THE SWEET SMELL OF SUCCESS: ENHANCING MULTIMEDIA APPLICATIONS WITH OLFACTION

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Olfaction, or smell, is one of the last challenges which multimedia applications have to conquer. As far as computerised smell is concerned, there are several difficulties to overcome, particularly those associated with the ambient nature of smell. In this paper, we present results from an empirical study exploring users' perception of olfaction-enhanced multimedia displays. Findings show that olfaction significantly adds to the user multimedia experience. Moreover, use of olfaction leads to an increased sense of reality and relevance. Our results also show that users are tolerant of the interference and distortion effects caused by olfactory effect in multimedia.

Categories and Subject Descriptors H.1.2 [**User/Machine Systems**]: *Human factors*; H.5.1 [**Multimedia Information Systems**]: *Artificial, augmented, and virtual realities*;
General Terms: Design, Experimentation, Human Factors

Additional Key Words and Phrases: Olfaction, Human-computer interaction, multimedia quality, quality of perception

ACM File Format:

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1. INTRODUCTION

Olfactory enhanced multimedia displays concerns themselves with associating computer generated smell with other media in order to enrich the users' experience and perception of a multimedia presentation or application. That olfaction-enhanced multimedia is a challenging research area is reflected by the relative paucity of research works in this area.

Current usage of olfaction in multimedia has mostly been limited to the area of multi-modal information displays, particularly in the area of presenting system and application output in alternative modes for end users. In such systems, there are different output modes available for presenting information, but only one data medium is used at any time to convey the required information and olfactory data usage in such application systems would often be used in response to, or to signify, the occurrence of some application event. Our interest with olfaction in multimedia displays is however concentrated with its usage when combined with other media. To this end, olfactory data may be used to enhance the meaning and provide clarity of user presented information and increase the sense of reality and enjoyment in multimedia applications. Most of the existing work done using olfactory data integrated with other media objects has mostly been done in the virtual reality field (Boyd et al., 2006; Dinh et al., 1999; Drolet et al., 2009; Jones et al., 2004; Kaye 2001; Nakamoto et al., 2008; Richard et al., 2006; Tijou, Richard and Richard, 2006; Washburn and Jones, 2004; Zybura and Eskeland, 1999), and only one of the reported cases (Washburn and Jones, 2004) shows any significant results to show that adding olfactory data to such systems impacted on the sense of reality of the application quite considerably.

For the experiment discussed in this paper, we have implemented a multimedia presentation display tool which combines visual, audio and olfactory data and presents olfaction-enhanced multimedia information content to users. We have used this tool to analyse and understand the end users' perception of olfaction-enhanced multimedia and our findings are reported herein. The rest of the paper is structured as follows: in section 2 we present a summary of related work done, while sections 3 and 4 discuss the details of our experimental methodology and the results obtained from our experiment respectively. Lastly, section 5 discusses our conclusions and identifies directions for future work.

2. RELATED WORK

Olfactory data is gaining grounds as a source of system output and research is relying on the human ability to recognise characteristic smells to add informational, entertainment or infotainment scented output to computing, and particularly multimedia applications. However, as a result of the challenges facing the use of olfactory data, much of the present work in the research field (Bodnar, Corbett and Nekrasovski, 2004) has focused on the practicality of using computer generated smell, mostly as an alternative, i.e. redundant, source of output from which conclusions may be drawn in multi-modal information displays. These research works have laid down important foundations for any future work involving the use of olfactory data, both in multimedia displays and other computing applications, and we provide an overview of the more relevant of these below.

One research effort that focused extensively on the practicality of using computer generated smell was the work carried out by Kaye (2001, 2004). His work has played a very significant role in creating an awareness of the issues, problems and limitations, associated with the use of olfactory data and incidentally also serves as a good summary of some interesting, general and main facts about smell, including its progress and applications in various industries over the years. The main highlights of Kaye's work have been to establish some form of guidelines on the use of olfactory data, and to distinguish between different types of olfactory data output. In the former case, he suggests that olfactory data are better suited for ambient displays of slowly, changing, continuous information and that its use should rely on differences between smell rather than the intensity of a particular smell and created a number of prototypical applications to support his theories. Finally, he distinguishes between smell output to convey information, where the smell released is related to the information to be conveyed, which he calls *olfactory icons*, and smell output to provide an abstract relationship with the data it expresses, which he calls *smicons*.

One benefit of having information displays that are multi-modal and interactive in nature is to share attention and information processing demands between our different senses. Applications used to gain the users attention, more popularly known as notification or alerting systems, represent one of the areas in which olfactory data output has shown great potential. Kaye (2001) designed two such applications, 'Smell Reminder', which allows users to use smicons to create personal, notification alarms, and 'Honey, I'm home', an application shared between two people which ensures that out of sight, is not out of mind where smicons are used to alert the other that you are thinking of him/her. Unfortunately, he does not report on any detailed evaluation of these applications.

Bodnar, Corbett and Nekrasovski (2004) also created a notification system that makes use of olfactory data. In their work, they conducted an experimental study to compare the effect the use of visual, audio or olfactory displays to deliver notifications had on a user's engagement of a cognitive task. Participants were given an arithmetic task to complete and at various intervals two types of notifications were triggered, one where the participants had to immediately stop what they were doing and record some data before returning to the completion of their task, and the other they were to ignore. With their experiment, they found that while olfactory notifications were the least effective in delivering notifications to end users, they had the advantage of producing the least disruptive effect on a user's engagement of a task. It is also worthy to note that they encountered most of the problems of using smell output as highlighted by Kaye in their experiment and had participants mostly commenting that some of the smells used were too similar to be distinguishable, lingering smells in the air made it difficult to detect the presence of new ones and the lack of experience of working with olfactory data impacted on their performance of the assigned task.

In the realm of information processing, we mention the study carried out by Brewster, McGookin and Miller (2006) in which they use olfactory data for multimedia content searching, browsing and retrieval, more specifically to aid in the search of digital photo collections. In their experiment, they compare the effects of using text-based tagging and smell-based tagging of digital photos by users to search and retrieve photos from a digital library. To achieve this, they developed an olfactory photo browsing and searching tool, which they called Olfoto. Smell and text tags from participants' description of photos (personal photographs of participants were used) were created and participants had to use these tags to put a tag on their photos. At a later date, participants then had to use the same tags to search and answer questions about the previously tagged photographs. The results of their experiment show that although performance with the text-based tags was better, smell and its ability to trigger memories in individuals does have some potential for being used as a querying method for multimedia content searching.

There are profound benefits to be gained from the success of olfaction-enhanced multimedia in a variety of industries, and there are already significant applications of its use in education and training systems and gaming and virtual reality systems. Washburn and Jones (2004) mention two such efforts carried out to discover the impact of olfaction in virtual reality environments. The first reported is the Research in Augmented and Virtual Environment Systems (RAVES) work done by University of Central Florida, research that involved the addition of multi-modal technologies to virtual environments in order to make them more robust and useful to their users. It was reported that an olfactory enhanced virtual reality study was carried out as part of the RAVES research, but that there were no significant results to be deduced from this study. The other study reported was conducted at Georgia Tech and, whilst the results of their experimental study showed that olfaction did increase the sense of reality to some extent, their results were not statistically significant. A popularly reported case (Kaye 2001, Washburn and Jones, 2004) on the use of olfaction-enhanced multimedia in a virtual reality application is the fire-fighter virtual reality training system by Cater and his team. The user wears a backpack mounted device, which emits a range of scents, including burning wood, grease and rubber, sulphur, oil and diesel exhaust, through an oxygen mask connected to the device, whilst immersed in the virtual reality environment. The essence here is to familiarise potential firefighters with those smells often associated with fires as it is often

thought and argued that it is easier to recognise smells already known by a person. In a firefighter's profession, being able to easily detect the presence of such smells could well prove to be invaluable. Notable feedback from Cater's virtual reality training system, and another worthy contribution to the guidelines on the use of olfactory data, was that one has to be careful with the intensity of smells used in any experiments involving the use of olfactory data as users can suffer a variety of reactions from smells, ranging from headaches to allergic reactions and being physically sick.

Further work by Boyd Davis et al. (2006) used olfactory data to create an interactive digital olfactory game. However, the main aim of their experiment, what should the designer of interactive systems know about olfactory data, is a question already answered by predecessors in the field as already highlighted in this review of existing work. In their work, they developed a suite of digital games in which they use olfactory data, 3 different scents, to engage users in game play and the users' sense of smell is the main skill needed to win the games. The findings from their work further confirm what previous researchers like Kaye have discovered about the use of olfactory data and set down guidelines for.

In research closely related to that reported in this paper, Nakamoto and Yoshikawa (2006) report on an experiment of a four-minute movie consisting of 11 scenes, with 8 out of these being accompanied with one or two different scents, in which they found that the scenes with smell attracted the experimental subjects' attention. Moreover, the contrast of the pleasant smell with the offensive one emphasized their attention. From his work, he suggests a few guidelines: the duration between successive olfactory data output should be at least 5s; if an ambient background smell is to be used, then its output must be stopped during the presentation of another smell; and, lastly, when smell change is expressed, the change from one smell to another one similar to it is not recommended.

In concluding, we remark that there is an incipient – and growing - use of olfaction in multimedia. However, while research continues to show that olfactory data remains a challenge and consequently poses a variety of technical difficulties in achieving quality olfactory-enhanced multimedia displays, it has up to now mainly neglected to examine the user's perception of olfaction-enhanced multimedia displays – the main aim of the study reported in this paper.

3. EXPERIMENTAL STUDY

In exploring the user perception of olfaction-enhanced multimedia displays, we specifically sought to answer the following question: *does augmenting multimedia applications with olfaction enhance the user experience of multimedia?* The first challenge that this question poses is one of how to measure this user experience, and it is this that we now turn our attention to.

3.1. Measuring the User-Perceived Experience

In (Gulliver and Ghinea, 2006), a unified assessment model was proposed to effectively consider both the technical and the user perspective of the quality of multimedia applications at all levels of abstraction. The model (Fig. 1), which extends a multimedia quality model originally defined by Wikstrand (in Gulliver and Ghinea, 2006), defines the following three levels at which the quality of multimedia applications can be measured: 1) network level: concerned with the communication of data over networks; 2) media level: concerned with quality issues relating to the transference methods used to convert network data to perceptible media information; and 3) content level: concerned

with how media information is presented to, and perceived and understood by, the end user – i.e. level of enjoyment, ability to perform a defined task and ability to assimilate critical information from a multimedia presentation. Furthermore, the model emphasises that there is a need to consider multimedia quality from two separate perspectives: 1) the technical perspective, which concerns quality issues that relate to the technological factors involved in distributed multimedia and can be measured and varied at the three levels; and 2) the user perspective, concerned with quality issues that rely on user feedback or interaction and can be measured and varied at only the media and content levels. Accordingly, it is with the latter of these that our research focuses on, and we define below how we intend to capture the user-perceived quality of experience of olfaction-enhanced multimedia at the media and content levels.

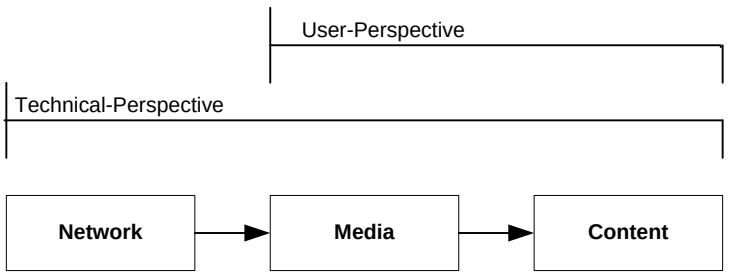

Fig. 1 Multimedia quality assessment model proposed in (Gulliver and Ghinea, 2006)

3.1.1. The Content Level

The content level considers quality issues that rely on user feedback or interaction of the perception of the media used to inform or entertain users in a multimedia presentation. Although our investigative study involves the use of olfactory media and video media content, the media data content of primary interest to us in this research is the olfactory media. As such, our focus will be concentrated on the users' perception of the olfactory media data and not video media content, which has already been explored in previous research studies (Ghinea and Thomas, 1998; Serif, Gulliver and Ghinea, 2004; Jumisko-Pyykkö, Kumar and Korhonen, 2006; Jumisko-Pyykkö, Häkkinen and Nyman, 2007; Kato and Hakozaki, 2006). To this end, we measure user feedback of the olfactory media content according to the following subjective measures which we believe extensively capture a user's perception of olfactory data:

- Odour Detection: that is, was the emitted scent detected. This will be ascertained by participants' responses to all smell-related questions of our experimental questionnaire, but more specifically from responses to a statement asking participants to select an option from a list which best describes the nature of the emitted scent smelt. The list of options also includes 'did not detect any smell' for cases where the participant did not detect the emitted scent released during the olfaction-enhanced video clips. See section 4.4 for a detailed description of the experimental questionnaire.
- Odour Acceptance: as mentioned in (Gulas and Bloch, 1995), the primary affective response to scent is to either like or dislike it. This affective response is captured by measuring how annoying the olfactory media was. This will be ascertained by participants' responses to the statement, '*The smell was annoying'*.

- Odour Quantity: that is, how intense an odour is (Kaye 2001), which we capture by determining if the intensity of the olfactory media was so strong that it was consequently found distracting. Participant feedback will be ascertained from their responses to the statement, '*The smell was distracting*'.
- Contextual Awareness: while the above perceptual measures determine user awareness to odours, they do not capture the contextual awareness that a user has towards an odour. For many situations in life the context in which an odour occurs is extremely important as an odour may indicate a sign of danger, e.g. fires. Accordingly, we capture this by measuring the sense of relevance of olfactory media and its ability to heighten the sense of reality. The feedback on contextual awareness of the olfactory media will be ascertained from responses to the following two statements: '*The smell was relevant to what I was watching*' and '*The smell heightened the sense of reality whilst watching the multimedia video clips*'.
- Influence on Mood: there has been much talk about odours influencing our moods and emotions (Herz, 2002), to which we consider how enjoying the olfactory-enhanced experience was found. This will be ascertained by participants responses to the statement, '*I enjoyed watching the video clip*'.

3.1.2. The Media Level

At the media level, measuring multimedia quality is concerned with how the combined media objects are coded for transport of information and considers if the user subsequently perceives the integrated media objects, both separately and together (combined relationship) as being of good or bad quality. To this end, we consider two issues affecting the user perspective at the media level in our research: media synchronisation and content association. In the case of media synchronisation, we consider participants' perception of how timely they considered the olfactory media in relation to the video content it was presented with. We ascertain this from responses to the questionnaire statement, '*The smell was released*'. For content association, we investigate if participants are able to correctly associate the olfactory generated data with the video content.

3.2. Experimental Process

The experiments involved participants watching a set of six multimedia video excerpts of 240 x 180 pixels, enhanced with olfactory data content. To this end, we designed an olfactory enhanced multimedia display program, which displays video clips synchronised with olfactory data at predefined time intervals. Video content was chosen as the media content to combine olfactory data with on the simple basis that audiovisual content is the most popular combination of media objects used in multimedia applications. However, participants were randomly split into taking part in either a control experiment, in which odour neutralisers were used to enhance the video clips, or the experiment proper, where the smells identified in Table I were used to enhance the multimedia video excerpts. Odour neutralizers, although having an active smell themselves, have the specific functionality of removing ambient odours that may be present in the air, subsequently making them undetectable by our sense of smell. Thus, the use of odour neutralisers in place of the actual scents for the control experiments can be likened to the use of placebos as control substances in medicinal experiments.

The duration of each multimedia video excerpt lasted for approximately 90 seconds, with the duration of the olfactory data lasting for about 30 seconds when present. The duration of 30s for the olfactory data was chosen since, as a result of odour adaptation, scents are generally recognisable in the ambient vicinity for a period of 30s (Washburn, et al., 2003). Moreover, a duration of 90s for the multimedia clips may be thought of comprising of 3 segments of 30s each. The excerpts of these video clips were specifically chosen so that audiovisual content relating to the olfactory data the videos were augmented with coincided with the middle 30s segment. Thus in this respect, a 90s olfaction-enhanced multimedia clip may be thought of comprising of the following 3 synchronisation temporal segments: before olfaction is emitted, olfaction emitted during video and after olfaction is emitted respectively.

After each video excerpt viewing, participants were asked to complete a questionnaire (detailed in section 3.4) relating to the video excerpt viewed. Participants were told prior to the start of the experiments that a smell may or may not be released during the playback of each of the videos and they should be on the alert for this. Originally, we were going to track when exactly participants detected the presence of a smell by asking them to click the mouse button as soon as they detected the presence of any distinct smell(s) in the air. However, participants involved in a pilot study conducted with this feature, often forgot to do this, and usually remarked that they forgot because they were concentrating on watching the video clips and detecting the smells. Thus, this feature was eliminated from our final experimental design.

3.3. Experiment Materials

The experimental materials used comprise of the following: the six multimedia clips viewed, the olfactory data, i.e. smells, used to enhance each of these video clips and the olfactory data generating device used to emit the smells. We describe each of these in detail in the following sections.

3.3.1. The Multimedia Video Excerpts

Table I shows a summary description of the six multimedia video excerpts of dimensions, 240 x 180 pixels, viewed by participants. The multimedia video excerpts were chosen so that the audiovisual content related to the smells (see next section) they were eventually combined with, and hence the naming convention of the video clips. With respect to content, the clips were chosen so that the action displayed in the videos was relatively the same across the six different videos. This is because previous research studies (Ghinea and Thomas, 1998; Gulliver and Ghinea, 2006; Jumisko-Pyykkö, Häkkinen and Nyman , 2007) have shown that the amount of activity within a multimedia video clip has an impact on the user-perceived experience of the clip, e.g. highly dynamic scenes have a negative impact on user understanding and information assimilation (Ghinea and Thomas, 1998). For these reasons, we did not try to vary content with respect to content activity, and the video clips generally reflect content that is relatively static in nature, i.e. news, documentary reports and recipe instructions. However, we did vary the content of the video clips on the infotainment spectrum of multimedia, with some video excerpts being more entertaining in nature than others, which were either predominantly informational or on an infotainment level. The playback of the video excerpts with each

of the predefined associated scents was also randomised in order to minimise order effects.

Table I. Video categories and the smells used

Video Name	**Burnt**	**Flowery**	**Foul**	**Fruity**	**Resinous**	**Spicy**
Video Description	Documentary on bush fires in Oklahoma	News broadcast featuring perfume launch	Documentary about rotting fruits	Cookery show on how to make a fruit cocktail	Documentary on Spring allergies & cedar wood	Cookery show on how to make chicken curry
Smell Used	Burning Wood	Wallflower	Rubbish Acrid	Strawberry	Cedar Wood	Curry
						

3.3.2 The Smells, or Olfactory Data

Despite the distinctive uniqueness associated with smell that makes it possible to detect its presence in the air, research has shown that it is easier for people to smell something than it is for them to identify what they have smelt, and more often than not people will try to identify a smell by associating it with a smell they are familiar with (Bodnar, Corbett and Nekrasovski, 2004; Brewster, McGookin and Miller, 2006; Kaye 2001). Odour identification is also usually influenced by social and cultural factors (Saito et al., 2006). For these reasons and also due to the lack of standard smell classification schemes (Chastrette, 2002; Kaye, 2001), it is advised that familiar smells be used for experiments involving the use of olfactory data (Kaye, 2001; Saito et al., 2006). We finally opted for six smells which distinguish between the odour classes, *flowery*, *foul*, *fruity*, *burnt*, *resinous* and *spicy*.

This decision was motivated by our need to limit the number of smells used in the study to a small number of distinguishable reference smells to avoid cases of odour adaptation, i.e. losing one's sensitivity to detecting odours as a result of continuous exposure to odours and prolonged stimulation of the olfactory sense (Köster, 2002). Moreover, Chastrette (2002) points out that there are still no known standard classification schemes for smells and certainly none found acceptable to all, with the consequence that the available odour classification schemes are established with different aims and objectives in mind. Thus, the consequence is that each of these classification schemes in reality suits different purposes. As a result, we chose a smell categorisation scheme, to work with, that suited our specific purpose. Moreover, we also felt that it would not be too difficult to find at least one smell that is easily recognisable and identifiable to most participants within each of the six smell categories of our chosen classification scheme, which incidentally also has a fair distribution ratio between what can be termed as pleasant and unpleasant smell categories.

The reason for subjecting participants to unpleasant smells is due to the fact that it has been recognised that one of the potential areas that olfactory-enhanced applications can be applied is in education and training systems. It has already been suggested that there is great potential for the use of olfaction in medical training systems, such as those being

used to simulate medical procedures or even in diagnosing medical conditions with symptoms of specific body odours (Krueger in Dinh et al., 1999). More often than not, it is highly unlikely that such odours associated with the medical field as described here are going to be pleasant in nature. Furthermore, Cater and his team (Dinh et al., 1999; Kaye, 2001; Washburn and Jones, 2004) also developed a virtual reality training system to train potential fire-fighters to recognise characteristic smells commonly associated with fires. The smells used in this system included burning wood, grease and rubber, sulphur, oil and diesel exhaust, which cannot exactly be described as being pleasant in nature. Thus, there is much potential for the use of both pleasant, and unpleasant, smells in computing and human evaluation experiments should therefore incorporate both types of smells.

3.3.3. The Olfactory Data Device

We have used Dale Air's Vortex Active scent dispensing system (shown in Fig. 2) to generate computer controlled olfactory data for our experiments (Dale Air). This is a personal computer smell dispensing system which uses miniature fans to propel the emitted smells in the right direction. The Vortex Active device connects to the computer via a USB port, and we used the USB fan controller application supplied with the device to control the synchronised release of olfactory data during each video clip playback.

Adopting a line of sight approach, the Vortex Active was placed about half a metre away from the participant, tilted an angle in line with the participants' nose. We adopted this approach because our device was not head-mountable, and moreover, we wanted to create the effect of a natural breeze of scent rather than a choking release. In the pilot study, we also observed that it took about 2s for the scent emitted by the Vortex Active device to reach the target users' nose at this distance, which we accordingly factored into our experimental design setup.

Fig. 2. Dale Air's Vortex Active Scent Dispensing System

3.4. Experiment Questionnaire

To arrive at answers to the questions we set out to answer with our experiment, participants were asked to complete a questionnaire at the end of each video clip. With the exception of the questions relating to identifying the smells used in each video, participants were asked to specify their level of agreement on a five-point Likert scale to each of the statements expressed for each question.

Table II shows the questionnaire that participants had to complete after each video, and they are the six statements participants had to rate on a five-point Likert scale. In statement 1, participants had to agree with the timeliness of the release of olfactory data and the five response categories available for this statement were '*Too Early*', '*Early*',

'*At an Appropriate Time*', '*Late*' and '*Too Late*'. The other five statements required participants to indicate their degree of agreement with the statements using the popular five response categories '*Strongly Disagree*', '*Disagree*', '*Neither Agree or Disagree*', '*Agree*' and '*Strongly Agree*' used to measure either positive and negative response to a statement.

Table II. Experiment Questionnaire

	Questionnaire Statements
1.	The smell was released
2.	The smell was relevant to what I was watching
3.	The smell was distracting
4.	The smell heightened the sense of reality whilst watching the video clip
5.	The smell was annoying
6.	I enjoyed watching the video clip

3.5. Participants

A total of 36 participants, 16 males and 20 females between the ages of 18 and 40 took part in the study. Participants were recruited from a wide variety of backgrounds, including undergraduate and postgraduate students from different universities and departments, as well as both blue and white collar workers. Furthermore, recruited participants were screened to prevent any bias in the experimental results. Accordingly, recruited participants were asked if they had undergone any smell recognition training, and if they responded in the affirmative, they were not allowed to participate in the experiment. Potential participants also suffering from colds, or any other conditions that might have impaired their sense of smell were also stopped from participating in the study, or asked to return at a later date when their sense of smell was no longer impaired if they so wished. Participants were also allowed to opt out of the experiment at any point in time.

Participants were also randomly split to take part in the control study or experimental study experiment. Participants in the experimental group viewed the multimedia content with olfactory stimuli as detailed in Table I, whereas the olfactory stimuli emitted for the control group participants via the Vortex device consisted solely of odour neutralizers.

4. EXPERIMENT

In this section, we present the results of our experimental study, which are based on our analysis of participants' responses to the questions asked at the end of each video clip. The impact of olfaction on users' experience of multimedia will be ascertained from participants' opinions of the following:

- User-perceived experience of the synchronisation effect
- User-perceived experience of the sense of relevance of the olfactory media
- User-perceived experience of the sense of reality of the olfaction-enhanced multimedia
- User acceptability of olfactory media in terms of how distracting or annoying they find it
- User-perceived enjoyment of the olfaction-enhanced multimedia experience.

A repeated measures ANOVA test suitable for testing data from a within-subjects, between-subjects experimental design was applied to analyse participants' responses. The video category, of which there were 6, is our within-subjects factor that every participant was exposed to, whilst the study group, dividing participants into the control and experimental subgroups, is our between-subjects factor. As previous research studies (Ghinea and Thomas, 1998; Jumisko-Pyykkö, Häkkinen and Nyman, 2007) have shown that content, i.e. subject matter, is an important quality influencing the user-perceived quality, our within-subjects factor will show if the user-perceived experience of olfaction-enhanced multimedia differs across different categories of multimedia content. The between-subjects factor on the other hand, will show if, indeed, olfaction does enhance the user-experience of multimedia applications. Furthermore, we applied a one sample t-test to investigate whether or not the mean opinions reflecting participants' perception of the olfaction-enhanced multimedia video clips differs significantly from specific mean opinion score values. A significance level of $p < 0.05$ was adopted for the study. We summarise our results based on the question we set out to answer with our experiment, as outlined in section 3.

4.1. User-perceived experience of the synchronisation effect

To discover whether or not participants perceived the olfactory data generated during the olfactory enhanced video presentations occurred at the right time, participants were asked to rate how early or late they felt the olfactory data released for each video was in relation to its content. Each video presentation was set up such that the computer generated smell would be released when a related scene was showing in the video. Available rating responses were '*Too Early*', '*Early*', '*At an appropriate time*', '*Late*' and '*Too Late*', with each of these responses corresponding to a rating on a scale of 1 to 5 respectively.

The results from the repeated measures ANOVA test showed that the difference between the control group and experimental group participants' opinions as regards the synchronisation effect was statistically significant, i.e. ($F=14.658$, $p=0.001$). This thus shows that, the scents used in the experimental case created a more synchronised effect than the odour neutralisers used for the control group participants. However, the results show that content, as defined by the different video categories, did not have a significant impact on participants' perception of the synchronisation effect ($F=0.946$, $p=0.453$), and neither did the combination of content and olfaction ($F=1.674$, $p=0.144$). In Fig. 3 we show the mean opinions relating to these results and use them to discuss further observations in respect of participants' perception of the synchronisation effect of the olfaction-enhanced clips.

The mean opinion values show that generally participants in the control study group, in which the scent of an odour neutraliser was emitted, were mostly of the opinion that the smell was released too early. On the other hand, with the exception of the *Fruity* clip, participants in the experimental study group mostly agreed that the smell was emitted at the right time.

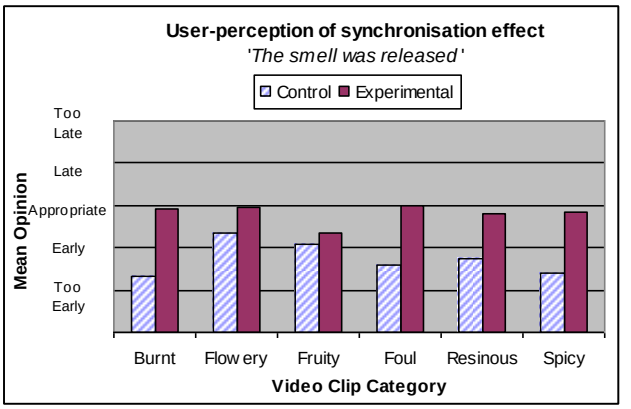

Fig.3. Participants' perception of the synchronization effect

Furthermore, we consider if the general opinion of the synchronisation effect between olfactory media and audiovisual content as reflected by the mean values obtained from participants' perceptions was in line with our expectations. As the olfaction-enhanced multimedia video clips were designed so that the olfactory media synchronised with related audiovisual content, we expected participants to perceive the olfaction-enhanced multimedia clips as being in-sync. To this end, we conducted a one sample t-test to compare the mean opinions of the perceived synchronisation effect obtained in our study to the case for a perfectly synchronised presentation (Test value 3 – *The smell was released at an appropriate time*).

The one sample t-test result, (t=0.553, p=0.581), shows that the mean opinion value of the experimental participants' perceived opinion of the synchronisation effect, i.e. 3.04, does not differ significantly from our test value, 3, indicating a synchronised presentation. Hence, these results have shown that we managed to provide participants with synchronised olfaction-enhanced multimedia video excerpts, as the mean opinion reflect that they generally found the correlated olfactory media and audiovisual content to be in-sync.

4.2. User-perceived experience of the sense of relevance of the olfactory media

In this section, we consider the user-perceived experience of the sense of relevance of the olfactory media used to augment the multimedia video clips. In order to do this, we analyse participants' agreement with the statement, '*The smell was relevant to what I was watching*'. Responses were restricted to the popular five-point Likert scale response categories reflecting agreement, that is, '*Strongly Disagree*', '*Disagree*', '*Neither Agree or Disagree*', '*Agree*' and '*Strongly Agree*'.

We conducted a repeated measures ANOVA test conducted to investigate participants' perception of the sense of relevance of the olfactory media in relation to the content of the multimedia video clips viewed. The results from the test showed that there was a statistically significant difference of the perceived sense of relevance of the olfactory media used to enhance the video clips between the control group participants and experimental group participants (F=18.491, p=0.000). Thus, the control study participants did not find the odour neutralisers used to augment the video clips as relevant as the experimental participants found the use of the actual scents. Content, however, did not appear to influence the perception of relevance as there was no significant difference

across the six video categories (F=1.409, p=0.224), but the combined effect between video content and the use of olfactory media versus odour neutralisers was statistically significant (F=3.839, p=0.003).

The mean values obtained in respect of the repeated measures ANOVA test discussed are shown in Fig. 4. The mean opinion values reflecting participants' agreement in terms of the sense of relevance of the olfactory media used to augment the multimedia video clips was higher for the experimental case, where scents relating to the audiovisual content were used, than in the control case where odour neutralisers were emitted. As such, it is not surprising that participants allocated to the control study were mostly of the opinion that the emitted scent, i.e. odour neutraliser, was not relevant to the video clips watched. This is reflected by the mean opinion values obtained from this group of participants, which are mostly between the values of 1 and 2, reflecting disagreement on the ordinal scale used. There were however a few exceptions, with the control group participants having a more neutral attitude in respect of the sense of relevance of the odour neutralisers used in the case of the *Fruity* and *Flowery* video clips. On the other hand, the mean opinions of the experimental group participants reflect that they were generally in agreement, or at the very least neutral as in the *Fruity* video case, that the olfactory media was relevant to the multimedia video clips watched.

It is interesting that the *Fruity* video produced ambivalent opinions in both study groups. Having said that, however, a higher number of participants did not detect the presence of the *Strawberry* scent emitted in this olfaction-enhanced video clip and especially for the experimental study group. Nonetheless, considering the variety of fruits used in the fruit cocktail recipe followed in this video clip, it might be the case that participants were expecting another type of fruity smell to be released during this video. Indeed, the most suitable mix of olfactory stimuli in the case of multimedia content with a variety of smells is an interesting avenue for future work.

Furthermore, we are also investigated if the selected smells used in our study were appropriate in terms of their semantic relationship to the audiovisual media content they were combined with, and participants would in turn be able to interpret the connection between olfactory media and this other media content. Accordingly, we used a one sample t-test to compare the mean opinion of participants perception of the sense of relevance of the olfactory media used to augment the video clips against a neutral opinion mean score

The overall mean opinion score in respect of the experimental participants' perception of the sense of relevance of the olfactory media in relation to the multimedia video clips was 3.71. This mean opinion score and the results from a one sample t-test (t=7.540, p=0.000) revealed that this positive bias was statistically significant, thus highlighting that the olfaction-enhanced multimedia clips did convey a correlated relationship between the combined olfactory media and audiovisual media content.

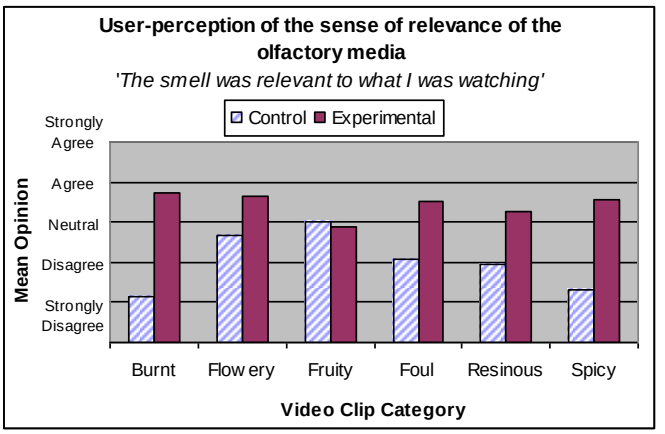

Fig. 4. Participants' perception of the sense of relevance of the olfactory media

4.3. User-perceived experience of the sense of reality of the olfaction-enhanced multimedia

The results from a repeated measures ANOVA test highlight that there were statistically significant different opinions of the control group and experimental group participants ($F=25.304$, $p=0.000$) in respect of their agreement with the phrase *"The smell heightened the sense of reality whilst watching the video clip"*, with average opinion scores being higher in the case of the experimental group. Again, content was not found to influence the perceived sense of reality ($F=1.855$, $p=0.105$), while the differences in opinions across different video categories by study group were statistically significant ($F=5.055$, $p=0.000$). In Fig. 5, we show the mean opinion scores obtained in respect of these results and use them to discuss any further patterns observed.

The mean opinion values show that generally the perception of the sense of reality was far greater for the experimental group participants than it was for the control group participants. As a matter of fact, and not surprisingly, the means show that participants in the control study generally disagreed with the statement *"The smell heightened the sense of reality whilst watching the video clip"*. On the other hand, with the exception of the *Fruity* and *Resinous* video clips, participants in the experimental study group were generally in agreement with the statement

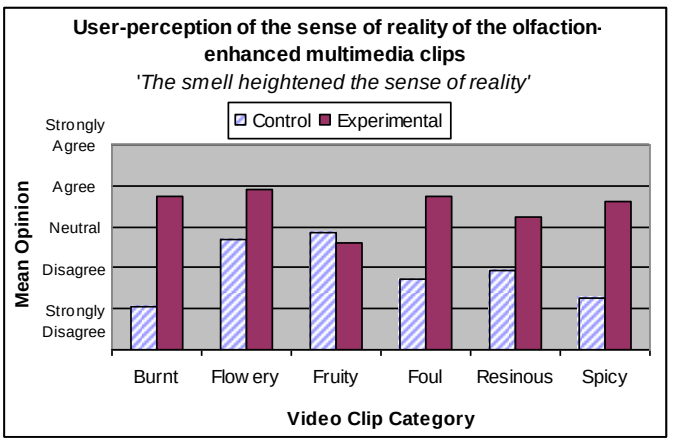

Fig. 5. Participants' perception of the sense of reality of the olfaction-enhanced multimedia videos

In the case of the *Fruity* video clip, the experimental group participants' answers displayed a slightly negative tendency in respect of their agreement that olfactory media heightens the sense of reality, and were even more negative than their corresponding control study participants as regards this particular video clip. However, this is consistent with the neutral opinions that these participants had towards the sense of relevance of the added olfactory media for this same video clip, especially when compared with the more positive opinions for the other videos. We believe that this may be due to the familiarity of the scent used in this case. The scent emitted for this video clip in the experimental case was *Strawberry*. This is a well known smell and is easily recognisable, being found in a variety of items, such as ice-cream, biscuits, drinks, jam, etc., with the consequence that one does not necessarily need to be an expert to identify a synthetic strawberry smell. Comments from participants confirmed this, as of all the smells used for our experiments, this smell was the only one where participants used words such as 'fake' or 'artificial' to describe what they had smelt in their own words (in response to statement 8 of the experimental questionnaire).

To conclude our analysis, we used a one sample t-test to see if the opinion mean obtained from the experimental study group differs significantly from a neutral opinion (Test value 3 – *Neither agrees or disagrees that the smell heightened the sense of reality whilst watching the olfaction-enhanced video clips*). The results of the one sample t-test revealed that the positive bias of the experimental participants' opinions, as reflected by the overall mean opinion score of 3.76, was statistically significant (t=8.892, p=0.000). Consequently, these results emphasise that the addition of olfaction to multimedia does tend to influence participants' tendency to agree with the statement *"The smell heightened the sense of reality whilst watching the video clip"*.

4.4. User acceptability of olfactory media

To ascertain user acceptability of the olfactory media employed to augment the multimedia video clips, we measured how distracting and annoying participants found the presence of olfactory media. We do this by analysing participants responses based on their agreement with the statements, '*The smell was distracting*' and '*The smell was annoying*'.

We conducted a repeated measures ANOVA test to investigate to what degree participants found the emitted scents or odour neutralisers (as was the case for the control group participants) distracting and/or annoying respectively. The results from the ANOVA test revealed that there was a significant difference in participants' opinions as regards the amount of distraction caused between when the emitted olfactory media was an odour neutraliser and when it was one of the actual experimental scents ($F=17.696$, $p=0.000$). Similarly, there were significant differences in participants' opinions between how annoying the olfactory media was when an odour neutraliser was emitted and when one of the actual experimental scents were released ($F=11.936$ and $p=0.002$). Content, however, had no significant impact on participants' opinions in respect of how distracting ($F=0.640$, $p=0.669$) and/or annoying ($F=0.969$, $p=0.438$) they found the emitted scents or odour neutralisers. The combined influence of content and scent emitted on participants' opinions as to what degree they found the olfactory media distracting and/or annoying was statistically significant in both cases, that is, for how distracting ($F=6.257$, $p=0.000$) and for how annoying ($F=5.165$, $p=0.000$).

The mean opinion values reflecting participants' opinions in respect of the amount of distraction the olfactory media caused are shown in Fig. 6. Unsurprisingly, the mean opinion scores show that generally the control group participants did not find the odour neutralisers distracting. In the case of the experimental group participants, the opinions were mixed and either reflected a negative bias or a neutral opinion towards the polled statement, '*The smell was distracting*'. Nonetheless, these results reflect that generally the experimental participants also did not find olfactory media used to augment the video clips distracting, or at the very worst were mostly neutral. However, the more ambivalent attitude of the experimental participants towards what can be termed as unpleasant smells shows that, as is to be expected, participants have a more positive bias towards pleasant scents. This is further reflected by the mean opinion of the experimental participants for the *Foul* video clip, which suggests that they did find the *Rubbish Acrid* scent used to enhance this particular video clip slightly distracting.

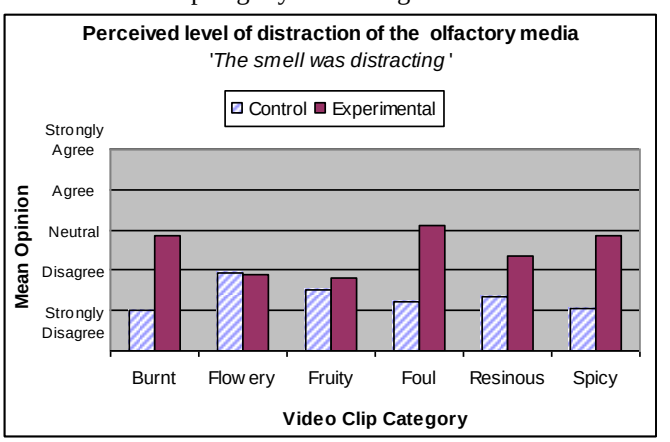

Fig.6. Mean opinions reflecting the degree of distraction the olfactory media caused participants

The mean opinions in respect of how annoying participants found the experimental scents and odour neutralisers are shown in Fig. 7. These mean opinions show that the control group participants generally did not find the odour neutralisers emitted with the video clips annoying, whilst there was a mix of opinions in the case of the experimental

group participants. The opinions of the experimental group participants reflect a mostly negative bias or neutral attitude towards the polled statement, '*The smell was annoying*', and hence these participants also generally did not find the added olfactory media annoying, or at worst had a neutral opinion towards it in this respect.

The bias for pleasant smells is again displayed by the more negative opinion of the experimental participants in respect of the annoyance of the *Wallflower* and *Strawberry* scents emitted with the *Flowery* and *Fruity* video clips respectively, that is, participants generally did not find these smells annoying. These two scents are among the more pleasant smell categories amongst the six smells used for the experiment. Moreover, the mean opinions also show that the experimental participants found these two scents less annoying than the control group participants did the odour neutralisers emitted with the same *Flowery* and *Fruity* video clips.

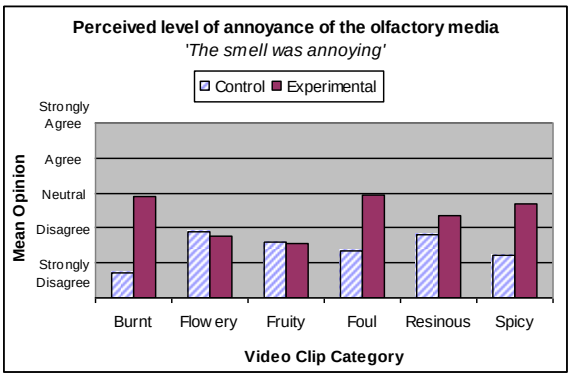

Fig. 7. Mean opinions reflecting the level of annoyance the olfactory media caused participants

Furthermore, we conducted a one samples t-test to investigate whether the mean opinion of the experimental participants differs significantly, and it what way, from a neutral opinion. The results showed that the negative bias of the experimental participants' opinions towards how distracting they found the olfactory media, as reflected by the mean opinion value of 2.68, was statistically significant ($t=-3.004$, $p=0.003$). In addition, the mean opinion value of 2.56 obtained in respect of how annoying the experimental participants found the olfactory media was also statistically significant ($t=-3.991$, $p=0.000$). Thus, the t-test result indicates that these mean opinions do differ significantly from a neutral opinion, and that, more importantly, the negative bias towards the statements in both respects shows that participants generally did not find the added olfactory media distracting or annoying

4.5. User-perceived enjoyment of the olfaction-enhanced multimedia

An ANOVA showed that there was no significant difference in the level of enjoyment experience between when odour neutralisers where used to augment the video clips and when actual scents were used ($F=1.905$, $p=0.177$). Content, defined by the different video categories, however had a significant influence on the perceived level of enjoyment ($F=4.000$, $p=0.002$), which is consistent with findings from similar perceptual studies in other types of multimedia applications (Ghinea and Thomas, 1998; Jumisko-Pyykkö, Häkkinen and Nyman, 2007). The combined impact of content and scent on participants' enjoyment was also not statistically significant ($F=1.516$, $p=0.187$). Nonetheless, we

examine the mean opinions obtained in respect of this analysis, shown in Fig. 8, to investigate if there are any other noticeable patterns worth mentioning.

The mean opinion values reflecting participants' enjoyment of the multimedia experience generally show that the user-perceived level of enjoyment was relatively comparable across the two study groups, and indicate that participants generally enjoyed the olfaction-enhanced multimedia experience regardless of whether the olfactory media was an odour neutraliser or actual scent. Bearing in mind that odour neutralizers do have an active scent of their own, this might well imply that participants enjoy the experience of olfaction generally speaking, and not necessarily the correct association between media content and the particular category of scent being emitted. Despite the repeated measures ANOVA test results showing that there was no significant difference in the opinions of the two participant groups, the mean opinions do reveal that participants in the experimental study appeared to have enjoyed the experience slightly more than the control study participants. This difference is most noticeable in the case of the *Burnt* video clip, where the difference in mean opinions between the control group and experimental group reflects quite a positive impact of olfactory-enhanced multimedia on the perceived level of enjoyment of this

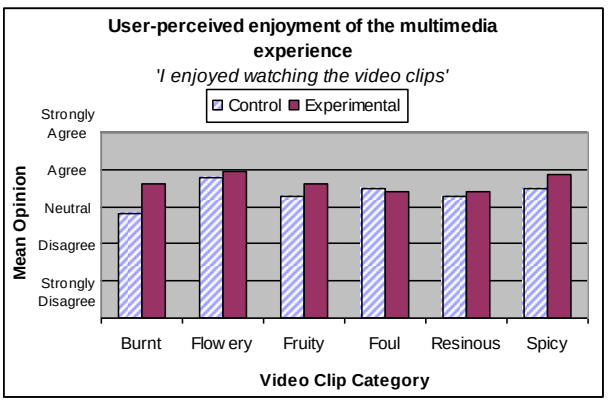

Fig. 8. Influence of olfaction on the user-perceived enjoyment of a multimedia experience

Lastly, we consider if the mean opinion value of the perceived level of enjoyment of the olfaction-enhanced multimedia video clips differs significantly from a neutral mean opinion and in what way. To this end, we conducted a one sample t-test for participants opinions obtained from our experimental study group. The t-test showed that the resulting mean opinion value, 3.63, does indeed differ significantly from a neutral mean opinion, and moreover, the positive opinions of participants reflect fact that they generally enjoyed the olfaction-enhanced multimedia experience ($t=8.689$, $p=0.000$).

5. CONCLUSIONS

Olfaction is one of the last barriers that multimedia applications have to overcome in order to truly engage a person's complete sensorial array. Problems in practice range from mis-association of smells, to diffusion and directional issues. The study reported in this paper has presented evidence, though, showing that users are prepared to overlook these drawbacks of olfactory devices, and that there is an across the board positive bias towards the use of olfaction in multimedia applications.

Whilst our work has limitations – a greater sample size would have been welcome, arguably the synthesis of olfactory data used in our study could have been improved upon, and it is debatable whether multimedia content is enjoyed for its 'sense of reality' alone – it has opened up exciting pathways for future work. The exploration of the boundaries of human perceptual tolerance to olfactory enhanced multimedia is one such direction, as is the determination of the most suitable mix of olfactory stimuli for given multimedia content. Both form the focus of our future endeavours.

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