The Impact of Scent Type on Olfaction-enhanced Multimedia Quality of Experience

Niall Murray, Brian Lee, Yuansong Qiao and Gabriel Miro-Muntean

***Abstract* — In the quest to increase user perceived Quality of Experience (QoE), the classic audio-visual content paradigm can be extended to include media components that stimulate other human senses. Among these, olfaction-enhanced multimedia has attracted significant attention, as it is both attractive from user point of view and challenging from research perspective. This paper presents the results of two subjective studies which analyzed user QoE of olfaction-enhanced multimedia. Diverse scent types and video content were considered. In particular QoE levels were studied when one and two olfaction stimuli enhanced audiovisual media. The results presented show that scent type influences user QoE. Statistically significant differences between pleasant and unpleasant scent types existed. Also, in certain cases, users were prepared to forgive the presence of unpleasant scent types with respect to QoE. Finally users reported a clear preference for olfaction presented after the video sequence with which the olfaction effect should be synchronized, as opposed to before the video sequence.**

***Index Terms*— Mulsemedia, Olfaction enhanced multimedia, Olfaction-based mulsemedia, Quality of Experience, Sensory experience.**

I. Introduction

TRADITIONAL multimedia components have stimulated two of the human senses: sight and hearing. In recent times, research and industry have reported works involving multiple sensorial media (mulsemedia) [1][2]. It is assumed that extending traditional media with tactile [3], gustatory [4] and olfaction [5][6][7] will result in enhanced user Quality of Experience (QoE) levels.

Among the diverse media experimented with, olfaction is an attractive mulsemedia component for both users and researchers. The use of olfaction has been employed alongside multimedia content in entertainment (movies) [8], gaming [9], health [10][11][12], education [13] and tourism [14]. The literature has reported many significant challenges associated with olfaction-based mulsemedia, mostly due to lingering effects and synchronization with the audio-visual content [5][6][15].

The motivation for correctly presenting olfaction as part of a mulsemedia experience includes increased sense of reality, relevance and enjoyment [5][6]. The inclusion of olfaction was shown to provide benefits in information recall [16] and as a form of therapy [11]. However, the user QoE of olfaction is complex to model and is affected by numerous influencing factors (IF). The literature reports results on the effects of age, gender, culture [6], life experiences, emotions and mood [15] and temporal relations between olfaction and other media components [5][17][18][19]. To the best of the authors' knowledge no works have analyzed the impact of scent type on user QoE.

The major contribution of this work is that it presents an analysis on the impact of scent type on user QoE of olfaction-based mulsemedia. The results presented are the outcome of two experimental studies (referred to as experimental study 1 and experimental study 2, heretofore). The video sequences were enhanced with one olfactory stream and two olfactory streams, respectively. In total 14 olfaction-based mulsemedia clips were used. The QoE levels of 187 assessors were captured considering the factors: scent type and inter-media skew. The user QoE when two olfactory streams were presented considered 3 aspects. Firstly: the same skew sizes between the two olfactory stimuli exist i.e. both streams early or late by the same amount (conceptual delay between the olfactory streams). Secondly: variable skew sizes for the olfactory streams with one stream early and one late (conceptual jitter between the two olfactory streams presented). Thirdly: variable skew sizes for the olfactory streams which result in overlapping or "mixing" (conceptual jitter between the two olfactory streams presented). The latter is a unique approach never attempted before.

The rationale for this work was to determine if user QoE levels were affected by scent type and to identify acceptable synchronization boundaries considering scent type for single and two-scent presentation. This paper is organized as follows: section 2 discusses related work, section 3 describes the components of the olfactory and video media display system used during the subjective testing. Section 4 outlines the assessment methodology employed, section 5 and section 6 present the results and analysis of the completed subjective testing with discussion on findings. Section 7 introduces a preliminary mathematical model for olfaction-based

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mulsemedia and section 8 concludes the paper and highlights directions for future research.

II. Related Works

Kaye prototyped a number of olfactory displays (OD) and evaluated the potential for olfaction in two general strands: presenting smell to convey information (called olfactory icon) and presenting smell in abstract relationship with the data it expresses (called olfactory smicons) [20][21].

A fundamental requirement of any mulsemedia application is the synchronized display of multiple media streams. Recent articles reported findings on how users perceived inter-stream synchronization of olfactory data with audiovisual [5][17], and haptic [18] media components. The user perception of these mulsemedia experiences was captured by presenting assessors with artificial skews between the media and evaluating if (a) assessors could detect the skews and (b) what effect the different skew levels had on QoE. This methodology to capture the user experience was initially reported in [22]. Using the same video clips and scents as used in section V, [5][17] analyzed the impact of asynchrony between olfaction and audiovisual media on user QoE. The authors focused on QoE as a function of annoyance, distraction, enjoyment, sense of reality and sense of relevance. They found that olfaction presented before audiovisual content was more tolerable than olfaction after audiovisual content. They defined a temporal synchronization boundary for a 90 second olfaction enhanced multimedia clip. If olfaction was presented 30s ahead of video or 20s after video, assessors perceived the experience as being synchronized. In [23], the same authors combined audiovisual media with semantically related and semantically unrelated olfactory content and rated the assessors' QoE. Their results showed significant differences in assessor enjoyment when the semantically unrelated olfactory content was presented compared with the related olfactory content. The experiments reported here differ in that the olfaction was always semantically related and as such, the authors focus solely on the impact of skew and comparison between different scent types (primarily pleasant vs. unpleasant).

The authors of [24] tested 54 subjects and noted the importance of intensity of some mulsemedia components as a key factor for QoE. For haptic and air-flow stimuli, they reported that as intensity decreased, user preference for these media components followed the same pattern. The same authors presented in [25] a mulsemedia delivery system which proposed priority packet scheduling and mulsemedia flow adaptation based on network conditions and user preferences. The reported system resulted in enhanced QoE compared with non mulsemedia aware delivery systems. The research presented in [26] focused on the requirements for understanding the temporal relations between various mulsemedia components and presented the results of subjective evaluation of temporal relations between audiovisual components and combinations of haptic and airflow effects. A sample size of 48 indicated that if haptic was presented up to 1s behind video content, it was synchronized and air flow effects could be presented between 5s ahead or 3s after video without having adverse effects on user QoE. In none of the works discussed, the influence of scent type on user QoE was examined. In the context of standardization, MPEG-V defined metadata representations for olfactory data among other sensory effects as part of its Sensory Effects Description Language (SEDL) within Sensory Information (part 3) [21].

The authors' previous work reported results analyzing the temporal relations between olfaction and visual media [27]. It was found that the absence of contextual audio significantly reduced the acceptable temporal boundaries in comparison with the results in [19][28]. In [6], the influence of age, gender and culture on user perception of olfaction-based mulsemedia was examined. Surprisingly age was not found to be a significant factor on user's ability to detect skew or perception of skew as gender and culture. Generally, when olfaction enhanced visual media, if olfaction was presented 10s ahead of video or 15s after video, assessors reported the experience as being synchronized. In [7], the effect of multiple olfactory streams on user QoE was presented. Not considering scent type, a minimum of 20s was required between consecutive scent presentations to ensure enhanced user QoE. Also not considering scent type, no evidence existed that assessors enjoyed the mixing of scents. Finally, the presentation of a skew for one scent affected the ability of the assessors to detect subsequent skews and assessors perception of subsequent skews of olfaction-based mulsemedia.

Considering the related works discussed, there is a clear need for analysis focused on the impact of scent type on user QoE of olfaction-based mulsemedia. This is the focus and contribution of this paper.

III. Experimental Set-up

This section outlines the olfaction based mulsemedia presentation system, assessors as well as video and scents used.

A. Olfaction-based mulsemedia presentation equipment

The olfaction-based mulsemedia display system, first presented by the authors in [19], is shown in Fig. 1. The olfactory display (OD) used was the SBi4 – radio v2 scent emitter [29]. This OD stores four interchangeable scent cartridges at once and presents scents by blowing air (using four in-built fans) through the scent cartridges. The SBi4 system was controlled using the Exhalia java-based SDK. The video content was played using the VLC media player 1.0.1 Goldeneye. A software framework was developed to control the presentation of olfactory data and video (both synchronized and the introduction of artificial skews). Skew levels between the various media components were presented in step sizes of 5s. The skew levels tested in this work were conceptual, and not caused by network transmission effects. Rather, the aim was to simulate such effects and capture the user response. For experiment 1, the skew levels were from ranges of -30s to +30s and for experiment 2, -20s to +20s. The

range of test cases for experiment 2 was reduced based on the findings of experiment 1 where users reported significant decrease in QoE levels outside this range. Further discussion is provided in section IV. In both studies, negative

Fig. 1: Olfactory and video media display system [23].

skew levels indicate olfaction presented before video whereas positive skew levels indicate olfaction presented after video.

The time taken to deliver scent from the OD to the user was considered as part of the delivery process with detailed information presented in section IV.A. The test laboratory was designed in accordance with appropriate ISO standard [30].

B. Assessors experimental studies 1 & 2

As mentioned the results presented here were based on two studies. In experimental study 1, the user perception of a single olfactory stimulus enhancing video media was captured. The sample size was 86. In experimental study 2, 2 olfactory stimuli enhanced audiovisual media for 103 assessors.

For both groups, assessor ages ranged from 19 to 60 years, with an even distribution across age and gender. A convenience sampling approach was undertaken with respect to assessor recruitment with persons from a wide range of socio-economic and cultural backgrounds part of the sample. A number of eligibility criteria were examined (e.g. assessors could not be involved in any sensory analysis testing in the twenty minutes preceding the tests, assessors must not have been affected by cold or flu, and must avoid wearing perfume, aftershave or scented deodorants on the day of the testing etc.). In addition, assessors were screened for anosmia, as per [31].

C. Video sequences and scents

14 video clips and 11 different scent types were used in the two studies. In study 1, 6 video clips were used. The clips (90s in duration) were in form of documentaries, cookery programs and movies. The middle 30s block of each clip contained content related specifically to the scent being presented. In experimental study 2, 8 video clips were used. These clips were again in form of documentaries, cookery programs and movies, but were of 120s duration. Each of the video clips could be divided into four 30 second blocks whereby the middle two 30s blocks contained content related specifically to the scents presented. Finally, for both study 1 and 2, the clips were chosen as they contain video content which related to pleasant and unpleasant scents and combinations thereof.

In experimental study 1, the scents of f*ruity, flowery, spicy, resinous, foul* and *burnt* were used. These reflect a fair distribution of what can be termed pleasant and unpleasant scent types. In experimental study 2, 10 scents in total were used via combinations of *fruit-flowery, forest-burnt, fruit-foul, foul-burnt, orange-chocolate, horse stable-grass, forest-seawater* and *grass-seawater* to enhance multimedia clips. Since each experiment employed 10 scents or less, they complied with [28] in terms of the numbers of scents that should be used for user tests. In terms of storage of scents cartridges, as per recommendations of the provider and [31], there were stored in sealable plastic bags in a cold bag at approximately 5^{o}C. Hence, the cartridges were protected from sunlight, in a cool location with maintained concentration of the scents presented for the duration of the subjective testing.

IV. Assessment Methodology & Questionnaires

A. Methodology and questions

A number of methodologies are available for subjective testing involving traditional multimedia components [34][35]. These methodologies have been employed to date to evaluate user perception of mulsemedia. In [36], the issue of designing paired comparison subject tests was discussed in order to address a key issue of non-uniform distribution of quality ratings. To address (a) the novelty of olfaction and (b) the variable perception of olfaction, the degradation category rating (DCR) assessment methodology [34][35] was selected for this work. As such, participants were presented with two media samples. The first stimulus presented in each pair was the reference, whist the second stimulus was the sample under test. The reference sample was always a synchronized presentation of olfaction based mulsemedia.

In experimental study 1, assessors experienced a single olfactory stream enhancing visual media. The questionnaire used is available in [36]. For the 90s clip, artificial skews in step sizes of 5s were simulated ranging from olfaction presented 30s before video and to 30s after video. As per [36], statement 1 queried the assessors' ability to detect inter-media skew. Question 2 analyzed the user perception of skew (if it existed) in terms of its annoyance. Statements 3-5 considered the impact of skew on user QoE (in terms of enjoyment (statement 3), relevance (statement 4) and reality (statement 5)). Table 1 shows the possible answers assessors could have selected.

Table 1 Rating scales for each of the statements/questions (Likert Scale) for experimental study 1 [7]

Score	Statement 1	Question 2	Statement 3,4,5
5	Too Late	Imperceptible	Strongly Agree
4	Late	Perceptible but not annoying	Agree
3	Neither Early or Late	Slightly annoying	Neither Agree or Disagree
2	Early	Annoying	Disagree

1	Too Early	Very annoying	Strongly Disagree

In experimental study 2, two olfactory streams enhanced audiovisual media. The findings from experiment 1 indicated that skew levels outside of -20s to +20s resulted in significantly reduced user QoE. Hence to focus on higher impact scenarios and minimize the number of testing combinations, the temporal boundaries evaluated were between -20s and +20s. 103 assessors were divided randomly into two groups. One group of 50 (group 1) experienced the same skew levels for scent A and scent B in step sizes of 5s from -20s to +20s. The second group of 53 assessors (group 2) experienced variable skew levels for each scent stream. Such test scenarios reflect varying the temporal distance between the releases of the two olfactory streams. This variance resulted in (1) the gap between the presentations of the two olfactory streams was extended or (2) the gap was reduced and the two olfactory streams can overlap. Further information is provided in section VI.B. The questionnaire is available at [31]. As per experimental study 1, assessors were queried with respect to their: ability to detect the presence of skew (statements 1 and 2) and perception of skew (questions 3 and 4). In addition, the impact of skew on user QoE for each of the two scents was analyzed. Statement 5 captured if assessors enjoyed when the two olfactory streams enhanced the multimedia content, statements 6 and 7 analyzed how relevant the two olfactory streams were, and statements 8 and 9 queried how the olfactory streams heightened the user sense of reality .

In addition, questions 10 to 13 (asked of assessors in group 2 only) were introduced to help understand the users' perception of mixing of the two scents (if detected) . Question 10 aimed to understand the assessor detection and perception of mixing of scents in terms of annoyance. In terms of analyzing the assessors QoE of mixing scents, the assessors were queried in terms of their enjoyment, sense of relevance and sense of reality. The rating scales that were available to assessors are presented in Table 2.

B. Determination of detection instant

Due to the slow moving nature of olfactory data compared with audio or video media, it was critical for the synchronization study to determine how long it took assessors to detect the presence of odors once emitted i.e. the time for a user to detect a scent once the fans in the OD were turned on. Different scent types have different concentration profiles, and as such differences exist in the time to delivery and for users to perceive each scent. 25 participants (13 male, 12 female) were presented with the 11 scents twice in random order. Assessors clicked on the mouse once they detected a scent. As we considered it took 1 second for assessors' reaction and click on the mouse, we determined, on average, but per scent, how long in advance the olfaction device's fans should be started in order to ensure timely presentation to the users. With on the SBi4 being 0.5 meters from the assessor, it was found that it took assessors between 2.7s - 3.5s to detect the scents as shown in Fig. 2.

Table 2 Rating scales for each of the statements/questions (Likert Scale) for experimental study 2 [7]

Score	Statements 1 & 2	Questions 3 & 4 & 10	Statement 5-9 & 11-13
5	Too Late	Imperceptible	Strongly Agree
4	Late	Perceptible but not Annoying	Agree
3	Neither Early or Late	Slightly annoying	Neither Agree or Disagree
2	Early	Annoying	Disagree
1	Too Early	Very annoying	Strongly Disagree

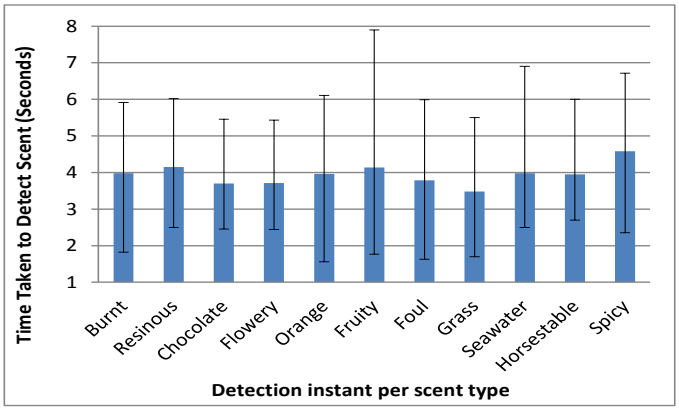

Fig. 2: Detection instant per scent average and maximum/minimum detection instants per scent [7].

The information in Fig 2. was incorporated into the software control framework outlined in section III.A and as such the olfactory component could be delivered according to the desired skew levels and synchronized presentation based on the scent type delivery time.

C. Classification of scent types

As part of the experiment, assessors were asked to specify if they felt the scents presented were pleasant or unpleasant. The results are presented in Table 3. These findings are the basis for the classification of scents being defined as pleasant (P), unpleasant (U) or maybe pleasant or unpleasant (UP) scent and are the basis for the analysis reported in sections V and VI.

V. SINGLE-SCENT TEST RESULTS

The results reported in this section reflect assessor ratings from experiment 1 whereby the scents of *burnt*, *fruity*, *flowery*, *spicy*, *foul*, *resinous* were used to enhance video media clips. Statistical analysis was performed using an independent samples t-test with 95% confidence level. The statistically significant results are presented in Tables 4-8 for detection, perception, sense of enjoyment, sense of relevance and sense of reality respectively. In each of these tables, "Sig." represents the two tailed p value. The results are presented in the Skew level / Sig. value format.

Table 3: Assessor ratings of scents as being pleasant or unpleasant

Scent	% that rated as pleasant	% that rated as unpleasant	Scent Classification: P=Pleasant U=Unpleasant UP=Maybe P or U
Fruity	94.6%	5.4%	P
Flowery	81.96%	18.04%	P
Forest	75.3%	24.7%	P
Burnt	46.1%	53.9%	UP
Foul	9.3%	90.7%	U
Orange	93.8%	6.2%	P
Chocolate	92.3%	7.7%	P
Horse Stable	38.8%	61.2%	U
Spicy	62.5%	22.5%	P
Sea Water	81.75%	18.25%	P
Grass (Clip 6) / (Clip 8)	58.2% / 66.15%	41.8% / 33.85%	UP / P
Resinous	49.1%	50.9%	UP

A. *Detection of skew based on scent type*

The impact of scent type, if any, on user ability to detect inter-media skew is analyzed and discussed here. If it is found to be the case, then scent type is a factor that should be considered by recommender engines for context based mulsemedia presentation. As per Fig. 3, assessors, irrespective of scent type, were able to identify the presence of skew reasonably well. Assessors clearly rated an unpleasant scent (such as *foul*) and a pleasant scent (such as *flowery*) similarly (see Table 3 for classifications). Table 4 shows the skew level and scents where statistically significant differences existed (via independent samples t-test with confidence interval of 95%).

The pleasant scent "*spicy*" was statistically different compared to *resinous*, *foul*, *fruity* and *flowery* at a skew level of -30s. Assessors rated skews of +30s between *spicy* and *burnt* as being statistically significant. For the generally pleasant scent "*flowery*": statistically significant differences exist between it and *burnt* at skew levels of +15s. The *resinous* scent type was also statistically different to *foul* at skew levels of +10s and +15s and interestingly between *resinous* and all the "pleasant scents" of *fruity* at skews of +10s and +15s, of *spicy* at skew levels of +30s and *flowery* at skew levels of -10s. For *foul*, statistically significant differences were found with *burnt* at +15s and between the two pleasant scents of *spicy* and *flowery* at skew levels of +30s and +20s respectively. Finally for the *fruity* scent, statistically significant differences were found with the unpleasant *burnt* scent at +15s and with the pleasant *spicy* and *flower* scents at skews of +30s and +20s respectively.

As per Table 4, 15 comparisons were found to be statistically significant. Further inspection considering scent type shows that 9 of the 15 statistical differences were when one of the scents was pleasant and the other either unpleasant or maybe pleasant or unpleasant as per the classifications of Table 3; 3 of the statistically significant differences were when both scent types were pleasant and the remaining 3 were when one of the scents was unpleasant and the other was maybe pleasant or unpleasant.

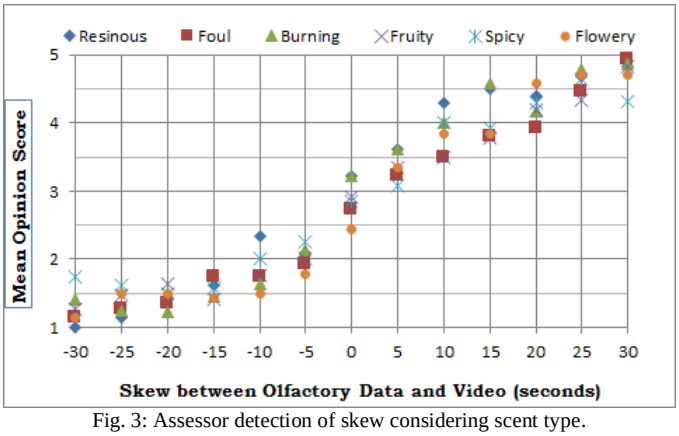

Fig. 3: Assessor detection of skew considering scent type.

Table 4: Statistical analysis on influence of scent type on detection of skew based on 95% confidence level.

	Foul (U)	**Burnt (UP)**	**Fruity (P)**	**Spicy (P)**	**Flowery (P)**
Spicy (P)	No stat. sig.	+30s/(Sig. = 0.011)	-30s/(Sig. = 0.0027)	N/A.	-30s/(Sig. = 0.0009)
Fruity (P)	No stat. sig.	+15s/(Sig. = 0.019)	N/A.	No stat. sig.	+15s/(Sig. = 0.033)
Flowery (P)	No stat. sig.	+15s/(Sig. = 0.033)	N/A.	N/A.	N/A.
Resinous (UP)	+10s/(Sig. = 0.006) +15s/(Sig. = 0.033)	No stat. sig.	+10s/(Sig. = 0.007) +15s/(Sig. = 0.032)	+30s/(Sig. = 0.030)	-10s/(Sig. = 0.024)
Foul (U)	N/A.	+15s/(Sig. = 0.019)	No stat. sig.	+30s/(Sig. = 0.005)	+20s/(Sig. = 0.034)

B. *Perception of skew based on scent type*

This section reports how assessors rated the various skew levels in terms of annoyance based on scent type. The literature has reported that users are quite tolerable to large skew levels for olfaction-based mulsemedia [5][6]. No works have considered scent type as an influencing factor on annoyance level. As per Fig. 4, for each of the scent types, whether pleasant or unpleasant, it is clear that assessor's found scents presented after video less annoying than before between skews levels of -25s to +25s. This was particularly exaggerated with the "unpleasant" scent types such as *foul* and *burnt*.

Table 5 presents statistically significant differences between the scent types at the same skew levels for user perception. 21 statistically significant differences existed in total. As per Table 5, 15 of the 21 differences existed when comparing one pleasant and one maybe unpleasant/pleasant or unpleasant scent type. Furthermore, more than double the number of differences exist when scent is presented after (14) video than before (7) video. The low annoyance ratings of *foul* presented before video when presented correctly or with small skews after video are notable.

The same trend existed for burnt scent type. In summary, assessors' found scents presented after video less annoying than scents presented before video. This was consistent for both pleasant and unpleasant scent types, but was particularly exaggerated with the "unpleasant" scent types.

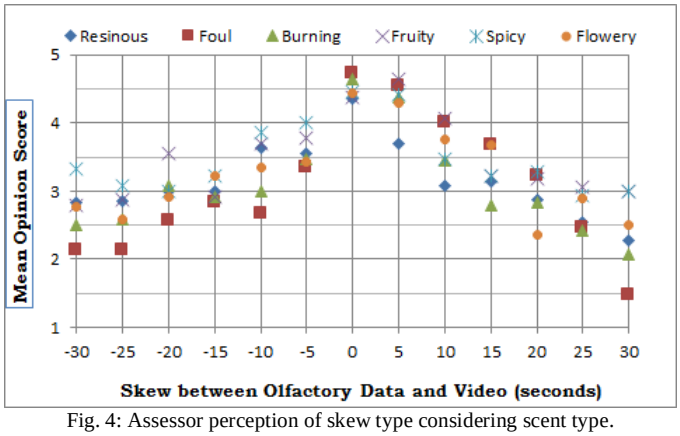

Fig. 4: Assessor perception of skew type considering scent type.

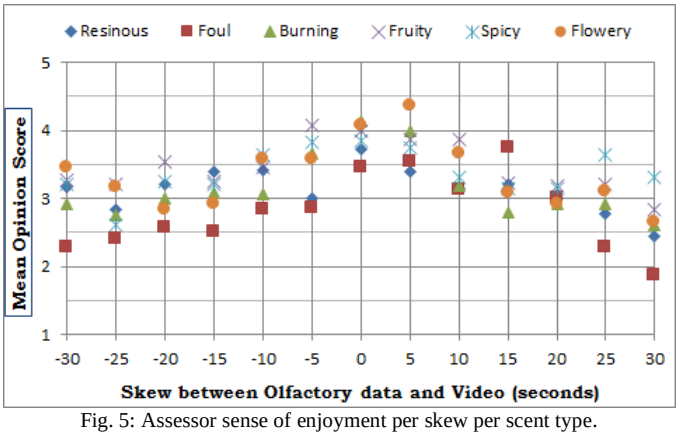

Fig. 5: Assessor sense of enjoyment per skew per scent type.

Table 5: Statistical analysis on influence of scent type on perception of skew based on 95% confidence level.

	Foul (U)	**Burnt (UP)**	**Fruity (P)**	**Spicy (P)**	**Flowery (P)**
Spicy (P)	-30s/(Sig. = 0.016)	-10s/(Sig. = 0.036)	No stat. sig.	N/A.	+20s/(Sig. = 0.024)
Flowery (P)	+20s/(Sig. = 0.037) +30s/(Sig. = 0.012)	+15s/(Sig. = 0.038)	No stat. sig.	N/A.	N/A.
Resinous (UP)	+10s/(Sig. = 0.026) -10s/(Sig. = 0.032) +5s/(Sig. = 0.004)	+5s/(Sig. = 0.017)	+5s/(Sig. = 0.001) +10s/(Sig. = 0.020)	+5s/(Sig. = 0.014)	+5s/(Sig. = 0.036)
Foul (U)	N/A.	+15s/(Sig. = 0.029)	-20s/(Sig. = 0.031) -10s/(Sig. = 0.018) +30s/(Sig. = 0.000)	-25s/(Sig. = 0.041) -10s/(Sig. = 0.006) +30s/(Sig. = 0.000)	N/A.

Table 6: Statistical analysis on influence of scent type on enjoyment per skew level based on 95% confidence level.

	Resinous (UP)	**Burnt (UP)**	**Fruity (P)**	**Spicy (P)**	**Flowery (P)**
Resinous (UP)	N/A.	No stat. sig.	-5s/(Sig. = 0.005)	-5s/(Sig. =0.034) +15s/(Sig. = 0.038) +30s/(Sig. = 0.043)	+5s/(Sig. = 0.005)
Foul (U)	-30s/(Sig. = 0.047) -30s/(Sig. = 0.035)	-5s/(Sig. = 0.021) +5s/(Sig. = 0.015)	-30s/(Sig. = 0.020) -20s/(Sig. = 0.025) -5s/(Sig. = 0.001) +25s/(Sig. = 0.033) +30s/(Sig. = 0.016)	-30s/(Sig. = 0.029) -10s/(Sig. = 0.023) -5s/(Sig. =0.009) +25s/(Sig. = 0.002) +30s/(Sig. = 0.000)	-30s/(Sig. = 0.007) -10s/(Sig. = 0.038) -5s/(Sig. = 0.044) +5s/(Sig. = 0.017) +30s/(Sig. = 0.042)

C. Impact of scent type on QoE

This section reports on the impact of scent type on assessor QoE for olfaction-based mulsemedia experience.

1) Impact of skew on enjoyment considering scent type

Assessors generally enjoyed pleasant scents more than unpleasant scent across the majority of skew levels as per Fig. 5. Assessors fond scents presented after video less annoying between skews levels of -15s to +15s whether pleasant or unpleasant. Assessor's in most cases found the pleasant scents more enjoyable at each of the skew levels compared to the unpleasant scent types. They also reported that they enjoyed scents presented after video as opposed to before video.

Table 6 presents 24 statistically significant differences between the scent types at the same skew levels. Of the 24 statistical significant differences, 20 existed when one of the scent types was pleasant and the other maybe unpleasant or pleasant or unpleasant. This was supported in the number of statistically significant results with *burnt*, and in particular the *foul* scent type as opposed to the pleasant scent types *fruity*, *flowery* and *spicy*. Also notably at skew levels of +15s, the highest enjoyment rating was for *foul*. Assessors rated pleasant scents above MOS 3.5 from -10 to +10s whereas for unpleasant scent types, they only rated synchronized, +5s and +15s (*foul* only) at this level of enjoyment. The highest enjoyment rating was for *flowery* at +5s.

2) Impact of skew on sense of relevance considering scent type

Fig. 6 and Table 7 present the MOS ratings and statistical analysis of assessors' ratings of sense of relevance considering scent type. The MOS ratings across a range of skew levels indicate that assessors found pleasant scents to be more relevant than unpleasant scents. Certainly, assessors found *fruity* and *flowery* as being quite relevant with olfaction before video when compared to the other scent types. The *fruity* scent type was also reported as providing higher levels of relevance when synchronized and up to +10s. As per Fig. 6, at skew levels of +15s and +20s the foul scent type was higher that pleasant scent types which is notable. The ratings for *foul* at these skew levels is similar to the rating for *foul* at 0s, +5s and +10s. This indicates that skew level does not have a major impact of sense of relevance for *foul* scent types when compared to, for example, *flowery* scent type, where there was a noticeable decrease in relevance from +10s to +15s.

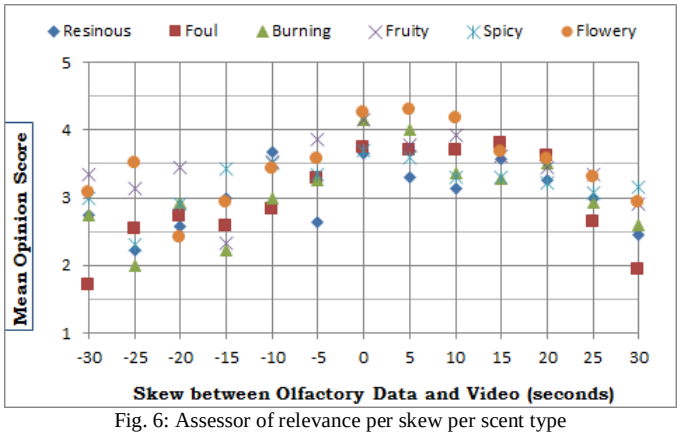

Fig. 6: Assessor of relevance per skew per scent type

Table 7: Statistical analysis on impact of skew on sense of relevance based on scent type

	Foul (U)	Burnt (UP)	Fruity (P)	Spicy (P)	Flowery (P)
Spicy (P)	No stat. sig.	-15s/(Sig. = 0.006)	No stat. sig.	N/A.	-25s/(Sig. = 0.014)
Flowery (P)	No stat. sig.	-25s/(Sig. = 0.003)	No stat. sig.	No stat. sig.	No stat. sig.
Resin-ous (UP)	-30s/(Sig. = 0.039)	No stat. sig.	-25s/(Sig. = 0.048) -5s/(Sig. = 0.010)	No stat. sig.	-25s/(Sig. = 0.009) -5s/(Sig. = 0.048) +5s/(Sig. = 0.014) +10s/(Sig. = 0.018)
Foul (U)	N/A.	-30s/(Sig. = 0.039)	-30s/(Sig. = 0.001) +30s/(Sig. = 0.041)	-30s/(Sig. = 0.007) +30s/(Sig. = 0.010)	-30s/(Sig. = 0.006) -25s/(Sig. = 0.038) +30s/(Sig. = 0.032)
Fruity(P)	No stat. sig.	-25s/(Sig. = 0.016)	N/A.	-15s/(Sig. = 0.014)	-20s/(Sig. = 0.049)

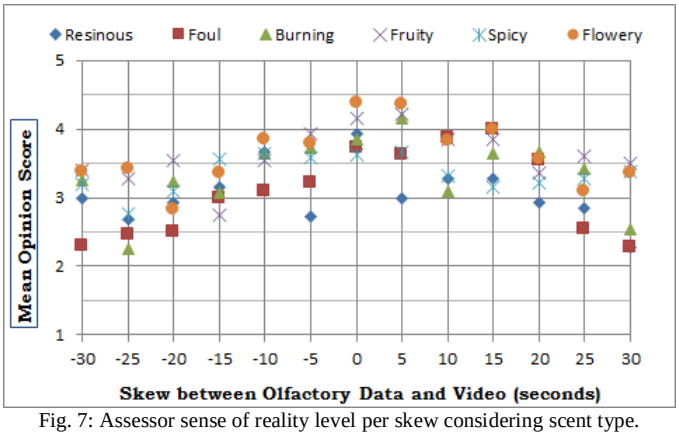

Fig. 7: Assessor sense of reality level per skew considering scent type.

Table 8: Statistical analysis on impact of skew on sense on reality based on scent type

	Foul (U)	Burnt (UP)	Fruity (P)	Spicy (P)	Flowery (P)
Spicy (P)	+30s/(Sig. = 0.017)	No stat. sig.	No stat. sig.	N/A.	0s/(Sig. = 0.043)
Flowery (P)	No stat. sig.	-25s/(Sig. = 0.020) -20s/(Sig. = 0.018)	No stat. sig.	No stat. sig.	N/A.
Resin-ous (UP)	+30s/(Sig. = 0.017)	-5s/(Sig. = 0.021) +5s/(Sig. = 0.002)	-5s/(Sig. = 0.007) +5s/(Sig. = 0.001)	+30s/(Sig. = 0.028)	-5s/(Sig. = 0.017) +5s/(Sig. = 0.000) +30s/(Sig. = 0.029)
Foul (U)	N/A.	No stat. sig.	+25s/(Sig. = 0.029) +30s/(Sig. = 0.010) -30s/(Sig. = 0.017) -20s/(Sig. = 0.018)	No stat. sig.	-30s/(Sig. = 0.024) -25s/(Sig. = 0.045) +5s/(Sig. = 0.036) +30s/(Sig. = 0.018)
Fruity(P)	No stat. sig.	-25s/(Sig. = 0.032) +30s/(Sig. = 0.042)	N/A.	No stat. sig.	No stat. sig.

Table 7 presents 21 statistically significant differences and highlights two key aspects. 16 out 21 statistically significant differences existed when olfaction was presented before video. Pleasant scent types have more relevance than unpleasant scent types. Of the 21 statistically significant differences, 16 existed when there was one pleasant scent type compared with a scent type that was unpleasant or maybe unpleasant or pleasant. There was an increase in the perceived sense of relevance for the "unpleasant" scent types when scent was presented after, rather than before video. For the *foul* scent type, approximately the same level of relevance was reported from 0s up to +20s. *Fruity* and *flower* scent types were generally more relevant than the other scent types.

3) Impact of skew on sense of reality considering scent type

This section reports differences in sense of reality at the various skew levels based on scent type. Fig. 7 and Table 8 present the MOS ratings and statistical analysis. The MOS ratings across a range of skew levels indicate that assessors found pleasant scents as being more realistic than unpleasant scents. Assessors reported *flowery* as being quite relevant with olfaction before video compared with the other scent types. Generally assessors reported that olfaction presented after video provided a greater sense of reality than olfaction before video.

The statistical analysis supports the same trends that existed sense of enjoyment and sense of relevance i.e. the greatest number of statistically significant differences exist when one scent is pleasant and the other was unpleasant or maybe pleasant or unpleasant. This occurred in 15 of 22 statistically significant cases. 10 of the 22 statistically significant differences existed when olfaction was presented before video, with 11 when olfaction was presented after video. The remaining differences existed when 0s skew existed between *flowery* and *spicy*. For scent before video, pleasant scent types were more realistic than unpleasant. It is clear that scent type had a significant weighting on how assessors rated their sense of reality.

This section has reported a clear differentiation on user perception of olfaction-based mulsemedia between the scent types tested. In the next section, how assessors rated the mixing of different scent types and the required gap between the presentations of consecutive scents is the key focus.

VI. MULTIPLE-SCENT TEST RESULTS

Assessors for experimental study 2 were randomly divided into two groups. Group one experienced the same skew levels between the two scents and as a result the gap (6s) between the olfactory stimuli presentation was maintained. Hence, the impact of delay was the focus and as such the results section for group one is presented as the effect of delay on user QoE (Section VI.A). For the second group, there were different skew levels for each of the olfactory streams and as such varying timings between the release of the two scents (gap between presentations widened or reduced such that mixing occurred). Consequently, the impact of conceptual jitter was the focus and the results section for group two are presented as effect of jitter on user QoE (Section VI.B). Due to space on constraints the authors limit the analysis presented in this section to the impact of skew considering scent type on user QoE.

A. Effect of delay on user QoE.

The analysis presented here considered the following scent combinations: two pleasant scents (P/P) (*fruit-flowery*, *orange-chocolate*, *forest-seawater*, *grass-seawater*); a mix of pleasant and maybe unpleasant or pleasant (P/UP) (*forest-burnt*); unpleasant and maybe unpleasant or pleasant (U/UP) (*horse stable-grass*, *foul-burnt*) and finally pleasant and unpleasant (P/U) (*fruit - foul*).

1) Effect of delay on enjoyment considering scent type

From Fig. 8, at all skew levels, assessors reported the pleasant with unpleasant (P/U) scent combinations with low levels of enjoyment. The Pleasant/Pleasant (P/P) scent combinations, from -15s to +20s all had MOS greater than 3.5 with 0s, +5s and +10s reporting the highest enjoyment scores. A similar trend existed for Pleasant/Maybe pleasant or unpleasant (P/UP) with the exception being +10s. It is notable that the MOS values for this group were higher than the Pleasant/Pleasant (P/P) group for 5 of the 9 skew values tested. The Unpleasant/Maybe pleasant or unpleasant (U/UP) reported surprisingly high MOS ratings, values greater than 3.5 at skew levels of -5s and +5s to +20s values. The trend for pleasant/unpleasant reported when olfaction was before video, low levels of enjoyment existed. Skew had a marginally greater impact on enjoyment for Pleasant/Pleasant and Pleasant and Maybe Unpleasant or Pleasant groups. Between boundaries of -15s to +5s, the largest enjoyment ratings were reported. The most interesting result was the pleasant / unpleasant or maybe pleasant scent combinations, which had the highest sense of enjoyment across a number of skew levels. The *forest* and *burnt* scent types had pleasant ratings of 78.1% and 50.7% respectively as per Table 3. The Unpleasant / Maybe pleasant or unpleasant group (*horse stable-grass*, *foul-burnt*) also resulted in reasonably high levels of enjoyment. Both findings require further research.

The latter suggests some relationship to what Seferidis et al. reported in [32] and termed the "forgiveness effect" where assessors were prepared to 'forgive' impaired video when it is followed by a substantial period of unimpaired video. Also Aldridge in [33], reported that when good quality video

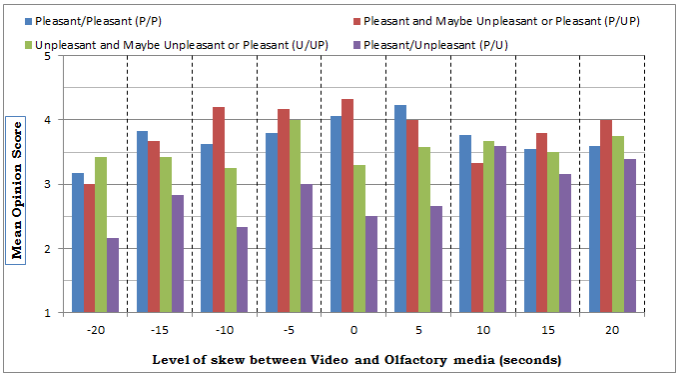

Fig. **8**: Assessor sense of enjoyment of scent A and B grouped based on scent categories

Table 9: Statistical analysis on impact of skew on sense on enjoyment based on scent type

	(U/UP)	(P/U)
(P/P)	0s/Sig. =0.031	-20s/Sig. =0.029 -15s/Sig. =0.003 0s/Sig. =0.0002 +5s/Sig. =0.0002
(P/U)	-20s/Sig. =0.014 -15s/Sig. =0.036 -5s/Sig. =0.038 +5s/Sig. =0.0018	N/A
(P/UP)	-15s/Sig. =0.041 0s/Sig. =0.015	-15s/Sig. =0.001 -5s/Sig. =0.034 0s/Sig. =0.0002 +5s/Sig. =0.005

precedes poor-quality content, the rating will be awarded on the basis of the poor-quality section, thus possibly linking this phenomenon to the recency effect of memory. Finally from Fig. 8, it is also valid to conclude that if multiple scent presentations are to be made, and if assessor enjoyment is the aim, the presentation of two consecutive scents should not involve a pleasant scent followed by a scent type that is unpleasant as this had the lowest MOS ratings consistently across all skew levels.

The authors suggest that some of the findings reported potentially indicate an effect specific to olfaction and is discussed further in future work. We also conclude that the context of the actual audiovisual content for this particular clip (i.e. *forest /burnt* scents enhancing the Avatar movie) may have had an influence on the assessor enjoyment as was also the case in section IV for the foul scent type. A one way ANOVA analysis with 95% confidence level was employed to determine if statistically significant difference existed between the assessor ratings at each of the skew levels. The results are presented in Table 9.

As per Table 9, 15 statistically significant differences existed. 12 out of these 15 involved the P/U scent combination, spread evenly between the P/P, U/UP and P/UP combinations. Also notable from the statistical analysis was that all but 4 of the statistically significant differences were reported when olfaction was presented before video, with just one at 0s and 3 at +5s skew level.

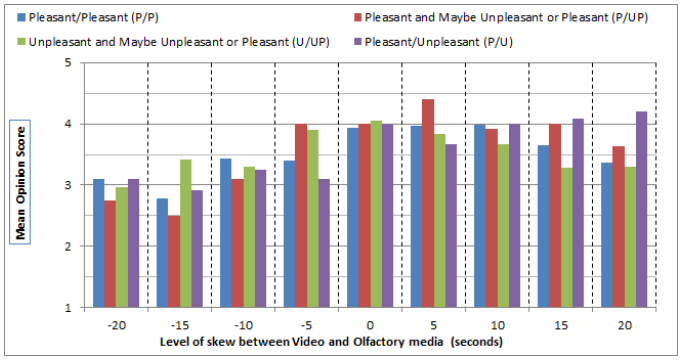

Fig. 9: Assessor sense of relevance for Scent A and B combinations based on different scent groupings

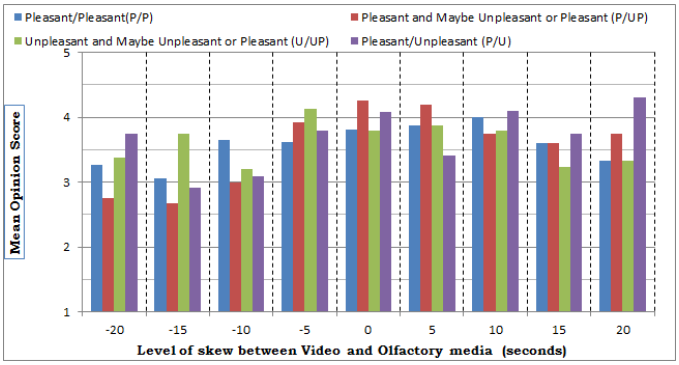

Fig. 10: Assessor sense of reality per skew level considering scent combinations

2) Effect of delay on sense of relevance considering scent type

In this section, the effect of scent combinations on assessor relevance considering scent type is presented. Fig. 9 reports how the scent combinations support sense of relevance across each of the skew levels. At skew levels of -20s to -10s, assessors reported a low relevance rating. Generally, the effect of scent type has less of an impact than one would expect given the previous findings of section IV. The relevance MOS ratings for scent combinations presented after video were higher than olfaction before video. Comparing the different combinations, the P/P MOS ratings were higher than 3.5 from 0s to +15s. Surprisingly for the P/UP grouping, the boundary is larger, from -5s to +20s. As was the case for enjoyment, the unpleasant and maybe unpleasant or pleasant also had higher than expected MOS ratings from -5s tot +10s. Contradictory to the results reported for enjoyment, the P/U grouping reported particularly high levels of relevance when olfaction was presented after video, even with large skew levels (0s up to +20s.). If the aim of the presentation of olfaction-based mulsemedia is relevance instead of enjoyment, these results suggest that a pleasant scent followed by an unpleasant scent type is particularly relevant for users.

A one way ANOVA with post hoc tests with 95% confidence interval was employed to determine any statistically significant differences between the different groupings. Statistically significant differences existed between P/U and U/UP (Sig. 0.032) and P/U and P/UP (Sig. = 0.033) and between P/P and U/UP with a Sig. value of 0.042 at skew levels of -5s, For olfaction after video, significant differences existed between P/U and U/UP at skew levels of +15s (Sig. 0.024) and +20s (Sig. 0.035) and between P/U and P/P at +20s (Sig. 0.034).

3) Effect of delay on sense of reality considering scent type

This section presents the impact of delay on sense of reality considering scent type. Fig. 10 presents the results of the assessor's sense of reality considering the scent classifications across the various skew levels. Consistent with previous findings was that the temporal boundary of between -5s and +10s provided assessors with the greatest sense of reality. For the P/P combinations, the greatest sense of reality was achieved from -10s to +15s. Scent combinations involving an unpleasant scent type provided the greatest sense of reality between -5s and +20s.

The MOS for U/UP between -5s and +10s were notably high as were the MOS for P/U when olfaction was presented after the video sequence. Statistical analysis was employed using a one way ANOVA within groups with post hoc tests based on 95% confidence interval. Statistically significant differences existed at skew levels of: -20s between P/UP and P/U (Sig. = 0.038); at -15s P/UP, U/UP (Sig. = 0.016) and the between P/P; at -15s U/UP and finally at -5s (Sig. 0.049 and Sig. 0.025 respectively). For olfaction presented after video, statistically significant differences were found between P/U and P/P and U/UP at skew levels of +20s (Sig. = 0.015 and Sig. = 0.025)

As was the case for enjoyment and relevance, the reality MOS rating for P/UP scent combinations were high particularly when the scent presentations were close to being synchronized and when olfaction was presented after video. Indeed the two highest MOS rates were for this combination at synchronized and +5s. It is also likely that the use of scents to enhance the clip from the avatar movie resulted in higher sense of reality based on this genre of clip.

B. Effect of jitter on user QoE.

This section discusses user QoE associated with two olfactory stimuli enhancing audiovisual media. It reports the effect scent type had on the assessor sense of enjoyment in the presence of jitter. Analysis was performed considering the scent classifications outlined in Table 3: The groups as per the video clips were: pleasant (*fruit* and *flower* clip 1, *orange* and *chocolate* clip 5, *forest* and *sweater* clip 7 and *grass* and *seawater* clip 8); unpleasant group included (*fruit* and *foul* clip 2, *foul* and *burnt* clip 3, *forest* and *burnt* clip 4 and finally *horse stable* and *grass* clip 6).

1) Effect of jitter on sense of enjoyment considering scent type

Fig. 11 presents the enjoyment ratings based on the level of gap or mixing of scents. For 9 out of the possible 12 scenarios tested, assessors reported higher sense of enjoyment for the pleasant scent combinations compared with the unpleasant scent combinations. Particularly notable given Fig. 11 is that assessors were in agreement that they enjoyed the mixing of pleasant scents at the overlap levels of -4s and -9s particularly, and to a lesser extent 14s and 24s. Mixing of combinations that involved an unpleasant scent

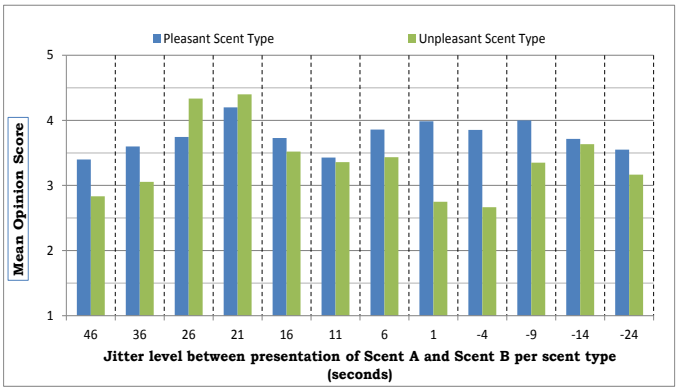

Fig. 11: Level of enjoyment comparing pleasant and unpleasant scent combinations based on gap between their presentations

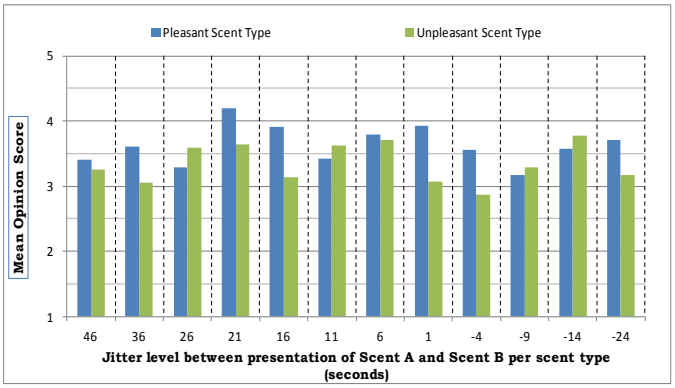

Fig. 12: Assessors sense of relevance in presence of jitter comparing pleasant and unpleasant scent combinations

were not enjoyable, with the exception of the 14s levels of overlap which was between 'agree' and 'neither agree nor disagree'. Also from Fig. 11, the levels of enjoyment with larger gaps between the scent presentations such as 21s and 26s (for the pleasant scents and especially unpleasant scent types) resulted in higher QoE. The skew levels in these cases were (-15s/0s), (0s/+15s) and (-15s/+15s) [7] for the pleasant orange and chocolate combination (MOS 3.6). The other unpleasant combinations of foul and burnt (-20s/+10s had a MOS of 3) and horse and grass (-10s/+20s had a MOS of 3.11) reported lower levels of enjoyment.

Statistically significant differences were reported between pleasant and unpleasant scent types at jitter levels of 1s (Sig.=0.001) gap and 4s (Sig.=0.013) mixing. The results for the remaining jitter scenarios were not statistically significant between the pleasant and unpleasant enjoyment ratings. What was particular surprising was that assessor enjoyed unpleasant scent types at jitter levels of 26s and 21s where, although not statistically significant, were comfortably greater than the pleasant scent type enjoyment ratings at the same jitter levels.

2) *Effect of jitter on sense of relevance considering scent type*

Fig. 12 reports the assessors' sense of relevance based on scent category and how it was impacted by jitter. Two trends emerge. Firstly for 8 out of the 12 jitter scenarios tested, the pleasant scent combinations were more relevant. At jitter levels of 21s, assessors found the pleasant scent combinations more relevant, whereas the opposite was the case for

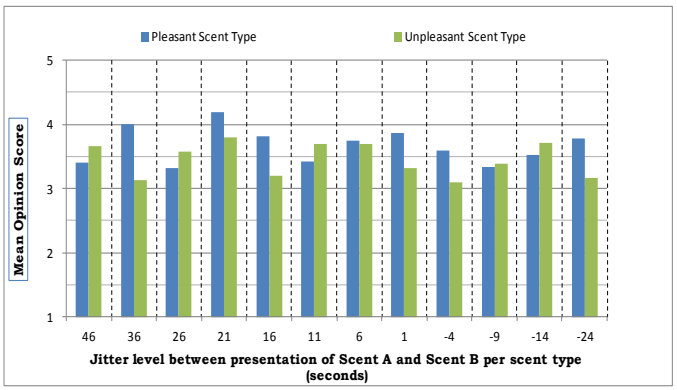

Fig. 13: Assessors sense of reality in presence of jitter comparing pleasant and unpleasant scent combinations

enjoyment. Similar to the enjoyment analysis, assessors reported greater relevance when mixing at levels of -4s and -24s but reported the opposite at mixing levels of -9s and -14s. Statistical analysis revealed that assessor ratings at jitter levels of 21s (Sig.=0.035), 1s (Sig.=0.01) and -4s (Sig.=0.047) were statistically significant between the pleasant and unpleasant scent combinations.

C. *Effect of jitter on sense of reality considering scent type*

This section presents and discusses the impact of scent combinations on the assessor sense of reality. As per Fig. 13, for 7 of the 12 jitter scenarios tests, assessors reported a higher sense of reality for the pleasant scent combinations. Similar to the enjoyment and relevance results, the highest reality rating was at jitter levels of 21s. Akin to relevance, the impact of scent type was not found as significant for reality as compared to enjoyment. This was supported by only one statistically significant difference between the pleasant or unpleasant scent combinations at the jitter levels was at 36s (Sig.=0.007).

VII. QoE Modelling of Olfaction-based Mulsemedia

The experimental study conducted and presented in this paper identified some of the most important aspects which influence the user QoE when exposed to olfaction-based mulsemedia content. Although aware of the high complexity of QoE modeling [39], the authors propose a preliminary QoE model for olfaction-based mulsemedia.

Eq. (1) shows how user QoE is a function of three major components, described as utility functions: QoS metrics (QoS), user profile (UP) and content type (CT). Each component and the overall QoE score are represented by a score which takes values in the [0,1] interval and no unit. In eq. (1) *w1*, *w2* and *w3* are weightings for the considered components, reflecting their importance in the overall QoE model. Eq. (2), (3) and (4) present the most relevant parameters to model user QoE. Throughput, delay and jitter are major parameters for QoS as reported in [7][19], user profile highly depends on age, gender and culture as reported in [6][28] and content type considers the type of the various mulsemedia components including for instance video and scent as outlined is this article.

$$QoE = QoS^{w1} * UP^{w2} * CT^{w3} \quad (1)$$

$$QoS = f_{\mathrm{QoS}}(Throughput, Delay, Jitter) \quad (2)$$

$$UP = f_{\mathrm{UP}}(Age, Gender, Culture) \quad (3)$$

$$CT = f_{\mathrm{CT}}(VideoType, ScentType) \quad (4)$$

VIII. Conclusion & Future Work

This paper presented the results of two subjective studies which analyzed user QoE of olfaction based mulsemedia when diverse scent types and video content were considered. These studies involved one and two olfaction stimuli enhancing multimedia content, respectively.

A. Conclusion on impact of scent type for single scent experiment

Considering the user perception of a single olfactory stream enhancing visual media, the following conclusions can be drawn. Firstly, for both pleasant and unpleasant scent types, assessors preferred olfaction presented after video than before video. This is particularly exaggerated for unpleasant scent types such as *foul* and *burnt* and pleasant scent type *flowery*. Generally speaking, assessors reported higher QoE levels for pleasant scent types as opposed to unpleasant types, but the foul scent type stands alone as an unpleasant scent type for which the assessors reported high levels of QoE when it was presented after video. Further work on the reasons for this are required, but initial investigation suggests that the content of the video scene was emphasized with the scent (i.e. rate of rotting of the bowl of fruit increased significantly).

The high ratings for sense of enjoyment, relevance and reality at skew levels of +10s map well with the presentation of olfaction and context of the video clip at this time. In terms of temporal boundaries for synchronization of olfaction enhanced multimedia considering scent type, different temporal boundaries exist per scent type. For example, if we consider a MOS of 3.5 as the minimum required rating to be synchronized across the factors considered, for the *foul* scent type, presentation from 0s up to +15s was not annoying, whereas, small skew levels (e.g. -5s) when olfaction was presented before video were below this threshold. In contrast, for *spicy*, *fruity* or *flowery* scents, presentation from -10s to +10s was not reported as annoying by the assessors. For *resinous* scent, between -10s to +5s assessors reported acceptable levels in terms of annoyance and QoE. Finally for *burning* scent, assessors reported acceptable levels between skew of -5s to +10s. In conclusion, these findings are very important both for general understanding of influence of skew on user QoE and as the first step towards building a potential recommender engine which can use this data as input to determine context based presentation for olfaction-enhanced multimedia.

B. Conclusion on impact of scent type for multiple scent experiment

With respect to the enhancement of multimedia with two olfactory streams, the following conclusions are presented. Firstly there was a significant difference in the QoE levels reported by assessors between the delay and jitter tests. For unpleasant scent types it is recommended that a minimum gap of between 26s and 21s exists between the presentations of consecutive scents. For pleasant scent types assessors reported the highest QoE levels when a gap of 21s was present, but smaller gaps and even mixing of scents up to 9s was acceptable. Also with respect to scent type, assessors reported low levels of enjoyment when two unpleasant scent types were presented in the delay tests, but were prepared to forgive the presentation of one unpleasant scent type when it was accompanied with a pleasant scent type. As mentioned, it is concluded that the context of the video content has a significant influence here. The same phenomenon is not as exaggerated for the reality or relevance ratings.

In terms of the jitter tests, assessors did not report that they enjoyed the mixing of unpleasant scent combinations, whereas they indicated higher levels of enjoyment across a range of mixing levels of 4s and 9s for pleasant scent combinations. Where the gap between the presentation of consecutive scents exceeded the 20s margin, assessors reported higher levels of enjoyment for the unpleasant scent combinations. Generally, there is consistency between assessor enjoyment, relevance and reality, but as show in the results of the jitter tests, assessors differed in their views. Unlike for enjoyment, for both relevance and reality assessors reported higher ratings for the pleasant scent types at jitter levels of 21s and 26s. Also, they did not report a large difference for relevance/reality compared with enjoyment on the mixing of the different scent types.

C. Future Work

Future work will involve the refinement of the proposed QoE mathematical model reflecting the relative importance of the various influencing factors on user QoE for olfaction-based mulsemedia. Also evaluation of user QoE for mulsemedia experience that includes other multi-sensorial media such as haptic with olfaction will form part of our future work towards achieving a truly immersive multimedia experience.

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