental Framework

In order to demonstrate the hypotheses, the authors developed an augmented multisensory environment and defined an experimental framework to test it and carry out several experimental testing sessions. The experimental framework is a multisensory environment consisting of four components:

- a computer to run the multisensory reading and learning applications, control the olfactory display and record subjects' physiological data. The screen of the computer was used to display the reading and learning applications and subjects were asked to read a text on it.

- a Multi-odour Olfactory Display (MOD) to control the multisensory applications, which is a device connected to the PC through a USB port. Twelve cartridges for odours in liquid form were available, but in this study only 4 odours were used. The 4 odours were: bitter almond, stink fish, citrus and peppermint. The first three odours were included in the Reading augmented multisensory environment, while the last one was used in the Learning augmented multisensory environment. In all cases, the odours were produced by the ultrasonic atomisation of edible commercial water-soluble flavors, commonly used to supplement the organoleptic characteristics of food, and the concentration was around 0.5%.

- a ProComp physiological monitoring system to facilitate the acquisition of physiological data. It is made of different sensors connected to an encoder and a software tool (the BioGraph Infiniti Software), which captures and analyses raw data from the sensors and converts them into charts. In this study the electrocardiography, the skin conductance and the respiration sensors are used.

- a video camera, synchronised with the ProComp physiological monitoring system, to record the body movements of the subjects. It has been used to reduce the influence of external factors: after the testing sessions, the spikes in activity corresponding to body movements have been picked out and removed manually.

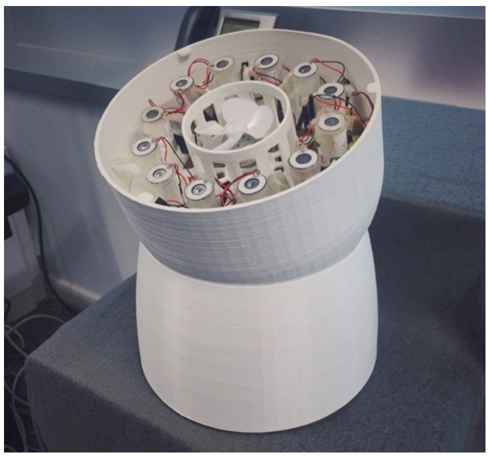


Fig. 4. The Multi-odours Olfactory Display (MOD)

3.2 Experimental Procedure

Subjects were asked to come at the lab where the authors would perform the testing sessions twice on two separate days. Each time they were asked to carry out first a testing session of the no-scent control condition (Learning or Reading), followed by a testing session with the integration of odours (Learning if the first one was about the Reading, or the opposite). In this way cross-contamination effects have been avoided, and each subject completed the four testing sessions at two different times.

Subjects were provided with an informed consent, were asked to complete a form with their background information and then a short test of Self-Assessment Manikins

(SAM test [63]). The SAM test is a non-verbal pictorial assessment technique that directly measures the pleasure, arousal, and dominance associated with a person's affective reaction to a wide variety of stimuli. A study of Bradley et al. [64] suggests that SAM is suitable for tracking the personal response to an affective stimulus. Subjects were required to stay still and perform a physiological baseline measurement, lasting 90 seconds, and then to start reading the text. Subjects had only 2 minutes for performing the Learning task, while no limitations were set for the Reading task.

After the testing sessions of the Reading augmented multisensory environment were concluded, apart from the SAM test and the baseline recording, subjects were asked to fill in a questionnaire about the reading experience.

After the testing sessions of the Learning augmented multisensory environment, besides the SAM test and the baseline recording, the subjects were requested to complete a questionnaire about the learning experience and a comprehension test, which contained 8 questions related to the content of the article read during the experiment. During all the testing sessions, physiological sensors were worn and the physiological data was recorded continuously. After each testing session both SAM test and baseline recording were executed.

3.3 Sample

Subjects were voluntary and did not receive monetary compensation. Subjects included 11 male students and researchers of Politecnico di Milano. Their average age was 27.3 (SD=4.8). Considering a resulting sample size of 11 participants, measuring 2 repeated conditions (Learning and Reading), an effect size of 0.25, an error probability ratio ß/a q = 1, it is possible to estimate a critical F value of 5.117 and an implied error probability of 0.687 and a power (1 - ß error probability) of 0.115. For this reason, in order to narrow the impact of individual difference, the background of the subjects has been controlled, and all of them are Italian. This choice has been made with the aim of reducing the influence of culture-specific experiences, which may significantly influence odour perception [65, 66]. Participant’s education level was from bachelor to PhD, only male volunteers were invited to the experiment. 36% of the subjects were smokers, and two of them had a cold during the experiment period. Three subjects had allergies: one a dust allergy and two a pollen allergy[2].

Concerning their reading habits, 91% of the subjects had a reading habit under 8 hours per week. All subjects had experienced reading online or with digital equipment. The average frequency of reading in a digital environment is 5.73 (SD = 2.45) on a 9-point scale. While reading, their highlighting and annotation habit level was 4.64 (SD=3.23) on a 9-point scale.

Concerning their study habits, 82% of the subjects were used to studying more than 2 hours per week, and 72.3% of them usually studied for more than 6 hours a week. All of the subjects had experience learning online or with digital equipment, and 82% of them spent more than 2 hours per week on this. Their preference of

[2] No significant impact due to smoking or allergies on physiological data or questionnaire results was observed.

studying with digital material compared to the traditional paper material is 4.9 (SD=1.58) on a 9-point scale. They were more willing to annotate while studying than reading: the annotation habit level is 6.82 (SD=2.13) on a 9-point scale.

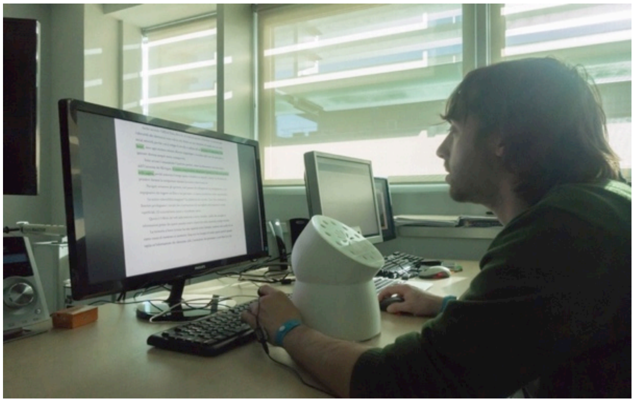


Fig. 5. A subject during the testing session with the Learning augmented multisensory environment

3.4 Statistical Analysis

As the reading speed varied for each person, the length of the Reading testing session varied for each subject. So, the physiological data of the last 20 seconds of each testing session was taken as sample for performing the results analysis. The data from the different channels were sampled down to 32Hz.

A 2x2 repeated-measures multivariate analysis of variance (MANOVA) for experimental condition (with odours, without odours) X task (reading, learning) was performed on the High Frequency component of heart rate variability (.15 - .40 Hz) and on the level of Skin Conductance.

For the questionnaires, two non-parametric Mann–Whitney tests for experimental condition (with odours, without odours) were used to assess the difference in the subjective responses to experimental factors: reading experience, learning experience and learning comprehensions.

4. Results

4.1 Cognitive Workload

Fig. 6 shows the normalized results of the High Frequency component of heart rate variability and Skin Conductance, under different conditions and tasks. The interaction effect of odours in the different tasks was statistically significant $F(1,22) = 6.642$, $p = .028$, $\eta_p^2 = .399$; with a significant decrease of the High Frequency component for the learning task in the experimental condition that presented odours compared to learning without odours, and for reading with odours vs. reading without odours (Table 1). This suggests a decrease of possible cognitive workload when odour is introduced.

On the other hand, the introduction of odour did not produce any differences in the sympathetic nervous system related to an eliciting stimulus. The main effects of experimental condition (odours) were not significant $F(1,22) = 1.386$, $p = .266$, $\eta_p^2 = .122$; in the same way that the main effect of task (reading vs. learning) was not significant $F(1,22) = .112$, $p = .745$, $\eta_p^2 = .011$. This suggests no disturbance effect of odours on the subject, as recorded by electrodermal activity.

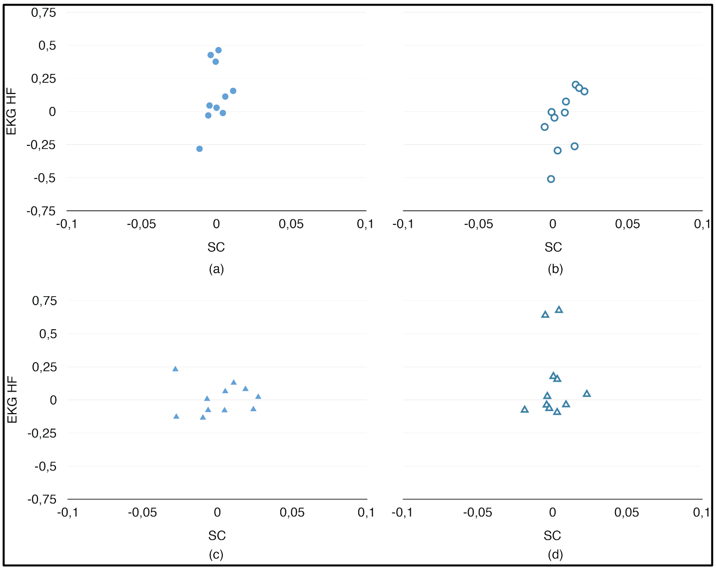


Fig. 6. Skin Conductance and High Frequency component of heart rate variability. (a) Learning task without odour; (b) Learning task with odour; (c) Reading task without odour; (d) Reading task with odour.

Table 1. Reactivity Scores compared to resting baseline of Autonomic Nervous System indexes

	Reading				Learning			
	With Odour		Without Odour		With Odour		Without Odour	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
High Frequency (HF)	.00*	.11	.12*	.27	-.05*	.22	.12*	.22
Skin Conductance (ER-SCR)	.00	.01	.00	.01	.01	.03	.00	.01

* p<.005 Significant differences between the presence and absence of odours

SAM results. Concerning the SAM test, the 9-point scale used can be divided into 3 levels. The valence scale is mapped as follows: 1–3 as “negative,” 4–6 as “neutral,” and 7–9 as “positive”. The emotional arousal scale is mapped as follows: 1–3 as “passive,” 4–6 as “neutral,” and 7–9 as “active”. The dominance scale is mapped as follows: 1–3 as “dominated,” 4–6 as “neutral,” and 7–9 as “dominant”. Generally, the SAM test results did not change before and after testing sessions. For the valence scale, subjects indicated their emotional states both before and after testing sessions always at the same level (“neutral” or “positive”). For the emotional arousal scale, their indications are “passive” or “neutral” both before and after the testing sessions. For the dominance scale, they expressed “neutral” or “dominant” both before and after testing sessions. It can be stated that, according to the user self-reports, odours do not represent an eliciting element during the reading/learning experience.

Reading experience. The Reading experience questionnaire contained 3 categories of aspect: Concentration, Pleasure, Usability. Each category had 4 to 6 questions, the results of which are shown in Fig. 7. The non-parametric Mann–Whitney test reported significant differences in the subjective levels of Concentration ($U = 29.50$, $p = .040$) and Usability ($U = 94, 50$, $p = .025$), when odours were present participants saw a significant increase respectively of Concentration and Usability, compared to the scores of participants when odours weren’t present. No significant differences in the subjective levels of Pleasure were reported by participants for the reading experience ($U = 66.00$, $p = .362$).

Learning experience. Similar to the construction of the Reading experience questionnaire, the Learning experience questionnaire contained 3 categories of aspect: Pleasure, Concentration, Usability. Each category had 4 to 5 questions, the results of which are shown in Fig. 8. The non-parametric Mann–Whitney test reported significant differences in the subjective levels of Pleasure ($U = 28.00$, $p = .034$), when odours were present participants saw a significant increase in perceived usability, compared to the scores of participants when odours weren’t present. No significant differences in the subjective levels of Concentration ($U = 44.00$, $p = .300$) and Usability ($U = 65.00$, $p = .797$) were found for learning experience ratings.

Learning comprehension. The average correct rate of the sessions with the use of odours was 84.1% (SD=.098), while the corresponding one after the no-scent control condition was 78.4% (SD=.178). Even if a tendency of improving the correctness of responses with odours compared to learning without odours was present, the non-parametric Mann–Whitney test reported no significant differences for number of correct answers ($U = 71.00$, $p = .471$) while reading with odours and without odours.

Interviews. All the participants were pleased by the experience. Some of them reported that the imitative level of the fragrance was not adequate, which could be improved in the future. Of 11 participants 7 thought that reading with smell could be a great way to improve the current reading experience, “...especially when children learning new words from a book, like when you touch the word of apple, your will feel the smell of an apple, and you will never forget it,” one of the participants said.

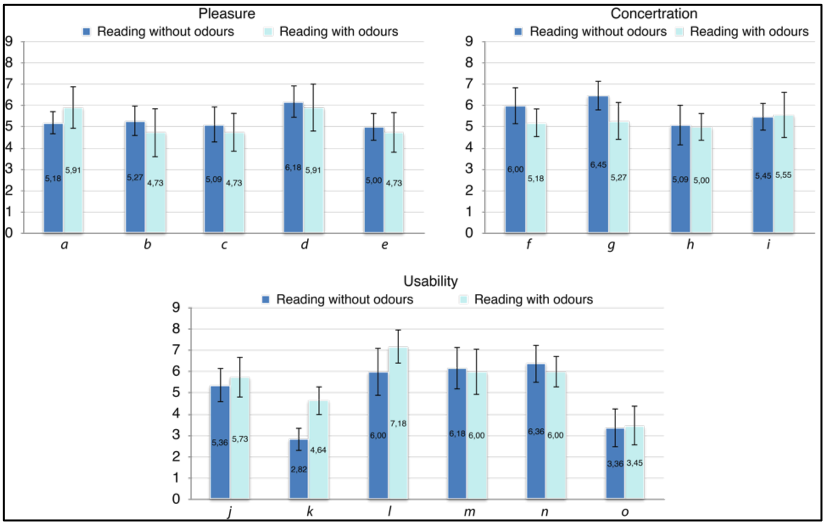


Fig. 7. Reading experience results. a) preference for the reading experience; b) annoyance level; c) interest level in the topic; d) level one feels at ease while reading; e) preference of the story; f) effort to read; g) comprehension level; h) difficulty level; i) capacity of maintaining concentration; j) ease of use of the drag and drop icon; k) possibility for highlighting to enhance the comprehension; l) disturbing number of highlighted words; m) ease of turning pages; n) comfort with font size; o) disturbing level of highlights.

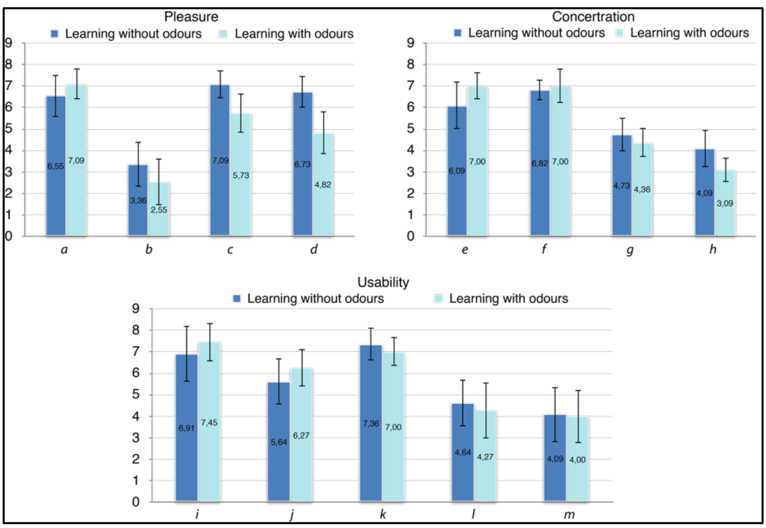


Fig. 8. Learning experience results. a) feel at ease while reading; b) level of nervousness while reading; c) interest level for the topic; d) topic attraction level; e) capacity to maintain concentration; f) comprehension level; g) effort to read material; h) difficulty level; i) ease of turning pages; j) ease of highlighting; k) comfort level with font size; l) possibility for highlighting to enhance the comprehension; m) disturbing level of highlights.

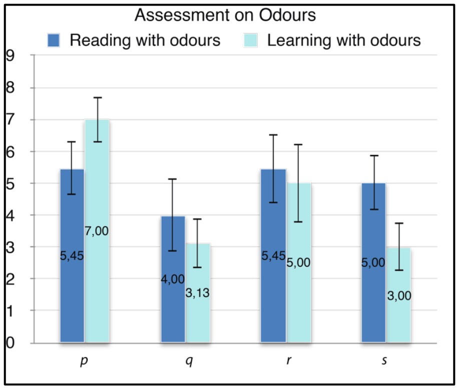


Fig. 9. Assessment of odours. p) preference of odour; q) disturbing level of the odour; r) attraction of odour; s) possibility for odour to enhance the comprehension.

5 Discussion of results

According to subjects, reading with odours may increase the pleasure level of the activity and decreased the effort level of reading, even though the two conditions had no evident difference when the difficulty level and the capacity to maintain concentration were measured. Subjects believed that highlighted words helped with the text comprehension more in the Reading with odours testing sessions than in the no-scent control condition. At the same time in the reading with odours testing sessions' highlighted words seemed to not interfere with the reading experience. Assessment of the odours used in the Reading with odours testing sessions showed that users had a positive attitude towards the possibility of odours enhancing the comprehension (Fig.9s).

The subjects felt that the comprehension of contents was easy in testing sessions with odours. For aspects concerning pleasure, Learning with odours did not have an advantage compared to Learning without odours. Concerning usability, Learning with odours condition presented more ease for use than Learning without odours condition. According to the subjects, odours showed very low disturbing level while reading. Compared to the Learning experience, Reading with odours had a lower average score about the level of pleasantness of the perceived odours than Learning with odours did. Moreover, after the Reading with odours testing sessions, the subjects believed that they got a better comprehension than after the Learning with odours testing sessions, even if no significant difference was found for the correctness ratio of the responses with or without odours.

The analysis of the physiological data shows significant changes in the High Frequency component of heart rate variability, which seems to suggest that the presence of odours in the Learning augmented multisensory environment can reduce the amount of parasympathetic nervous system inhibition, which is usually related to an increase in the cognitive effort and workload [60]. This positive tendency was recorded only for the learning task, which was considered to be the most difficult,

while the reading task did not present any specific fluctuation of the High Frequency component of heart rate variability, both in the case of odours present or absent.
At the same time, it is worth reporting that, in both learning and reading tasks, the presence of odours did not produce significant differences in the electrodermal activity of skin conductance when odours were introduced in the augmented multisensory environment. This means that subjects did not perceive odours as an eliciting event that could potentially distract them from the experimental task.

Finally, the analysis of the subjective data collected with the questionnaires showed that subjects had an open attitude to introducing odours into their reading and learning activities. Specifically, according to subjects, odours in reading activities can be influential as follows:

- decrease the effort level of reading, but also decrease the comprehension level;
- significantly improve scores about the pleasantness of the reading experience;
- reduce the annoyance level of the reading experience;

while odours in the learning activities:

- support the understanding of contents and also can enhance their comprehension;
- do not disturb subjects while reading;
- present a very high level of pleasantness.

6 Conclusion

Conventional books have undergone a radical transformation in recent years due to the use of new technologies. However, the technological devices used for reading e-books today are still poorly exploited, and while they can be used to improve the user experience by using a complete multisensory approach, in which more senses are stimulated in a unique stream, they have not done so up to this point.

In this perspective, one sense that represents an important element of human perception is the sense of smell. Indeed, odours can have an impact on the subconscious, thus affecting feelings, moods, and memories. Consequently, the authors of this paper make the hypothesis that the introduction of odours during text reading could increase the user experience and, during learning activities, could improve the learning performance. In particular, an experimental framework has been designed by the authors to:

- verify if and how the added odours disturb the reading behaviour, and can increase the mental workload;
- verify if introducing odours can improve the reading experience;
- verify if introducing odours can increase the learning efficiency.

The analysis of the collected data proved that the introduction of odours does not disturb the reader during reading activities but, on the contrary, can make the experience more immersive. Similarly, odours do not disturb learning activities, but they can instead increase the level of concentration and the learning performances of people. These results can be used for future practical applications. Indeed, they could represent the starting point for a possible integration of the olfactory technology into e-books. In order to carry out this integration, a unique system, made up of applications and hardware devices (similar to the system presented in this paper) can be developed.

To start with, miniaturized olfactory displays or even olfactory desktop displays (such as the Multi-odours Olfactory Display presented in this work) that can be plugged into e-book readers should be developed as e-book reader accessories. Therefore, odour palettes corresponding to specific books should be developed and used in the olfactory displays from time to time. In addition, the same olfactory displays could be used to spread peppermint or other stimulating odours during learning activities. In both cases, multisensory reading and learning applications of various books should be implemented.

The use of this system could make reading and learning activities much more engaging and stimulating, both for users already familiar with reading and for users first approaching reading and/or with specific needs, like cognitive difficulties. In fact, for instance, in the case of children or users with cognitive difficulties, the use of odours could contribute in creating enjoyable and positive contexts and experiences, which can lead to nice memories, thus stimulating interest in subsequent reading activities.

Moreover, in the case of "traditional" users, the introduction of odours could become an innovative feature of e-books, which can positively impact their diffusion and acceptance. Indeed, instead of representing a simple transposition of traditional books on technological devices, e-books can support a different use and experience. As example, through the introduction of odours in innovative e-books engaging experiences of faraway countries could be developed, also with the aim of improving intercultural exchange among different cultures [67]. Similarly, as for the learning activities, the integration of stimulating odours can be particularly effective in increasing the attention level of users and creating positive habits.

However, authors intend to further analyse some critical elements concerning the introduction of odours in reading and learning experiences in future research activities. Specifically, higher attention will be paid to the definition and testing of different kinds of odours associated with the meaning and content of the text, as well as of their intensity and persistence, although it is difficult to define standard thresholds and limitations, since olfactory perception is quite subjective and related to people's background.

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