Multiple-scent enhanced multimedia synchronization

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This study looked at users' perception of inter-stream synchronization between audiovisual media and two olfactory streams. The ability to detect skews, and the perception and impact of skews on user quality of experience (QoE) is analyzed. The olfactory streams are presented with the same skews (i.e. delay) and with variable skews (i.e. jitter and mix of scents). This paper reports the limits beyond which de-synchronization reduces user perceived quality levels. Also a minimum gap between the presentations of consecutive scents is identified, necessary to ensure enhanced user perceived quality. There is no evidence (not considering scent type) that overlapping or mixing of scents increases user QoE levels for olfaction-enhanced multimedia.

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1. INTRODUCTION

Multimedia content has mostly stimulated two of the human senses: sight and hearing. Recently, a number of works have emerged extending this list with so-called new media including tactile (Cha et al., 2009), gustatory (Narumi et al., 2011) and olfaction (Ghinea and Ademoye, 2012) (Murray et al., 2013D). The result is the emergence of multiple sensorial (multi-modal) media or “mulsemedia” content which aims to enhance users’ Quality of Experience (QoE) by stimulating additional senses beyond audiovisual. This trend brings user mulsemedia consumption much closer to the real life experience i.e. the information is spread across multiple senses. Olfaction is sense of smell. Scents have been used recently alongside multimedia content, in particular with movies, as it is assumed that presenting the scent according to the scenes would deepen the viewer’s understanding and sense of reality (Tomono et al., 2004). The use of olfaction has also spread to other domains such as gaming (Nakamoto et al., 2008), health (Spencer 2006)(Gerardi 2008)(Pair 2006), education (Shams and Seitz, 2008), training (Washburn, 2003) and tourism (Dann and Jacobsen, 2003). Research on modeling and analyzing the human perception of mulsemedia experiences is an active topic (Ghinea and Ademoye, 2012)(Timmerer et al., 2012)(Haung et al., 2012)(Lee et al., 2011). These works concentrate on how users perceive mulsemedia of various forms (scent, wind, lighting, tactile) integrated with traditional audiovisual media. With olfaction, how the user perceives the experience is particularly important, considering the number of factors that affect its perception e.g. age, gender, culture (Murray et al., 2013D), life experiences, emotions and mood (Ghinea and Ademoye, 2012). The advantages of correctly presenting olfaction as part of a mulsemedia experience range from increased sense of reality, relevance and enjoyment. It has also been shown to provide benefits in information recall (Brewster et al., 2006) and as a form of therapy (Gerardi et al., 2008).

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The study reported here considers synchronization of two olfactory streams with audiovisual media and the impact of the same on user QoE. An olfaction-enhanced multimedia display system was developed to present audio, video and olfactory data streams. Using this, the perception of the experience is analyzed considering two olfactory streams when presented with (1) the same skew sizes streams (i.e. both streams early or late by the same amount), (2) with varying skew sizes (e.g. one stream early and one late) and (3) uniquely where the two olfactory streams overlap or “mix”. The rationale for this work is multifold: to determine if synchronization boundaries are affected by two olfactory streams; to determine the impact of jitter (in particular the mixing of scents) has on assessor QoE. In this context, the contribution of this work is to further understand the factors that affect the user QoE of olfaction-enhanced multimedia, namely temporal relations between two olfactory streams (considering above mentioned three scenarios) and audiovisual media. 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 presents the results and analysis of the completed subjective testing with discussion on findings and section 7 presents conclusions and directions for future research.

2. RELATED WORKS

The use of olfaction to enhance user multimedia experience can be traced back to cinema in (Longino, 1999). However the more recent work of Kaye (Kaye, 2001) highlighted many potential uses for olfaction-enhanced multimedia and has been the basis for much of the current research since. Kaye designed a number of introductory olfactory displays in order to evaluate the potential for scent usage 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*).

A significant proportion of the works reported in the literature involving olfaction are focused on the development of olfactory displays (OD) and the supporting technologies required to address the unique challenges of olfaction i.e. lingering, slow movement, accurate presentation (to users’ olfactory field), quality of the scent, intensity and quantity of scents. In terms of OD classification, (Murray et al., 2013) categorize them based on their “location” (placed in environment or wearable) and scent generation technique. Devices placed in the environment have to address, among others, the challenge of slow moving scent and scent lingering. Works such as (Nakamoto and Minh, 2007), (Ariyakul and Nakamoto, 2011), (Sugimoto et al., 2010) and (Noguchi et al., 2011) focus on the hardware that enables controlled emission of minute amounts of scent. The aim is to minimize scent lingering and “enable instantaneous switching of scents” (Sugimoto et al., 2010) through precisely controlled presentation of olfactory data via devices based on the use of ink-jet technology. They incorporate fans to address slow moving nature of scent. *Wearable ODs* are an approach with great potential, as they are, by their nature, close to the user’s olfactory field. The challenge is not to appear intrusive and cumbersome. The *Scent necklace or scent collar* (Washburn, 2004) fits around a user’s neck, holds four scent cartridges and is controlled by a wireless interface. (Nakamoto et al., 2008) describe an interactive OD used as part of a cooking game. The OD itself, described in (Nakamoto et al., 2007) uses solenoid valves with high speed switching to emit scents. In addition the eScent product range (Tilletson et al., 2008) presents a number of wearable prototype devices, which include jewelry, clothing and handbags. They utilize microfluidics, a technology that enables the release of minute volumes of fluids.

Links between an ability to perceive olfactory stimuli and a number of neurodegenerative diseases exist in the literature: e.g. Alzheimer (Borromeo et al., 2010), Huntington (Warnock et al., 2011) and Parkinson (Haehner et al., 2009). (Stone et al., 2011) use olfactory data as part of their work to “determine the characteristics of natural environments that are beneficial to humans”. In (Gerardi et al., 2008), olfactory data is delivered via a scent palette in conjunction with audio and visual stimuli to treat a soldier with posttraumatic stress disorder (PTSD). Their findings indicate that following brief treatment, the veteran demonstrated improvement in PTSD symptoms. Numerous works report the use of scents to influence customer behavior (Emsenhuber 2011). (Chebat et al., 2003) state that “retailers should seriously consider ambient scent in their marketing toolbox” after investigating the impact of ambient odors on the behavior of mall shoppers. (Blackwell 1997) looked at the influence of olfactory cues on food choice and acceptability in a restaurant environment. (Gueguen et al., 2006) concluded that odor had an influence on restaurant customers’ behavior, with the length of time and amount of money spent positively affected by lavender. (Hirsch 1995) study showed significant increase in the use of slot machines enhanced with an odor.

A number of works have recently emerged reporting the use of olfaction in education and training. (Shams et al., 2008) discuss and conclude how multisensory training can be more effective than similar uni-sensory training paradigms. The authors reviewed studies that indicate how learning mechanisms operate optimally under multisensory conditions. This is based on the premise that "the human brain has evolved to learn in natural environments in which behavior is often guided by information integrated across multiple sensory modalities". In this context, the authors state that the extent of this benefit is based on the congruency of the stimuli i.e. how the relationship between stimuli is consistent with the prior experience of the individual or relationships between the senses found in nature (spatially, temporally and in terms of content).

A fundamental requirement of any mulsemedia application is the synchronized display of multiple media streams. Research on synchronization of mulsemedia applications is an active research area (Haung et al., 2011)(Eid et al., 2011)(Ghinea and Ademoye, 2010)(Ghinea and Ademoye, 2012)(Murray et al., 2013D). In the context of standardization, MPEG-V defines metadata representations for olfactory data among other sensory effects as part of its Sensory Effects Description Language (SEDL) within Sensory Information (part 3) (ISO/IEC, 2010). A number of recent works document user perceived inter-stream synchronization of olfactory data with other media, including (Ghinea and Ademoye, 2010)(Ghinea and Ademoye, 2012) for audiovisual and olfactory and (Hoshino et al., 2011) for haptic and olfactory. The methodology used in these works was originally documented in (Steinmetz, 1996). In addition to defining audiovisual and olfactory temporal synchronization boundaries, (Ghinea and Ademoye, 2010) analyzed the impact of asynchrony in terms of annoyance, distraction, enjoyment, sense of reality and sense of relevance. They found that olfaction before audiovisual content is more tolerable than olfaction after audiovisual content. Their work (Ghinea and Ademoye, 2010) on olfaction enhanced multimedia is the closest to our work found in the literature. In this context of related work, (Murray et al., 2013A) survey and classify ODs in terms of scent generation technique, delivery capability and application area. Another survey (Ghinea and Ademoye, 2011) reviews applications of olfaction in entertainment, movies, virtual reality, multimodal and alerting displays. The former survey addresses the use of olfaction in less apparent application domains such as tourism, health, education and training, highlighting the very significant potential for olfaction as a mulsemedia component. In addition, it presents a unique tutorial towards building a framework for subjective testing involving olfaction-enhanced multimedia based on expertise gained during the work of the authors (Murray et al., 2013B)(Murray et al., 2013C)(Murray et al., 2013D) and here. Considering our previous work where user perception of synchronization of a single olfactory stream and visual media was studied, here the focus is on the user perception of two olfactory streams enhancing audiovisual media. More specifically, the user perception of (1) the same skew sizes between olfaction and audiovisual media (i.e. both olfactory streams early or late by the same amount), (2) varying skew sizes between olfaction and audiovisual media (e.g. one olfactory stream early and one late) and (3) the overlap or mix of two olfactory streams.

3. EXPERIMENTAL SET-UP

This section outlines the olfactory and video display, laboratory design, assessors as well as video and scents used in this work.

3.1 Rationale for experimental design

From a user perspective, existing works only consider one scent and one video scene, which represents network delay scenarios. This paper investigates on how network delay and jitter affect user perceived inter-stream synchronization between video and two scents. In addition, the impact on assessor QoE is examined considering; the number of scents; the time between the emission of scents; the impact one skew has on perception of the same subsequent skews (i.e. network delay); and the impact gap and overlap of two scents (varying forms of network jitter).

3.2 Olfactory-enhanced video presentation equipment

Fig. 1 illustrates the olfactory and video display system used which consists of the SBi4 – radio v2 scent emitter (item Y sitting on the laptop) from Exhalia (Exhalia). The SBi4 device was selected for testing as it was perceived both more reliable and more robust than the other devices available on the market. The scents available with this device were also better in terms of scent realism. The SBi4 can store up to four interchangeable scent cartridges at once. The scent cartridges contain scented polymer balls. It presents scents by blowing air (using four in-built fans) through the scent cartridges. The SBi4 system is controlled using the Exhalia java-based SDK. It is connected to the laptop via a USB port. The video content was

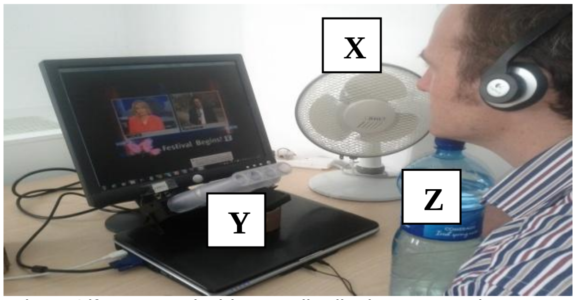

Fig. 1 Olfactory and Video media display system (Murray et al., 2013B)

Fig. 2 SBi4 V2, scent cartridges and bespoke extension. (Murray et al., 2013B)

Table 1 Video Categories and Scents Used

Scent Category	Fruit / Flower	Forest / Burnt	Fruit / Rubbish	Rotting / Burnt	Orange / Chocolate	Horse stable /Grass	Forest / Seawater	Grass / Seawater
Clip No:	Clip 1	Clip 2	Clip 3	Clip 4	Clip 5	Clip 6	Clip 7	Clip 8
Video Description	Documentary on Flower Garden and Orchards	Scene from Avatar Movie	Documentary about rotting fruit cocktail	Scene from Lord of the Rings Movie	Cookery documentary: chocolate orange biscuits	Documentary about horse stable cleaning	Scene from Avatar Movie	Documentary on grass plant and Sea life

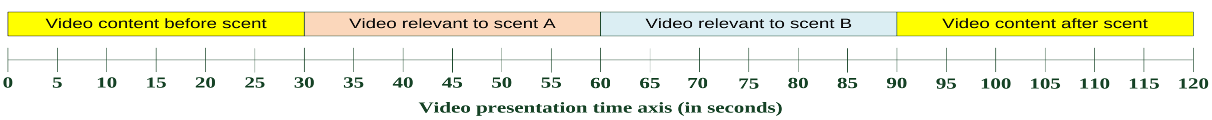

Fig. 3 Breakdown of video content

played using the VLC media player 1.0.1 Goldeneye. A special control program was developed that controlled the synchronized presentation of olfactory data and video, including the introduction of artificial skews between the various media components presented in step sizes as per Table 2 and Table 3 in section 5.1. Fig. 2 shows the SBi4, scent cartridges and the bespoke extension that was designed and added to the SBi4 as shown in Fig. 1 (Item Y). The purpose of this extension was to facilitate an accurate presentation of the scent to the users' olfactory field, as opposed to a more general presentation. Based on the SBi4 being 0.5 meters from the assessor, it was found that it took assessors between 2.7s - 3.2s to detect the scents depending on the scent type. Further discussion of how this was determined is documented in section 5.1. The laptop has an Intel Core™ 2 Duo CPU @ 1.66GHz, 2GB RAM and runs the Windows 7 professional operating system. In addition, Fig. 1 also includes a bottle of water (item Z, approx. 30 cm in height) that the assessors placed under their chin during testing to ensure consistency across all assessors in terms of the location of their olfactory fields regardless of posture or physical size.

3.3 Laboratory design

The design of the test laboratory is in accordance with ISO standard (ISO/IEC 8589) on "Sensory analysis – General guidance for the design of test rooms". The aim of this standard is to design test rooms such that it is possible (1) to conduct sensory evaluations under known and controlled conditions with minimum distraction and (2) to reduce the effects that psychological factors and physical conditions can have on human judgment. The laboratory design is described in detail in (Murray et al., 2013B).

3.4 Assessors

A total of 100 assessors took part in this study. This group included assessors between the ages of 19 to 60 years, with an even distribution across the age range and gender. The assessors were from a wide variety of backgrounds: students, post graduate researchers, academic staff, health care professionals, members of defence and police forces, accountants, farmers, teachers, IT industry professionals, persons from medical and construction industry and also persons unemployed. In order to be eligible, assessors could not be involved in any sensory analysis testing in the twenty minutes preceding the tests. In an attempt to provide contamination free results, 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. In addition they were requested to avoid chewing gum, eating food, drinking tea or coffee in the 30 minutes prior to the test. Assessors were also screened for anosmia as per (ISO 5496:2006), the screening process is outlined in section 3.6.

3.5 Video sequences and scents

Eight videos of 120s duration were used. Each of the video clips can be divided into four 30 second blocks whereby the two middle 30s block contains content related specifically to the scent being presented as per Fig. 3. The clips are in the form of documentaries, cookery programs and movies, and were chosen and altered such that the two middle 30s segments corresponded to the content relating to the olfactory media. These clips were also chosen as they contain a balance of video content that reflecting mix of pleasant and unpleasant smells and combinations thereof. Ten scents in total were used in the testing, complying with (ISO 5496:2006) in terms of the number of scents that should be used in subjective tests. The scents of fruit, flowery, forest, burnt, orange, chocolate, horse stable, grass seawater also reflect a “fair distribution ratio between what can be termed pleasant and unpleasant smell categories” (Ghinea and Ademoye, 2010). The scents outlined above were stored in sealable plastic bags and kept in a cool box at approximately 5°C as per (ISO 5496:2006).

3.6 Screening of assessors

Screening of assessors was performed in accordance with (ISO 5496:2006). The purpose of this standard is to provide a methodology for the initiation and training of assessors in the detection and recognition of odors. The aim is to teach assessors to (1) evaluate (2) identify odors and (3) use appropriate vocabulary and improve their aptitude. We have incorporated this standard for two key reasons (a) to address the key aims of the standard outlined above but most importantly (b) to identify assessors who could have anosmia. Anosmia is an olfactory related phenomenon whereby there exists a lack of sensitivity to olfactory stimuli. It can be total, partial, permanent or temporary. The processes of prescreening involved assessors being presented with scents and they were asked (1) if they could identify an odor (2) if they could recognize an odor (3) if they could name the odor they were presented with (ISO 5496:2006). As part of the training phase, if assessors could detect, but were unable to correctly identify the scent presented, the assessors were given the name of the odor thereafter for familiarization purposes. As part of this screening, 4 potential assessors were not selected for participation in the tests reported below based on suspicion of partial anosmia. A detailed tutorial on the execution of testing involving olfaction enhanced multimedia is available in (Murray et al., 2013A).

4. ASSESSMENT METHODOLOGY

On arrival, assessors were provided with an information sheet on the tests. Any questions were addressed and assessors were required to sign a consent form. Screening as outlined in section 3.6 was performed. Following the screening, assessors were asked to review the questionnaire they would answer on each olfaction enhanced multimedia test clip. Assessors were asked to engage for the duration of each test sequence. On completion of tests, windows in the room were opened and the fan was turned to remove any lingering scents. There was always a minimum of fifteen minutes between consecutive executions of tests between assessors. This gave ample time for removal of any lingering scents, collection of questionnaire sheets and preparation for subsequent assessor testing. It also included time for the new assessor to read the questionnaire sheets and sign consent forms, ask questions etc. The entire testing time for a single subject was approximately 65 minutes. This comprised approximately 350 seconds per test sequence (i.e. reference sample, break, sample under test and voting) as shown in Fig. 4. At the mid-point of the test, assessors were given a fifteen minute break to address any concerns over olfactory adaptation or fatigue. Assessors were permitted to drink water at any time during the testing period.

4.1 Introduction of skews between olfactory and video

As mentioned earlier, the purpose of these experiments was to analyze the user perception of multiple-scent enhanced multimedia experiences and the impact of skew, delay and jitter therein. 100 assessors were divided into two groups.

One group of 50 (group 1) experienced the same skew levels for scent A and scent B as per Table 2. Table 2 shows the skews introduced per video clip and how it was divided across participants on a per case basis. Once the presentation of the olfactory media was complete, a SBi4 fan with a non odor

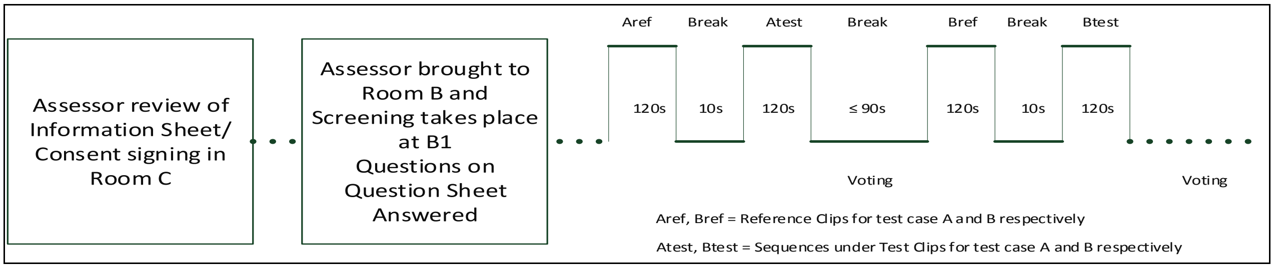

Fig. 4 Methodology for olfaction enhanced multimedia testing

cartridge was turned on to address scent lingering. Fig. 6 shows how olfactory media is presented at different times relative to the video time axis. For olfactory media to be in sync (0s skew) with the video, scent A should be presented for the middle 30s-54s block and scent B should be presented for the 60s-84s block as shown in Fig. 6. The six second "non odor" period is based on a recommendation that the time between presentation of two consecutive scents should be greater than 5 seconds (Nakamoto et al., 2006). Olfactory data before video content is represented by skew times of -20s, -15s, -10s and -5s and olfactory data after video content is represented by skews of +5s, +10s, +15s and +20s.

The second group of 50 assessors (group 2) experienced the set of skews as per Table 3. As shown, these test scenarios reflect typical packet jitter i.e. variable latency across a network. Within this set of tests there are two primary scenarios. The variance of delay can result in either (1) the gap between the presentations of the two olfactory streams being extended beyond 6s or (2) the two olfactory streams can overlap. Considering the latter case, for typical media transmission such as with audio, the simple result is to "drop" packets if overlap occurs. However considering that in these set of tests we are dealing with olfaction, in certain cases it may actually make sense if two scents "mix". Hence the set of tests experienced for the group 2 of reflect scenarios where both scent A and scent B are presented early and late and many of the possibilities in between. For clarity in Table 3, the mixing scenarios are highlighted in bold.

4.2 Questionnaire and rating scale

A number of approaches exist in the literature for offline subjective evaluations of multimedia applications. The absolute category rating (ACR) method proposed in BT.500 (ITU-T BT.500, 2002) requests participants to provide a rating score from 1 to 5 (5 being best) after observing a single sample. With this approach, there is no reference sample and scores are given based on user expertise. This leads to non-uniform distributions of rating scores, which can invalidate subjective results (Huang and Nahrstedt, 2012). Specifically in relation to olfactory media, considering the variable perception of olfactory media, this issue is exaggerated. In addition, feedback from assessors during preliminary testing indicated that the "novelty" of olfactory media made even large errors temporarily acceptable. (ITU-T P. 910, 2008) proposes an alternative assessment method to address the reliance on assessor expertise by exposing participants to two media samples and giving a comparative rating score. The first stimulus presented in each pair is always the source reference, while the second stimulus is the stimulus under test. This method is known as Degradation Category Rating (DCR) or Double Stimulus Impairment Scale method. To address the two issues highlighted above, this method was selected for the subjective testing. The reference sample was always a synchronized presentation of olfactory and video media. As per (ITU-T P.910, 2008), assessors were told that they would be presented with each olfaction enhanced clip twice and that the first time they saw each clip it was "the reference sample". They were told that the second time they saw each clip it was the "sample under test". They were requested to answer the questionnaire on their experience of the sample under test, and to base their judgments on their overall experience of the olfaction enhanced clips compared to the reference clip using the wordings available on each of the scales in Table 4 and Table 5.

As part of the preliminary testing, a reliability assessment was performed on the questionnaire to ascertain if the purpose and phraseology were clear and comprehendible to assessors. Discussion with each assessor was undertaken, feedback was recorded and necessary amendments were made to the draft questions. The questions explained in the remainder of this section are the final versions updated after feedback comments were considered and following a review by a Psychologist. Assessors were asked to select one of the five possible answers per question as per Table 4 (for group 1) and Table 4 and Table 5 (for group 2) relative to their experience of the stimulus under test. The questionnaire is available at: (Murray et al, 2013E).

Table 2. Test Group 1 (Delay only scenario): Case 1 applies to participants 1, 10, etc., case 2 applies to participants 2, 11 etc.

Case	Clip 1 Skew Fruit / Flower	Clip 2 Skew Forest / Burnt	Clip 3 Skew Fruit / Rotten	Clip 4 Skew Rotting / Burning	Clip 5 Skew Orange / Chocolate	Clip 6 Skew Horse Stable / Grass	Clip 7 Skew Forest / Seawater	Clip 8 Skew Grass / Seawater
1	0s/0s	-20s/-20s	-15s/-15s	-10s/-10s	-5s/-5s	+5s/+5s	+10s/+10s	+15s/+15s
2	+20s/+20s	0s/0s	-20s/-20s	-15s/-15s	-10s/-10s	-5s/-5s	+5s/+5s	+10s/+10s
3	+15s/+15s	+20s/+20s	0s/0s	-20s/-20s	-15s/-15s	-10s/-10s	-5s/-5s	+5s/+5s
4	+10s/+10s	+15s/+15s	+20s/+20s	0s/0s	-20s/-20s	-15s/-15s	-10s/-10s	-5s/-5s
5	+5s/+5s	+10s/+10s	+15s/+15s	+20s/+20s	0s/0s	-20s/-20s	-15s/-15s	-10s/-10s
6	-5s/-5s	+5s/+5s	+10s/+10s	+15s/+15s	+20s/+20s	0s/0s	-20s/-20s	-15s/-15s
7	-10s/-10s	-5s/-5s	+5s/+5s	+10s/+10s	+15s/+15s	+20s/+20s	0s/0s	-20s/-20s
8	-15s/-15s	-10s/-10s	-5s/-5s	+5s/+5s	+10s/+10s	+15s/+15s	+20s/+20s	0s/0s
9	-20s/-20s	-15s/-15s	-10s/-10s	-5s/-5s	+5s/+5s	+10s/+10s	+15s/+15s	+20s/+20s

Table 3. Test Group 2 (Jitter scenarios): Case 1 applies to participants 1, 7, etc., case 2 applies to participants 2, 8 etc. and so on

Case	Clip 1 Skew Fruit / Flower	Clip 2 Skew Forest / Burnt	Clip 3 Skew Fruit / Rotten	Clip 4 Skew Rotting / Burning	Clip 5 Skew Orange / Chocolate	Clip 6 Skew Horse Stable / Grass	Clip 7 Skew Forest / Seawater	Clip 8 Skew Grass / Seawater
1	0s/0s	-15s/0s	**-10s/-20s**	-5s/0s	**0s/-20s**	**+5s/-10s**	+10s/+20s	-20s/-10s
2	+15s/-15s	0s/0s	**0s/-10s**	-20s/+10s	-15s/+15s	**+10s/-10s**	-5s/+5s	**+20s/-10s**
3	**+10s/-20s**	**+15s/0s**	0s/0s	0s/+10s	**+5s/-5s**	0s/+5s	-10s/+10s	**+20s/-20s**
4	**+10s/-20s**	0s/+15s	-5s/-10s	0s/0s	+5s/0s	-10s/+20s	**+15s/+5s**	0s/+20s
5	-20s/0s	**0s/-15s**	-15s/-10s	**-5s/-20s**	0s/0s	-15s/-5s	+5s/+15s	0s/-5s
6	**+20s/+10s**	-15s/+5s	-20s/+20s	**+15s/-5s**	-10s/0s	0s/0s	**-5s/-20s**	**+10s/0s**

Table 4 Rating scales for each of the statements/questions (Likert Scale)

Score	Statement 1 & 2	Question 3 & 4	Statement 5-9
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

Table 5 Rating scales for each of the statements/questions (Likert Scale)

Score	Question 10	Statement 11-13
5	Imperceptible	Strongly Agree
4	Perceptible but not annoying	Agree
3	Slightly annoying	Neither Agree or Disagree
2	Annoying	Disagree
1	Very annoying	Strongly Disagree

Statements 1 and 2 aimed to determine assessor ability to **detect** the existence of a synchronization error, for scent A and B respectively. Assessors answered by selecting one of the five possible answers as shown under statements 1 and 2 in Table 3. Questions 3 and 4 aimed to determine how **tolerant** assessors were to different levels of skew for scent A and scent B. Hence they were asked to qualify their annoyance of the inter-media skew as per answers for questions 3 and 4 in Table 3. Statements 5, 6, 7, 8 and 9 were included to analyze the impact of inter-media skew for scent A and B on the user experience. To determine the impact of inter-stream skew, assessors' agreement with level of **enjoyment** of olfactory data as a media when in sync and explores any deterioration in this perception with the introduction of inter-media skew. Statements 6 and 7 queried the **relevance** olfactory media had to the video when skews existed as opposed to synchronized presentation. Assessors' agreement with statements 8 and 9 analyzed impact the level of skew has on assessors' sense of **reality** of an olfaction enhanced multimedia clip. In addition questions 10 to 13 were asked of assessors in group 2 only, with the aim to understand the users' perception mixing of the two scents, if they detected mixing of scent A and scent B. Question 10 aims 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, the sense of relevance and sense of reality.

4.3 Preliminary experiment: measurement of the detection instant

Because of 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. Different scent types have different concentration profiles, and as such differences exist in the time for users to perceive each scent. 25 participants (13 male, 12 female) were presented with the 10 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 - 3.2s to detect the scents as per Fig. 5. For each scent, the average time it takes an assessor to detect it is taken into account in terms of presenting the scent according to the above mentioned skews i.e. if it takes 3 seconds for a burning scent to reach the assessor, the fan to emit the scent is turned on at time 27s such that the scent reaches the assessor at time, t = 30s and as such is said to be synchronized with the video.

5. RESULTS AND DISCUSSION ON DETECTION, PERCEPTION AND QOE FOR TEST GROUP 1 (NETWORK DELAY SCENARIOS)

This section reports the results from test group 1 (as per Table 2), how assessors rated the presence of the same skew for both scents. This section also presents results of the impact of skew on assessor QoE.

5.1 Detection and perception of synchronization error for test group 1

5.1.1 Detection of skew

Fig. 7 and Fig. 8 present the results of statements 1 and 2, to determine users' ability to detect levels of inter-media skew between the video, scent A and scent B. The vertical axes in each figure shows the ratings related to the five possible answers to statements 1 and 2, i.e. when scent A and scent B arrived relative to the video. The horizontal axes indicate the level of skew artificially introduced between the olfactory and video media with the negative values representing olfactory media before video media. Both figures show assessors were able to identify the existence of inter-stream skew very well. The figures also indicate that that assessors were more sensitive to scent presented before video. Direct comparison of MOS (mean opinion scores) presented in Fig. 7 at skews of +5s and -5s show that the MOS for +5s of 3.38 was closer to being at the "correct time" (represented by a value of 3) as opposed to the value of 2.38 for -5s. Interestingly based on MOS comparison, assessors viewed skews of +10s and -5s similarly in terms of being Late or Early respectively. In order to analyze if significant differences existed in participants' perception between synchronized and unsynchronized scent and video, the data collected was analyzed using independent sample t-test with 95% confidence level. For all levels of skew between the olfactory data and video, statistically significant difference between assessors' opinion of mean of the synchronized and mean of participant responses for the "skewed" release times existed.

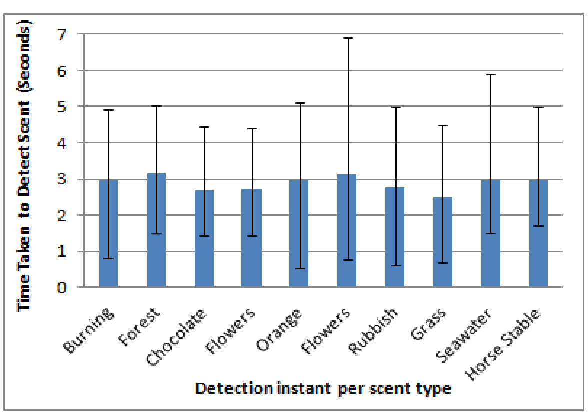

Fig. 5 Detection instant per scent average and maximum/minimum detection instants per scent.

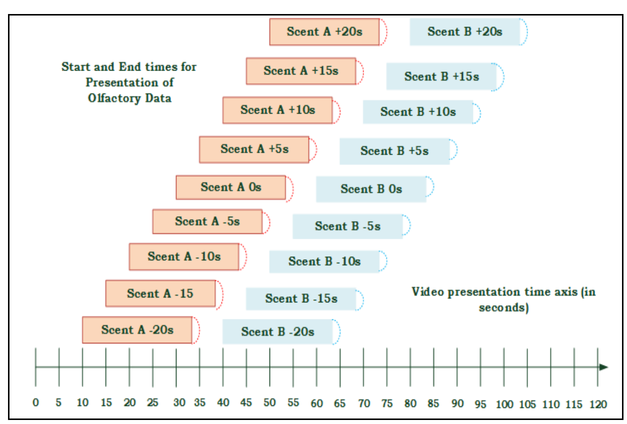

Fig. 6 The start and stop times for scent A and scent B and associated video presentation time for test group

With regards to scent B, interesting observations can be made. For the synchronized (i.e. 0s skew), assessors reported as being slightly early with a MOS score of 2.72 instead of a value of 3. As with scent A, assessors viewed olfaction presented after video as being closer to the correct time when compared with olfaction presented before video. Indeed assessors viewed skews of +5s (MOS 3.26) and +10s (MOS 3.3) as being as close to the correct time as the correct presentation time of 0s (2.72). Statistically significant differences were found for all skew levels with the exception of -5s and +5s.

Since assessors appear not to be as accurate in their detection of skew for scent B, analysis comparing the MOS scores between the same skew values of scent A and scent B was performed. As noted previously, the MOS values for 0s, +5s and +10s for scent B show that assessors considered the scent after olfaction to be closer to correctly synchronized. To determine if statistically significant between assessor ability to detect skew for scent A and scent B when presented with the same skews, an independent sample t-test within subjects analysis was performed. At skew values of +10s, there was a statistically significant difference between scent A and scent B results. The ratings for other skews were not found to be statistically significant.

5.1.2 Perception of skew

The task of question 3 and 4 was to determine an assessor's perception of a skew if it existed for the olfactory-video clip. The effect an error has is key to determine temporal boundaries, as works involving other media have shown that users can tolerate certain levels of skew (Steinmetz, 1996) (Ghinea and Ademoye, 2010) (Murray et al., 2013A). Hence, assessors were asked to qualify the level of impairment the inter-media skew had on the experience when comparing it to the synchronized reference sample. Fig. 9 and Fig. 10 show the MOS for level of annoyance for inter-media skew for scent A and B respectively. Based on the comparison of MOS scores with olfaction before and after video, that assessors are clearly **less tolerant** to olfaction **before** of video than they are of olfaction **after** video between skews of -15s to +15s for both scent A and scent B.

For scent A, Fig. 9 shows a sharp increase in annoyance between 0s and -5s with MOS values of 3.73 and 4.59 respectively. Although an increase in annoyance between 0s and +5s (MOS 4.35) exists, the rating for +5s remains in the imperceptible to perceptible to not annoying range. Skews of -5s and +10s are viewed similarly by assessors as are skews of -10s and +15s. For all skews with the exception of +5s, statistically significant differences were reported.

For scent B, the findings are particularly interesting. Assessors reported skews of +5s (MOS 4.35) and +10s (MOS 4.2) as being less annoying than synchronized presentation 0s (MOS 4), albeit all are in the range of perceptible but not annoying to imperceptible. Fig. 10 clearly shows the decrease in annoyance as the time of presenting olfaction before video decreases. Statistically significant differences existed for all skew levels except +5s, +10s and -5s.

To compare ratings between scent A and scent B an independent samples t-test with 95% confidence interval was executed. Interestingly only the synchronized presentation times of 0s reported statistically significant differences. With this said, from Fig. 9 and 10, the trends towards lesser levels of annoyance for olfaction presented after video are clear, particularly with assessor rating of annoyance for scent B. These findings are plausible, because in our everyday lives, we see first, smell after (Murray et al., 2013B). Olfaction presented without a visual cue, acts as a distraction, which in other contexts highlights the potential for use of olfaction in warning systems.

5.2 Impact of synchronization error on assessor QoE for test group 1

This section highlights the impact inter-media skew has on assessor QoE. In this work, the authors define QoE as a function of assessor sense of enjoyment, relevance and reality.

5.2.1 Impact of skew on sense of enjoyment

Fig. 11 shows MOS results reflecting assessor's level of agreement with statement 5 in the presence of varying degrees of inter-media skew. Assessors reported only minor differences in enjoyment relative to their mulsemedia experience across varying skew levels. Consequently, we define three boundaries based on Fig. 11: between skews of -20s and -10s, from -5s and +10s and skews greater than +10s. These ratings consider the assessors' opinion of the entire clip enhanced with two scents. MOS scores for the -20s to the -10s group range from 3.09 to 3.49 reflecting an opinion between *Neither agree nor disagree*

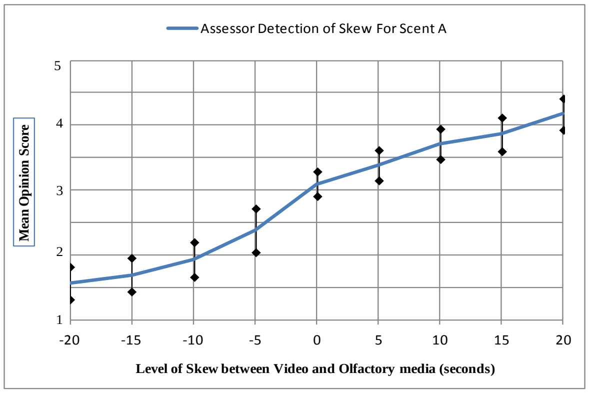

Fig. 7 Analysis of skew detection for scent A with confidence interval based on 95% confidence level.

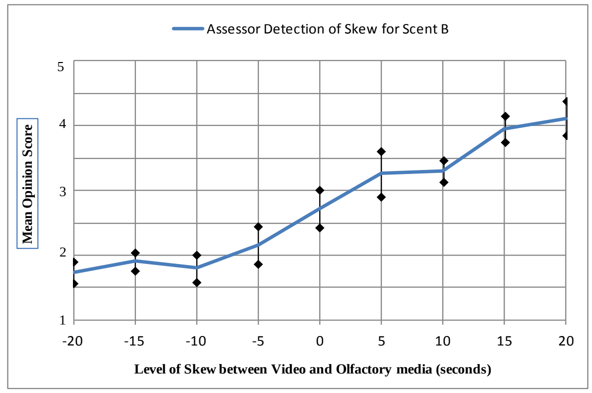

Fig. 8 Analysis of skew detection for scent B with confidence interval based on 95% confidence level

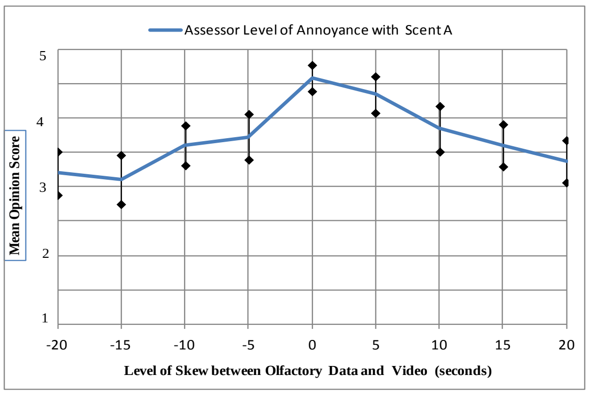

Fig. 9 Analysis of perception of skew for scent A with confidence interval based on 95% confidence level.

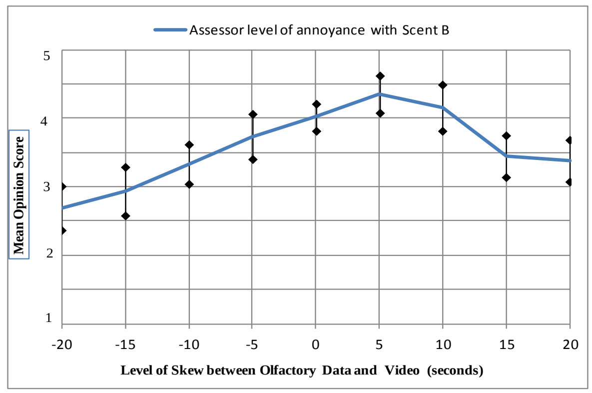

Fig. 10 Analysis of perception of skew for scent B with confidence interval based on 95% confidence level

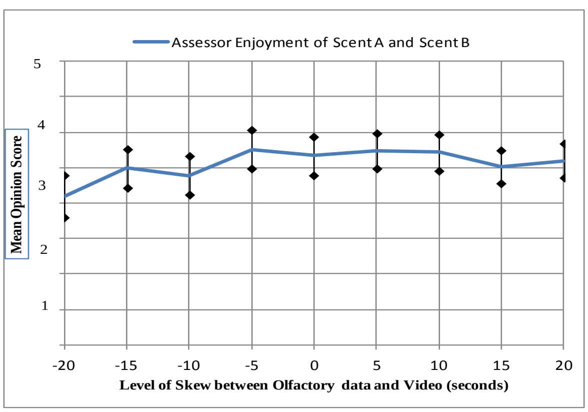

Fig. 11 Analysis of sense of enjoyment per skew with confidence interval based on 95% confidence level

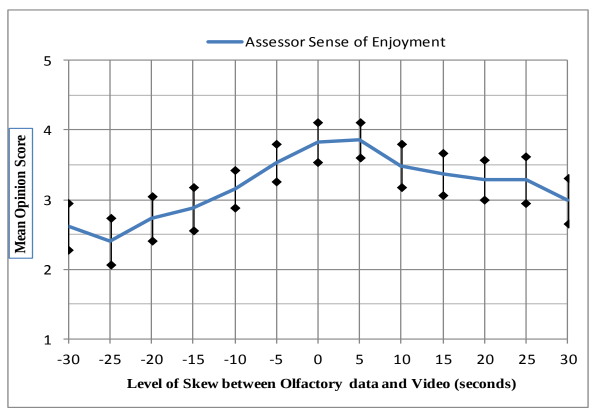

Fig. 12 Analysis of sense of enjoyment per skew with confidence interval based on 99% confidence level (Murray et al, 2013

and *Agree* with the statement that they enjoyed the experience. The boundary between -5s and +10s show MOS scores of 3.72 to 3.76 which are close to the assessor agreeing that they enjoyed the clip enhanced with two scents. Finally the last boundary, skews of greater than 10s reported MOS scores between 3.51 and 3.6. These values are at the midpoint of *Neither agree or disagree* and *Agree* that assessor enjoyed the clip with these skew levels. Using independent samples t-tests only opinions of skew levels of -20s were statistically significant compared with synchronized presentation. These findings are particularly interesting considering the authors previous findings in (Murray et al., 2013B), presented in Fig. 12, where skew had a statistically significant difference on assessor enjoyment beyond skew levels of -5s and +5s when only one olfactory stream was presented. Further discussion on this reduction in enjoyment for two olfactory streams is provided in section 7.

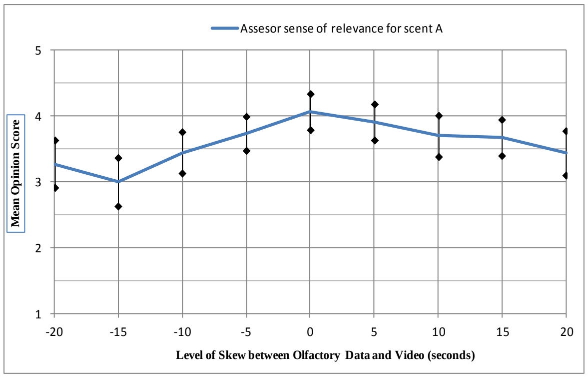

Fig. 13 Analysis of relevance of scent A with confidence interval based on 95% confidence level.

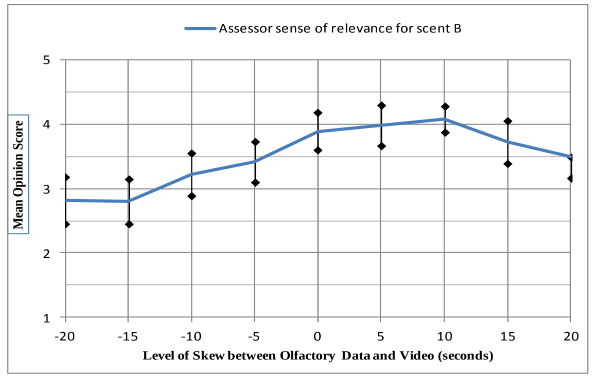

Fig. 14 Analysis of relevance of scent B with confidence interval based on 95% confidence level

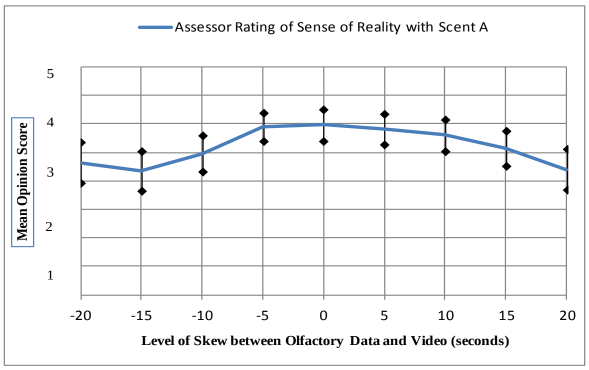

Fig. 15 Analysis of sense of reality for scent A with confidence interval based on 95% confidence level.

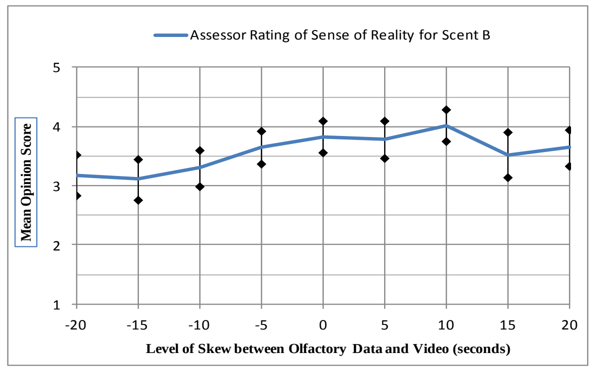

Fig. 16 Analysis of sense of reality for scent B with confidence interval based on 95% confidence level

5.2.2 Impact of skew on sense of relevance

Assessors rated the impact of skew on their perceived sense of relevance for scent A and B by agreeing or disagreeing with statements 6 and 7. Fig. 13 shows the MOS reflecting assessors' level of agreement that scent A was relevant to what they were watching. It is clear that in the presence of large skews, e.g. -20s & -15s the sense of relevance is affected. The MOS values show that generally participants neither agreed nor disagreed. Interestingly, the level of agreement deteriorated much more quickly as the levels of skew increased with olfaction before video as opposed olfaction after video. Olfaction after video is more relevant than olfaction before video, with a skew of +15s (15s after video) viewed as being very similar to olfaction presented with a skew of -5s. An independent samples t-test with a 95% confidence interval was used to determine if statistically significant differences existed in responses between synchronized and unsynchronized presentations of scent and video for scent A. For skew size of -5s, +5s and +10s the results were not significantly different with the significant. For all other skews the difference from the synchronized presentation rating was statistically significant. For scent B, the view that olfaction presented after video is more relevant than olfaction presented before video is further exaggerated. Indeed assessors reported that scent presented with skews of +5s and +10s was actually more relevant than any other time including synchronized presentation with MOS scores of 3.98 (+5s) and 4.07 (+10s) compared to 3.89 for synchronized presentation. +20s skew is viewed similarly in terms of relevance as -5s. Statistically significant differences exist for skews of -20, -15s and -10s. Analysis considering difference between the same skew levels between scent A and scent B, an independent samples t-test based on 95% confidence level was executed. A statistically significant difference exists between relevance of scent A and scent B at skew levels of +10s.

5.2.3 Impact of skew on sense of reality

Fig. 15 and Fig. 16 show MOS scores reflecting assessors' sense of reality for scent A and scent B. For scent A, when synchronized presentation took place, assessors agreed that the smell heightened the sense of reality of what they were watching. In the presence of large skews (e.g. -20 s or +20 s), the MOS values show that generally participants were between *Neither agree or disagree* and *Disagree* with statement 8 in the presence of skew. For olfaction before video, with skews of -5s, assessors perceived the olfaction contributing to an enhanced sense of reality with a MOS of 3.95, very close to the score reflecting agreement i.e. 4. Similarly with no skew, 0s, and +5s skew assessors *Agree* that the scent contributed to a heightened sense of reality with MOS scores of 3.98 and 3.91. The most interesting finding from analysis of the MOS from this question was the **slow reduction** in heightened sense of reality for olfaction **after** scent with skews of +5s, +10s and +15s where as there is a sharp decrease between skews of -5s and -10s.

For scent A, assessors' opinions were compared to determine if statistically significant differences existed in responses when a synchronization error was present with the case when olfaction and video were perfectly synched via a paired sample t-test. For skew size of +5s, +10s, +15s, +20s, -5s the results were not statistically significant. For all other skews the significant two tailed values were less than 0.05 ($p<0.01$), hence the results for skewed presentation were statistically significant when compared with ratings for in-sync presentation. Fig. 16 shows MOS scores reflecting assessor opinions on sense of reality for scent B. Furthermore for scent B, the trend that olfaction after video contributes to a greater sense of reality for olfaction presented after video is repeated. Indeed assessors reported scent B presented with skew of +10s as providing the greatest sense of reality. Analysis of Fig. 16 shows assessors rate skews of +15s and -5s to -10s similarly. Independent samples t-tests were run examining all skew levels for scent B based on 95% confidence level. Statistically significant difference exist for skew levels of -20s, -15s and -10s. All other skews which include -5s and all skews tested for olfaction after video were found to not be statistically significant. A within groups analysis between assessors ratings for scent A and scent B was performed using independent samples t-test with no statistically significant differences found between assessors ratings for skews for scent A and the same skew for scent B

6. RESULTS AND DISCUSSION ON DETECTION, PERCEPTION AND QOE FOR TEST GROUP 2 (NETWORK JITTER SCENARIOS)

This section reports the results for test group 2 (Table 3 in section 4.2). Packet jitter across constrained networks is a common challenge for other media and this section examines this problem for olfaction enhanced multimedia. The phenomenon of network jitter can result in: (A) a gap in the playout between the scent media streams or (B) overlap or mixing between the scent streams. The typical solution to scenario B above is to drop packets but a study on the users experience of "mixing of scents" remains an open topic for evaluation. Presented below are the results of assessors' ability to detect skew, their perception of skew and impact of same on QoE in the presence of varying latencies between the olfactory media streams. In addition, analysis is performed comparing results of this set of tests with group 1 in order to understand any difference between delay and jitter on the users QoE. To the best of the authors' knowledge, no works have studied such scenarios with respect to olfaction enhanced multimedia.

Group 2 assessors answered the same questionnaire as group 1 i.e. their detection of scent A and scent B, their perception of scent A and scent B, their experience of scent A and scent B in terms of sense of enjoyment, relevance and reality (questions/statements 1-9). In addition, group B assessors were queried on their detection and perception (in terms of annoyance) of "overlapping" of scents (question 10), and the impact on QoE of this overlapping in terms sense of enjoyment (question 11), sense of relevance for scent A and B overlapping (question 12) and sense of reality of scent A and scent B overlapping (question 13). Fig. 17 gives a flavor of the cross section of tests executed, showing a balance where the effect of jitter widened the gap between the scents and where it narrowed the gap such that it resulted in various levels of overlap. It specifies the level gap (positive number) and overlap (negative numbers) within the various test cases executed. As shown, 6 test cases were executed where the gap of 6s between scent A and scent B was increased. These were 46s, 36s, 21s, 16s and 11s. The 6s gap between scent A and scent B reflects synchronized presentation between scent A and scent B. One test case was executed where this 6s was reduced but didn't result in a mixing between scents, with just 1s between the end of presentation of scent A and the start of presentation of scent B. The remaining tests cases involved mixing of scent A and B with overlaps of 4s, 9s, 14s and 24s.

6.1 Detection and perception of synchronization error for test group 2

6.1.1 Detection of skew

Fig. 18 and Fig. 19 present the general results of statements 1 and 2, to determine users' ability to detect levels of inter-media skew between the video and the scents presented. They show assessors were able to identify the existence of inter-stream skew very well. Both figures also indicate that assessors were more sensitive to scent that was presented early rather than late in comparison with the video. Interestingly from Fig. 18, assessors rated skews of +5s approximately the same as they rated skews of +10s. Based on MOS comparison, ratings of skews at +10s and -10s support the view that assessors are more sensitive to olfaction presented before the video than after it. To determine if statistically significant results exists between the assessors rating of skews for scent A, an independent samples t-test was executed and reported that statistically significant difference exist between all skew levels and the mean when synchronized presentation based on 95% confidence level.

Fig. 19 reports assessor ratings of the various skews for scent B. Considering the results, we can see that although generally assessors could detect the presence of skew. However their ability to detect the presence of skew was affected by the jitter between scent A and scent B (i.e. the skew level of scent A affected assessor detection of skew level for scent B). Interestingly, little difference exists between user detection at skews of 0s, -5s and -10s all of which were rated as being between early and at the correct time (MOS values of 2.41, 2.27 and 2.21 respectively). For olfaction presented after video, assessors rated skews of +5s and +10s as being close to the correct time. Statistically significant differences between skewed values and the synchronized presentation were found at skew levels of -15s, +5s, +10s, +15s and 20s with 95% confidence level following the t-tests. To analyse the difference between the MOS values reported for detection of skews for scent A and scent B at the same skew levels, an independent samples t-test was performed. The purpose of this analysis is to determine if there are significant differences between how assessors viewed the same skew levels when impacted by jitter. Based on 95% confidence interval, statistically significant differences at skews of -15s, 0s and +5s were found.

Fig. 20 reports the assessor detection of scent B categorized by the scent A skew. The x axis shows the skew associated with scent A. Within each category, the assessor rating for scent A and the assessor rating for each of the scent B skews are presented. Scent A with skew of -20s was tested with a set of scent B skews which included {-10s,0s,+10s,+20s}. Comparing the group 2 MOS ratings of 2.29 (for -10s), 2.29 for (0s) with equivalent values for test group 1: MOS of 1.8 (for -10s), 2.72 (for 0s), assessors were less well able to distinguish between skews to scent presented before the video. For the second group, with scent A having a -15s skew, again we see that a 0s presentation of scent B is again rated as being early with a MOS value of 2.29 as opposed to a MOS of 2.72 for group 1. For the remainder of the scent B skews, assessors were accurately able to identify skew.

With scent A having a skew of -10s, again the outstanding rating from assessors was at 0s skew for scent B. In this case the assessors rated 0s for scent B with a MOS of 1.5. Considering the results so far and with scent A skew levels of -5s, 0s and +5s assessors continuously rated the scent as being early. Interestingly, with skew values for scent A presented at +10s, 15s and +20s assessors rated 0s for scent B 3.3, 2.7 and 3.25 respectively. Although not as exaggerated, a somewhat similar pattern exists for skews of -20s, -10s and +10s i.e. the first skew presented has a influence on the scent skew presented when a variance in skew levels exist. An independent samples t-test was executed between ratings for skews of scent A and B to determine if any statistically significant difference between the results exists. These were found at skew levels of -15s, 0s and +5s with a confidence level of 95%.

6.1.2 Perception of skew

In terms of group 2, Fig. 21 and Fig. 22 reflect assessors' perception of skew for both scent A and B. As was the case for group 1, assessors are more sensitive to and more easily annoyed by scent presented before the video than scent presented after the video. Fig. 21 presents assessors perception of skews with scent A. It shows assessors found synchronized presentation as being the least annoying with MOS of 4.28. Assessors rated skews of -5s similarly to +5s and +10s with MOS scores of 3.92, 3.85 and 4 all close to or at a rating of perceptible but not annoying. They also rated skews of -10s similar to +15s with MOS values of 3.52 and 3.41. Via independent samples t-test, skews of -20s, -15s, +15s and +20s resulted in statistically significant differences with confidence level of 95%. For skews of -10s the results were just on

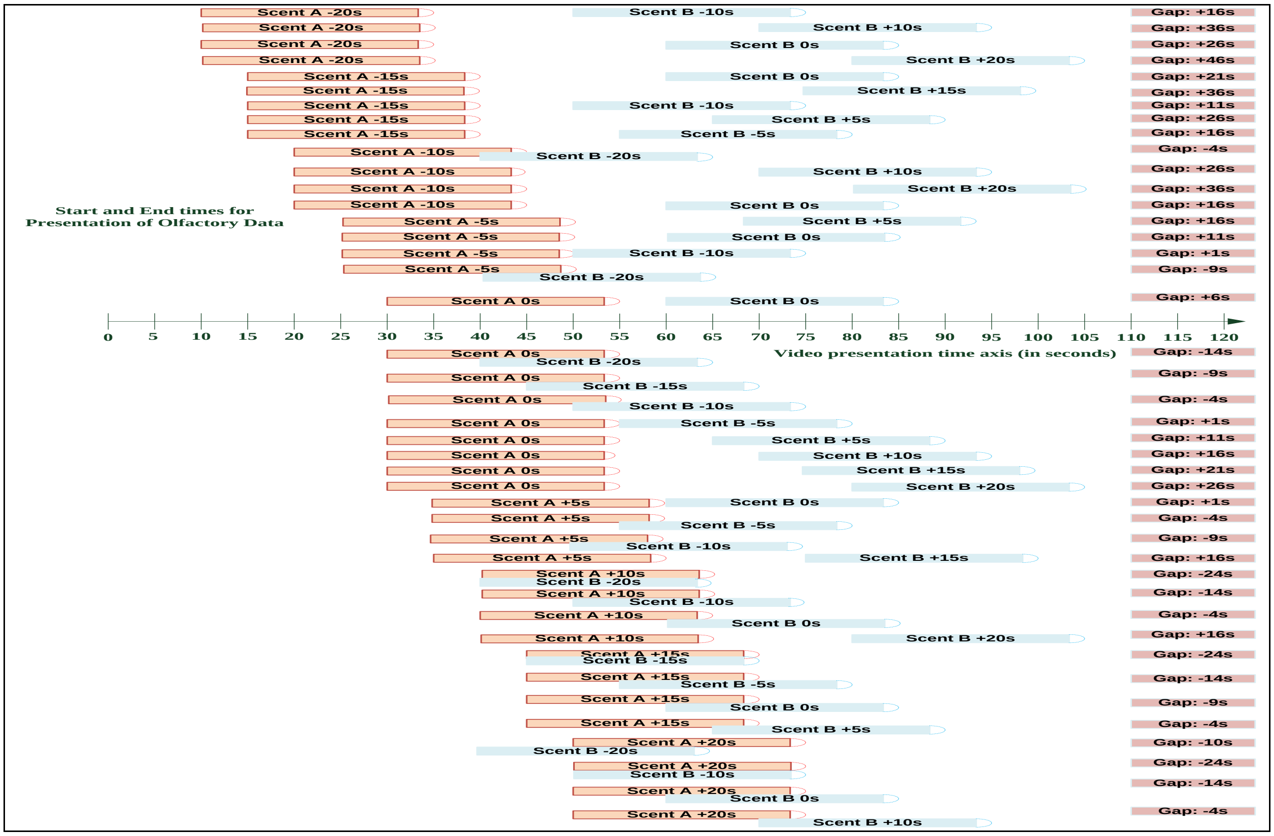

Fig. 17 Group 2 test scenarios showing balance between various jitter scenarios with associated gap between scents

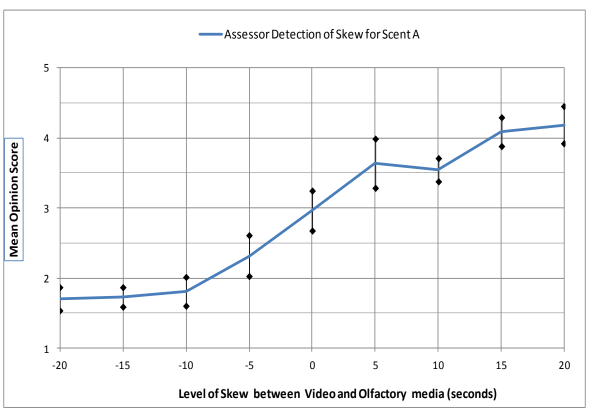

Fig. 18 Analysis of detection of skew for scent A with confidence interval based on 95% confidence level.

Fig. 19 Analysis of detection of skew for scent B with confidence interval based on 95% confidence level

the border of being statistically significant whereas for +10s it cannot be said that there is any statistical difference in the results with any significant confidence. For scent B, assessors reported a skew of +5s to be the least annoying with MOS of 4.24. As per Fig. 22, the assessors rated skews of -5s and +20s similarly, again validating the belief that the users are more tolerant of olfaction presented after the video than before it. Skews of -20s and -10s were found to be statistically significant with confidence level of 95%. As was the case for detection, the perception of scent B with skew of -15s appears at odds but as outlined above, given the assessors perception of this skew, the rating is understandable. An independent samples t-test was run between the MOS of the ratings for scent A and scent B. Statistically significant differences were found at -5s and 0s with confidence level of 95%. Fig. 23 provides assessor perception of scent A and scent B grouped based on the scent A skew values. As for detection, the skew level for scent A appears to have an impact on assessor perception of scent B skew. At large skews e.g. -20s,

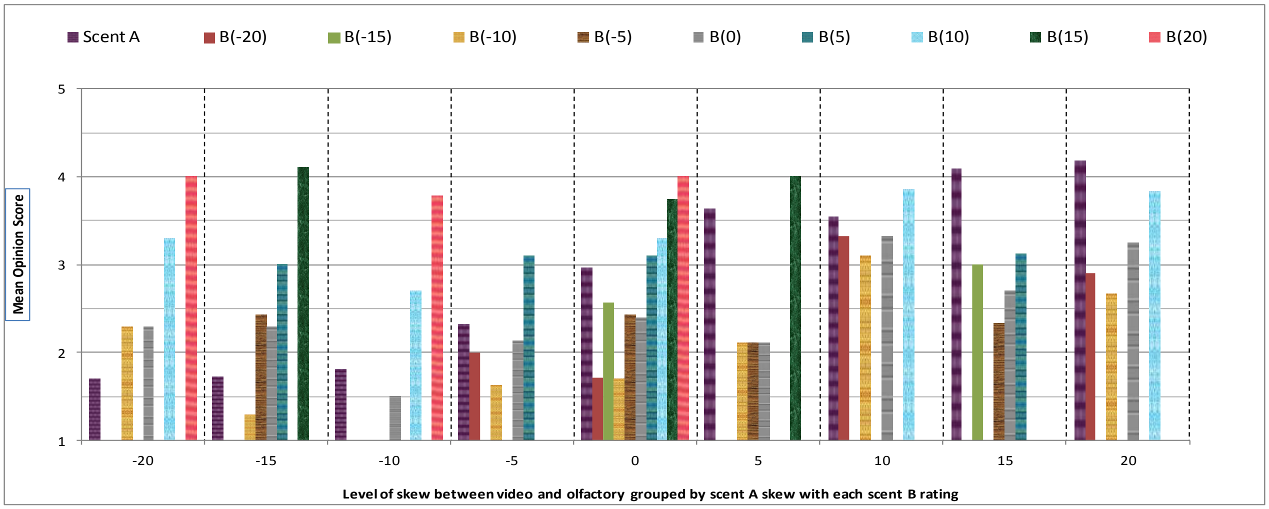

Fig. 20 Analysis of skew detection for scent A and B, grouped based on scent A skews.

+20s the perception of 0s skew for scent B has higher annoyance ratings. Another pattern that emerges is that where there is a large gap between the two scents and at least one of the scents is close to being synchronized, a high rating in terms of perception is reported. To understand the impact of jitter on assessor experience; we compare assessor perception of the same skew levels between test group 1 and group 2 via an independent samples t-test. Statistically significant differences between the groups existed at skew levels of +5s with confidence level of 95% for scent A. Performing the same analysis for scent B, there was no statistical significance between assessor perceptions at 95% confidence level.

For more specific analysis on the assessor perception of mixing of scents in terms of assessor annoyance, we perform grouping between the various test scenarios that have common mixing times e.g. test cases which resulted in overlaps of 4s, 9s, 14 and 24s. For the test cases where there were 4s and 9s overlaps, approximately 40% of the test case assessors actually detected the mix. For 14s and 24s overlap, the detection was approximately 60% and 70% respectively. Interestingly when the two scents were presented both at the same time (i.e. 24s overlap), assessors only reported detecting one scent in 3 of the 24 test scenarios executed all when the scents of fruit and flower were mixed. Assessors found 4s overlap the least annoying with a MOS of 3.52, on the mid-point between perceptible but not annoying and slightly annoying. They found overlaps of 9s and 24s respectively to be between slightly annoying and annoying respectively (MOS 3.05 and 3.32). 14s overlap was rated as between slightly annoying and the rating for 4s overlap with a MOS of 3.32. The results indicate that assessors found the experience of overlapping of scents as being somewhat annoying.

6.2 Impact of skew on assessor QoE for test group 2.

This section highlights the impact of inter media skew on assessor QoE considering skew and jitter. As mentioned previously, QoE is analysed as a function of assessors sense of enjoyment, relevance and reality of the olfaction enhanced multimedia experience.

6.2.1 Impact of skew on sense of enjoyment

Fig. 24 reports the overall experience of the assessor sense of enjoyment of the audiovisual clip enhanced with the two scents at each skew level. Interestingly assessors reported little difference across the entire range of skews from -20s to +20s. This being said, the ratings at each of the skew levels are the average given a number of different combinations of jitter combinations as per Table 3 and Fig. 18. In light of this, we perform grouping of this data for the enjoyment of the mulsemedia experience in the presence of jitter. Fig. 25 reports the assessor sense of enjoyment based on the gap between or the level of mixing between scent A and B. No overlap of the scents (i.e. a gap between the presentation of scent A and B), is reflected by the positive values in the horizontal axis in Fig. 25 whereas the negative values on the horizontal axis reflect an actual mixing of scent A and B and the time the two scents are mixing for. Clearly the highest level of enjoyment is when there are 21 seconds between the end of the presentation of scent A and the start of the presentation of scent B. As per Table 6 and Fig. 17, this occurs during “case 1 clip 2” (-15s/0s) and “case 4 clip 2” (0s/+15s). Fig. 26 presents the assessor rating of enjoyment grouped by scent A skew

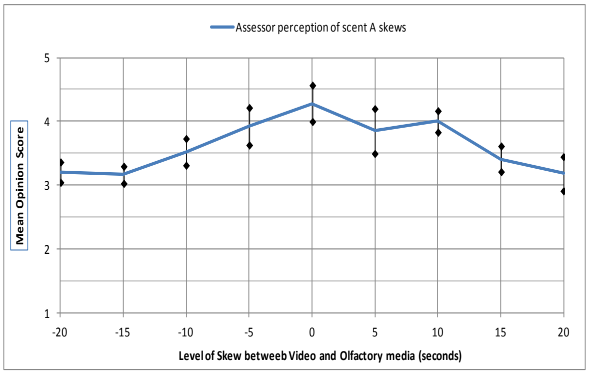

Fig. 21 Analysis of perception of skew for scent A with confidence interval based on 95% confidence level

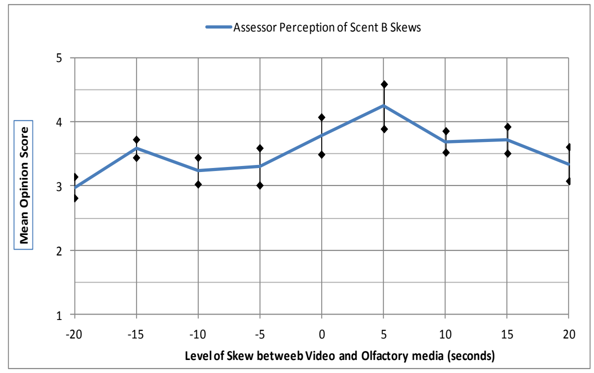

Fig. 22 Analysis of perception of skew for scent B with confidence interval based on 95% confidence level

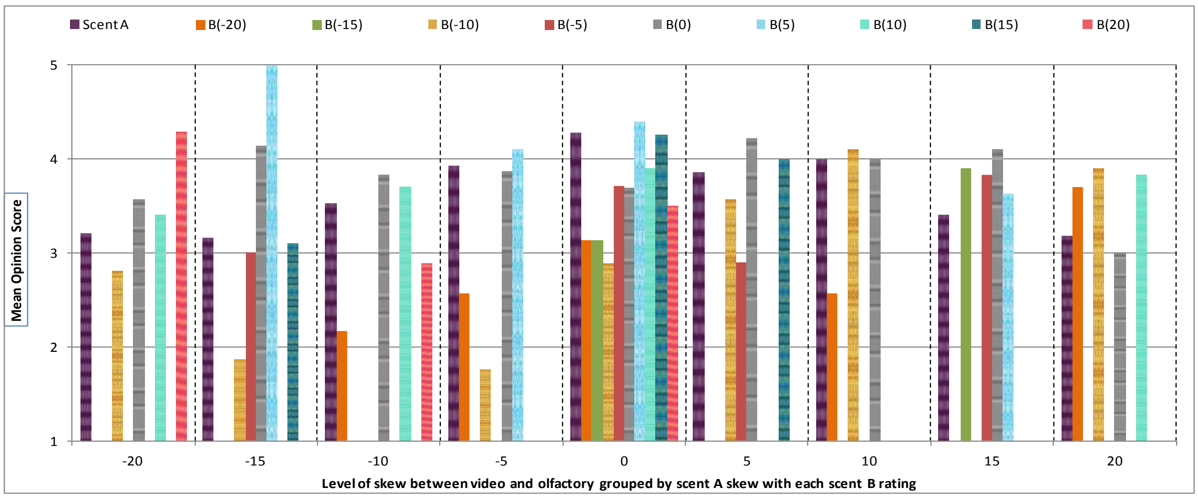

Fig. 23 Analysis of skew perception for scent A and B grouped via scent A skews

level. Enjoyment levels are reported as being highest when one of the scents is presented in sync and there is a large gap between the presentations of the two scents. In addition, assessors found skews where olfaction is presented after video is equally or more enjoyable than olfaction before video consistently across a number of skew values. Interestingly at scent A skew levels of -20s, -15s and -10s the enjoyment of the synchronized scent B (0s), are noticeably high, as is the +15s scent B rating when scent A is 0s. In both these cases, one of the scents is presented correctly and there is approximately 20s gap between the end and beginning of the presentations of scent A and scent B. As was the case with perception of overlapping, assessors rated the greatest enjoyment with the smallest overlapping of scent A and B and did not find the mixing of scents enjoyable via their rating of neither agree or disagree.

6.2.2 Impact of skew on sense of relevance

Fig. 27 presents the assessor rating of relevance for scent A across the various skew levels. The slow reduction in relevance for olfaction presented after video is consistent with findings in our previous work (Murray et al., 2013B) and with the findings from group 1 relevance for scent A. Statistically differences from the MOS of synchronized presentations were found at skew of -15s with 95% confidence. For scent B (Fig. 28), the trend of higher relevance remains with the exception of the -15s skew, but the assumption exists that this is based on assessors view of the presentation time of scents at this level as discussed earlier. As per scent A, the highest relevance levels exist from 0s to +15s when olfaction is presented after video. Statistically significant differences from the mean rating were found at skews of -20s, -15s, -10s and +20s based on 95% confidence level. No statistically significant differences were found between ratings of scent A and scent B. Fig. 29 shows the assessor ratings based on grouping via the scent A skews. Assessors reported the highest relevance values for synchronized presentation of scent B when scent A was presented early. Assessors reported that mixing of scents was not relevant to the video.

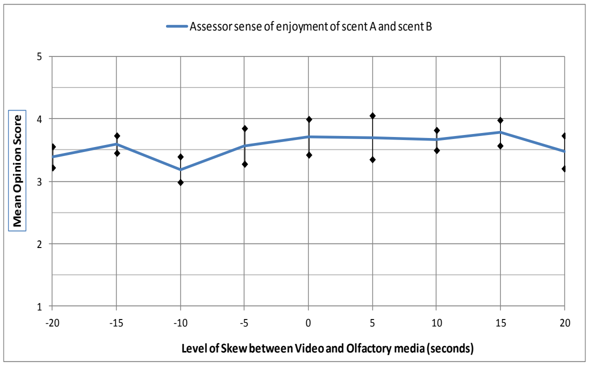

Fig. 24 Analysis of enjoyment of skew for scent A and B with confidence interval based on 95% confidence level

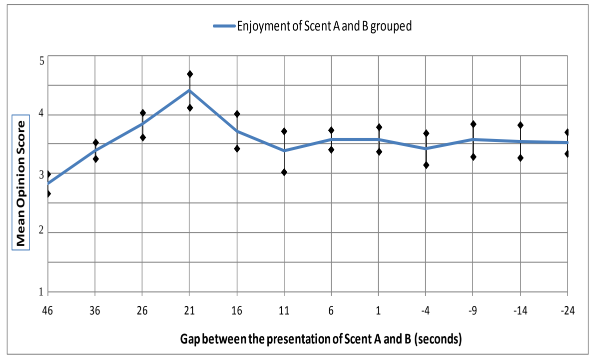

Fig. 25 Analysis of enjoyment of skew for scent A and B grouped on the gap or mixing between the scents with confidence interval based on 95% confidence level

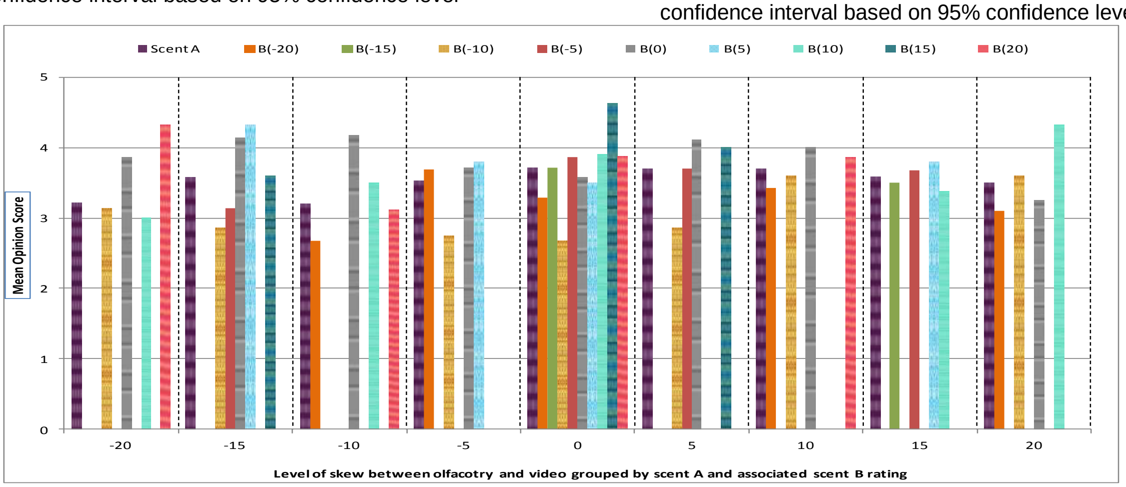

Fig. 26 Analysis of enjoyment of skew for scent A and B, grouped via scent A skews

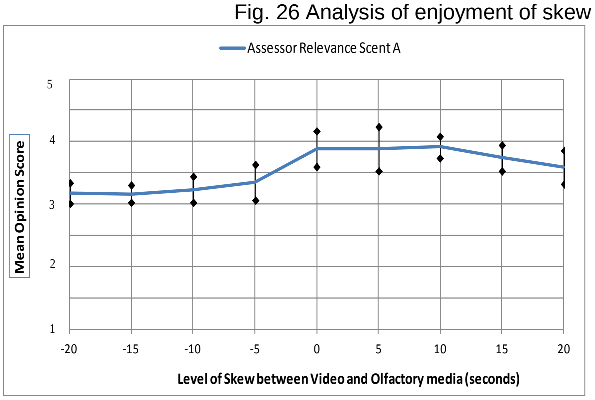

Fig. 27 Analysis of relevance of skew for scent A with confidence interval based on 95% confidence level

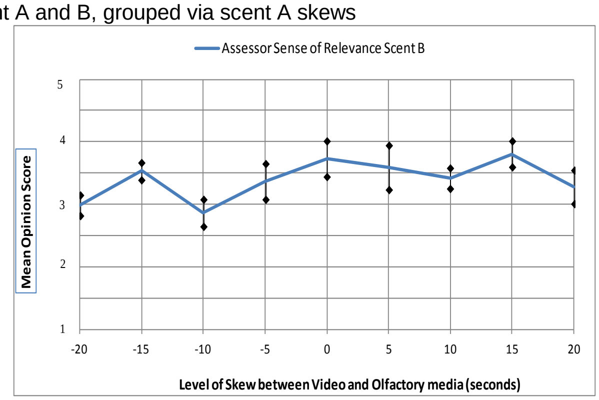

Fig. 28 Analysis of relevance of skew for scent B with confidence interval based on 95% confidence level

6.2.3 Impact on sense of reality

Fig. 30 and Fig. 31 presents the assessor rating for sense of reality for scent A and scent B for the group 2 tests. Both figures show slightly higher ratings for sense of reality for olfaction presented after video as opposed to before video, with the difference exaggerated more for scent A. Considering Fig. 30, the assessors rated skews of +5s, +10s and +15s higher than -5s. Statistically significant differences are found at skews of -20s with 95% confidence level. For scent B (Fig. 31), the ratings for assessor reality similar trends can be found in comparison with those for scent A (i.e. greater sense of reality for olfaction after video). Statistically significant differences exist between the various skews for scent B at skews of -20s, -10s, -5s, +10s and +20s with 95% confidence level. At the same confidence level, statistically significant differences exist between the same skews with scent A and B for skews of -10s and +10s. For all other skew values, the differences were not statistically significant. Analysis was also performed on the sense of

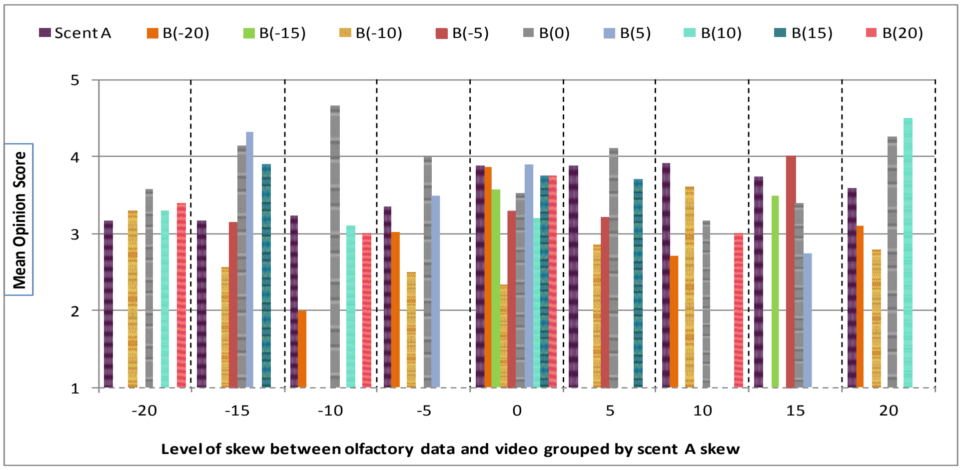

Fig 29 Analysis of relevance of skew for scent A and B, grouped via scent A skews

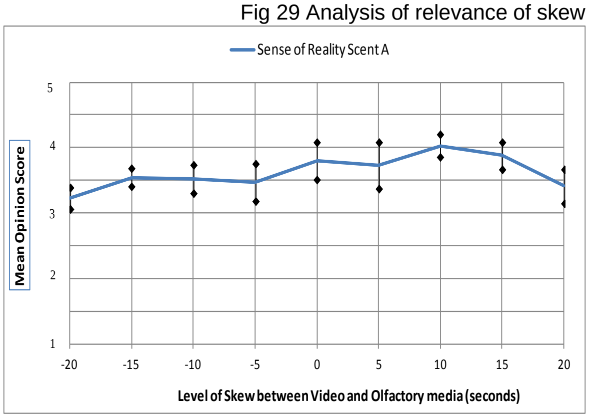

Fig. 30 Analysis of reality of skew for scent A with confidence interval based on 95% confidence level

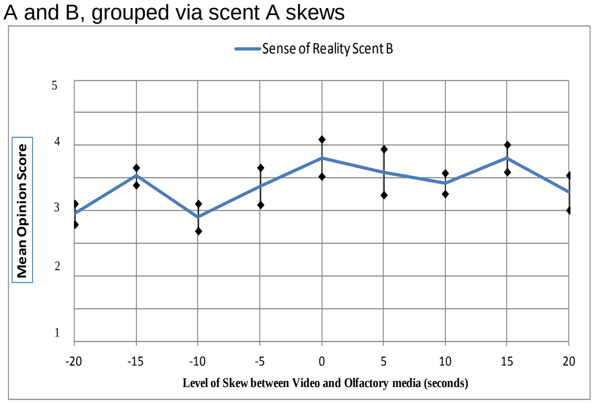

Fig. 31 Analysis of enjoyment of skew for scent B with confidence interval based on 95% confidence level

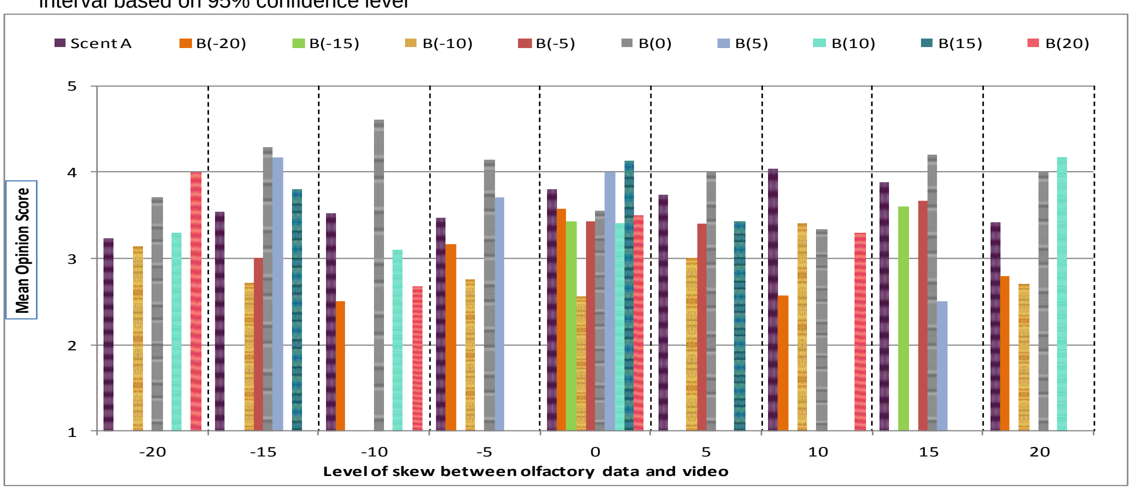

Fig. 32 Analysis of reality of skew for scent A and B grouped via scent A skews

reality achieved via the mixing or overlapping of scents. From Fig. 32, as was the case for enjoyment and relevance, the 0s presentation of scent B when accompanied by an early scent A contributed to highest sense of reality for scent B. The mixing of scents did not increase the sense of reality.

7. CONCLUSION AND FUTURE WORK

This work investigated the perception of inter-stream synchronization error between olfactory and video media and the affect on QoE for the user considering two olfactory streams with the same skew levels, variable skew levels and actual mixing of scents. Not considering age, gender or culture (which were addressed in (Murray et al., 2013B)), the following general temporal boundaries are proposed for olfaction enhanced multimedia synchronization based on results and statistical analysis:

- -5s to +10s as being the "in-sync" region for olfaction enhanced multimedia
- Skew values beyond this boundary are "out-of–sync".

Outside of the "in-sync" range, assessors reported skews as being annoying to varying degrees, and also that the skews has a negative impact on assessor QoE.

Considering assessor QoE, and in particular enjoyment but also for relevance and sense of reality, we deduce that a gap of 20s or greater is required between the consecutive presentation of two scents. Although contradictory to the suggested greater than 5s gap between consecutive scents (Nakamoto et al., 2006), this is consistent with the findings of (Washburn, 2003), whereby it was reported that scents should not be emitted close together, with a recommended separation of scent presentation of between 20-60 seconds in virtual environment training. This conclusion is derived from Fig. 25, 26 for enjoyment, and in addition in Fig. 27 for relevance and Fig. 32 for sense of reality.

As reported above, both delay and jitter between olfactory streams does have an impact on assessor detection, the perception and QoE of olfaction-enhanced multimedia. The assessor detection and perception of scent B skew was affected in both cases, but more pronounced in jitter tests (e.g. assessors reported +5s skew better than 0s). We also deduce form this work, that assessors do not report overlapping or mixing of scents adding to the enjoyment, relevance or sense of reality for olfaction-enhanced multimedia experiences. For all ratings in terms of enjoyment, relevance or reality, assessors reported neither agreeing or disagreeing when asked to agree that the mixing of scents contributed to a heightened sense of reality, was relevant or that they enjoyed the mixing of scents. A number of findings from our previous work are supported here in terms of temporal synchronization boundary size for each scent being consistent with what was reported in (Murray et al., 2013B) i.e. that when scents are presented with -5s when olfaction is presented before video and +10s when olfaction is presented after video, assessors' according to the perception of skew do not find these skew ranges annoying. When two scents are presented, assessors in these tests rate olfaction presented **after** video as more preferable than was the case when one olfactory stream was presented.

Our work on olfaction enhanced multimedia QoE thus far has shown that QoE is impacted by skew, jitter, number of scents, assessor profile and other media combined with olfaction. Future work will involve analysis based on scent type (pleasant or unpleasant) and also increasing the number of scent streams beyond two. A utility model that reflects users' perception of olfaction enhanced multimedia synchronization is another avenue of research to be undertaken.

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