The Influence of Human Factors on 360° Mulsemedia QoE

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Abstract

Quality of Experience (QoE) is indelibly linked to the *human* side of the multimedia experience. Surprisingly, however, there is a paucity of research which explores the impact that *human factors* has in determining QoE. Whilst this is true of multimedia, it is even more starkly so as far as mulsemedia - applications that involve media engaging three or more of human senses - is concerned. Hence, in the study reported in this paper, we focus on an exciting subset of mulsemedia applications - 360° mulsemedia - particularly important given that the upcoming 5G technology is foreseen to be a key enabler for the proliferation of immersive Virtual Reality (VR) applications. Accordingly, we study the impact that human factors such as gender, age, prior computing experience, and smell sensitivity have on 360° mulsemedia QoE. Results showed insight into the potential of 360° mulsemedia to in-

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spire and to enrich experiences for Generation Z - a generation empowered by rapidly advancing technology. Patterns of prior media usage and smell sensitivity play also an important role in influencing the QoE evaluation - users who have a preference for dynamic videos enjoy and find realistic the 360° mulsemedia experiences.

Keywords: 360° Mulsemedia, QoE, virtual reality, human factors, age, gender, prior experience, smell sensitivity

1. Introduction

The user experience of multimedia applications is indelibly linked to the notion of Quality of Experience (QoE). In a digital world, characterised by a plethora of devices, heterogeneous infrastructure and ever-increasing and diverse content, satisfying QoE expectations remains at the forefront of multimedia research.

According to Brunnström et al. [1], QoE relates to the utility and the degree of satisfaction with a service or an application from the outlook of users, taking into account the context of usage and the user characteristics (psychological and social factors). Whilst the term QoE has, in terms of nomenclature, similarities to QoS - Quality of Service - in practice the two have different targets. QoS focuses on technical factors, namely the performance of telecommunication services that could eventually affect the overall QoS. For one, they apply to different layers of the ISO/OSI protocol stack (and testimony to the efforts to bridge the QoE-QoS gap are the many research endeavours in cross-layer design [2, 3, 4, 5, 6, 7, 8]); given that measuring QoE is quite complex, due to the subjective nature of the human multimedia experience, objectively measuring QoS parameters is a relatively straight forward task in comparison. One aspect, however, in which both QoE and QoS are similar is that they both tend to report average values. Although average bit rates, error rates, throughput, and delay are the norm in QoS reporting, doing the same for QoE masks one crucially important aspect - that even though, for convenience of reporting (and analogously to QoS), average QoE values are reported, the user experience is individual/specific to each user [9] . Much as the average family of 2.4 children, which never exists in practice but is a convenient reporting mechanism, so is the case for average QoE.

We, therefore, contend that in order to have a realistic - and complete

- view of QoE, we need to look at individual experiences and what makes a user's experience of multimedia unique. Primordial in this respect are human factors - age, gender, personality, culture, learning and cognitive styles [10, 11, 12, 13, 14, 15, 16, 17, 18] have all been shown to have a bearing of how we interact with and assimilate information, as well as on the multimedia experience itself. However, whilst QoE is, by now, a staple of multimedia and HCI (Human-Computer Interaction) research, the influence of human factors on QoE is remarkably under-researched. This is starkly more poignant given the fact that, in a seminal paper providing a comprehensive view of QoE [1], it is acknowledged that human factors are an essential part of QoE and represent "any variant or invariant property or characteristic of a human user. The characteristic can describe the demographic and socio-economic background, the physical and mental constitution, or the user's emotional state."

Therefore, any total [19] or comprehensive [20] model of QoE has to include, by necessity, human factors. Indeed, if this is quasi-true about HCI and multimedia, it is even more starkly - and poignantly so - true when it comes to mulsemedia (multiple sensorial media [21, 22]) and HCI. Accordingly, in the context of mulsemedia, studies show that engaging more senses like the senses of smell, taste, and touch (i.e., olfactory [23, 24, 25], gustatory [26], and haptic stimulation [27, 28] respectively) produced in various modalities can improve the overall QoE of viewing audio-visual (AV) content. For example, the QoE impact of adding haptic effects through a cross-modal mapping of AV features into audio (and auto-generated vibrating haptic effects) is described in [29]. In this study, objective user experience data was captured using eye-gaze and heart-rate monitoring devices. Additionally, studies in [30, 31] reported an enhancement on users' experience in terms of achieving a sense of immersion while viewing AV content combined with olfactory cues. However, with the notable exception of Murray's work [32, 33], the influence of human factors in mulsemedia QoE has been by and large ignored.

Similarly, the viewing of 360° videos on virtual reality (VR) headsets can provide novel immersive user experiences and, by extension, enhanced levels of QoE [34, 35, 36]. Moreover, whilst the impact of incorporating mulsemedia and 360° video VR (namely, 360° mulsemedia) has been shown to significantly enhance QoE [37] and lead to substantial bandwidth savings without the need for reducing QoE [38], to the best of our knowledge, the impact of human factors on 360° mulsemedia remains completely unexplored. Therefore, the study reported in this paper concentrates on exploring how human factors such as age, gender, prior computer experience, and smell sensitivity impact QoE in a 360° mulsemedia context.

The paper is organized as follows. Related work is presented in Section 2, while research methodology and results are detailed in Sections 3, and 4, respectively. Finally, Section 5 provides conclusions and identifies future endeavours.

2. Human Factors in Multimedia and Mulsemedia

Human factors is the scientific discipline concerned with the application of known human behavior, abilities, limitations and other characteristics to the design of tasks, equipment/technology or the environment [39, 40]. Human factors has a rich grounding within the context of User-Centred Design with notable application in areas such as aviation [41], ergonomics [42], and design for the elderly [43], to name but a few.

In essence, it attempts to understand the human factors affecting a user's performance and behaviour (in a digital system's usage experience) and thereby build the user's profile. The user profile is, therefore, used as input to optimize the system through personalization. The process of personalizing the digital system involves activities such as extracting and modeling (semantic and structural) information about the system, retrieving the system's content according to the user profile, and adapting it to a user's context or preferences.

The significance of human factors has evolved with the proliferation of multi-user information systems as well as the diversity of services they provide. Today, the pursuit of adapting and personalizing web-based systems is a common phenomenon in areas such as e-commerce and e-learning [44, 45, 46, 47], to name but the most popular.

As far as multimedia systems are concerned, QoE - in common with the user experience associated with any digital system - is shaped by the interplay between system factors, context and human factors [10]. Indeed, the importance that human factors play in multimedia QoE has been underlined in [11, 15]. Generally, when performing subjective QoE tests, the impact of human factors such as age, gender, cognitive style, vision and expertise levels have been explored [16]. Additionally, personality [12] and cultural traits such as in [14, 15] can also be incorporated as human factors in the study of multimedia QoE. In respect of mulsemedia, to the best of our knowledge, there are but two studies which investigated the relationship between human factors and mulsemedia QoE [32, 33]. Here, the authors reported that age and gender influence the perception of olfaction based mulsemedia, thus indicating that these human factors have a significant influence on the user's QoE in mulsemedia.

Human Factors and QoE in VR. VR has been touted for the past years as a technology with a transformative effect on our lives and work. Devices are getting more powerful and applications more sophisticated. One exciting form of VR content which has recently come of age with the promise of 5G technology is 360° videos [48]. These display the full surroundings of a camera on a spherical canvas; however, because they need data to cover all spatial directions, 360° videos pose a challenge for the network to stream. This leads to solutions based on viewport-adaptive streaming [49]. Nevertheless, as pointed in [50], these approaches open questions related to user navigation patterns: what do people focus on in 360° videos?; how does the type of video influence a user's behaviour?; is there a correlation between this behaviour and the user's characteristics?

Indeed, for VR to be effective and successful, several human factor issues need to be addressed. Previous research focused on certain aspects that characterise the experience of a VR environment such as cybersickness and presence. Studies showed that cybersickness in computer-generated VR environments is affected by various human factors (e.g., age, gender, previous exposure to VR, alcohol consumption) [51, 52]. In [53], the authors showed there is a correlation between gender and metrics of presence, experienced realism, nausea, and disorientation, that led to female participants obtaining higher scores. Melo et. al [54] investigated whether exposure time, content type and gender influenced the experience of the participants in both captured and synthesized VR setups. Their results showed: no impact between the time of exposure and the VR experience; the 360° captured video content setup led to a greater sense of presence compared to the synthesized content; female participants reported higher experienced realism in the synthesized environment.

The QoE paradigm, intensively applied in the assessment of multimedia and mulsemedia systems, has also started to be employed in the modeling and evaluation of immersive experiences. Accordingly, in [55], the authors propose a framework for measuring the quality of immersive experience in storytelling, centred around human, system and design factors. The sense of presence is explored as an important factor influencing QoE in [56], where the authors predict it based on subjective evaluation scores together with physiological signals of users (EEG, ECG, and respiration). This type of objective QoE evaluation in immersive VR environments is also performed in [57]. Wu et al. [58] evaluate and provide guidance on which technical Quality of Service (QoS) metrics (e.g., delay, visual quality) may impact the QoE in 3D tele-immersive environments. The authors also identify that a number of human and contextual factors such as age, social interaction, and physical setup impact user experience.

Summing up, the importance of human factors on QoE cannot be understated. Whilst previous research has explored the impact of human factors in traditional, mainly desktop-based, multimedia, and there have been incipient efforts examining their influence in mulsemedia as well as immersive systems, the advent of brave new technologies makes opportune their investigation in novel contexts. One of these is that of 360° mulsemedia, and it is this that the current paper focuses on. To this end, an empirical study was conducted, the methodology of which we now proceed to describe.

3. Methodology

3.1. Experimental design

In this study, we aim to explore the influence of human factors on users' QoE when viewing 360° mulsemedia. Thus, we adopted a 2x3x3 mixed experimental design with between-subjects variables comprising participants' gender (female, male) and age (16-25, 26-35, >36 years old), whilst the within-subject variable was given by 360° mulsemedia (three different 360° mulsemedia videos).

The justification behind the choice of age and gender as independent variables rests in the fact that both have been shown to be important determinants of QoE [19, 59]; in particular, in a mulsemedia context [33] has previously explored the impact of age and gender on perceived visual and olfactory media synchronization and shown significant differences to exist. As already described, the gender variable was constituted from the Male and Female groups, while the age variable had 3 separate and approximately equal-sized age-groups: 16-25, 26-35, and over 36 years old. The three groups roughly correspond to different generations: Generation Z - people born between 1995 - 2010; Generation Y - people born between 1980 - 1994; Generation X - people born between 1960 - 1979[1]. Prior experience and smell

[1]Millennials, baby boomers or Gen Z available at `https://www.bbc.co.uk/bitesize/`

sensitivity, on the other hand, were ascertained through a series of questions, as will be presented in Section 3.4.

As regards the within-subjects variable, 360° mulsemedia, this was comprised of the three 360° video clip types, each with a different degree of dynamism (as will be described in Section 3.3), To avoid order effects, the presentation order of videos was also varied cyclically the way (see Table 2 in [37]).

The dependent variable of our study was the user QoE, as determined by a series of questions which shall be detailed in Section 3.4.

Other determinants of QoE, which were not manipulated, but monitored, in our study include prior computing experience, and smell sensitivity. The former has been shown to be an important determinant affecting QoE [19, 60], whilst smell sensitivity to congruent smells (as is the case of our study) has been shown to influence attributes such as stimulus sensivity, salience and sensory-motor integration [61], all important influencers of user sensory perception and, by extension, QoE [62].

3.2. Apparatus

In order to explore our research question, we built a 360° mulsemedia head-mounted prototype (Figure 1). This was composed of a smartphone mounted on a VR headset to render the 360° videos. The smartphone was a Samsung Galaxy S6, with a Super AMOLED capacitive touchscreen and 16M colors, 5.1 inches (71.5 cm^2) screen size, and 1440 x 2560 pixels (and 577 PPI density) resolution. Attached to the VR headset was a scent and wind-emitter device, controlled by DFRobot Bluno Nano. The device was composed of a frame, re-sizeable pipe (for directing the scent appropriately), cartridge, fan (for wind effects), as well as mesh bags with scent crystals. The power supply of the wind device was modified so that it can be used with an AC power source. An Arduino Uno microcontroller was used to control both the power supply and the wind blower fan.

A laptop running a mulsemedia effects renderer called PlaySEM SER [63] was also used to logically integrate the 360° video applications to the wind and smell devices. The laptop was a quad-core Intel Core i7-6700 HQ running at 2.6GHz, 16 GB RAM, 260 GB SSD, and GTX960M 4 GB GPU. We employed a WiFi router to wirelessly connect the laptop and the

`articles/zf8j92p`, accessed on 2020-09-11.

Figure 1: User with our 360° mulsemedia prototype.

smartphone.

Last but not least, mention must be made that participants sat on a swivel-chair which enabled them to spin around and experience the 360° videos.

3.3. Experimental material

Three 360° videos were used in the experiment. Our choice of these videos was determined based on their varying degrees of dynamism/content motion (static, semi-dynamic, and dynamic), intended to cover different types of video quality impairments that could eventually be perceived by users. Dynamism and motion in video scenes impact encoding parameters (such as the temporal and spatial activity measures or frame difference estimation) in almost all video codecs. Therefore, for the same bit rate, major modifications in terms of dynamism and motion may result in perceived quality impairment (visibility of smudgy or blocky parts) [64, 65]. Thus, the selected 360° videos are (Figure 2):

- Lavender field - Camera position: fixed. Content: static - a meander through a field of lavender. The background presents no activity and the user can only feel the wind and the smell of lavender;
- Coffee shop - Camera position: fixed. Content: semi-dynamic - a barista preparing a cappuccino. There a slight activity in the background and the user can feel the scent of coffee as it is prepared and experience a puff of air coming from the machine while pumping steam and frothing the milk;
- Roller-coaster - Camera position: moving. Content: dynamic - background that moves with the camera located in the carriage of a roller-coaster. The user feels slightly the scent of diesel as well as the wind in the face while riding the roller coaster.

Each of the 360° videos had a duration of 60 seconds and was combined with wind (W) and smell (S) effects on our developed prototype to produce 360° mulsemedia video content. These effects were synchronized with the AV content of the 360° videos and rendered at certain magnitudes (shown in Figure 2 as % just below the snapshots of the videos) across the duration of each of the three video clips. The percentage represents the fraction of full power the device utilized for rendering W and S effects. The schedule of sensory effects is congruent with the scenes in the videos. Therefore, the variations take them into account.

The particular scents employed were *lavender*, *coffee*, and *diesel* for the lavender field, coffee shop, and roller-coaster clips, respectively. Whilst the choice of the first two is self-evident, the *diesel* scent was particularly employed as it is reminiscent of the lubricant smell coming out in roller coaster rides due to the high friction experienced. A copy from each video's encoding qualities was annotated with MPEG-V which enables to render the mulsemedia effects based on metadata [66].

3.4. Research instruments

Firstly, as stated in Section 3.1, prior to the start of the experiment proper, users completed a previous experience and smell sensitivity questionnaires.

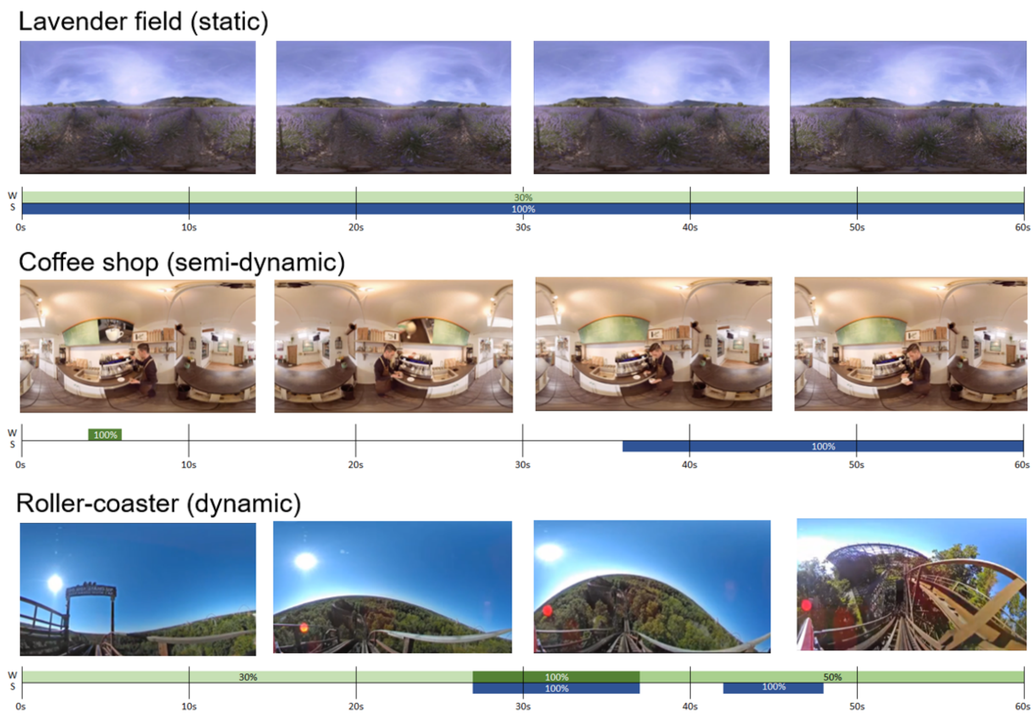

Figure 2: Different frames of the chosen 360° videos and their dynamism, and sensory effects schedule for them. W is Wind, and S is Scent. Both are represented in percentage considering the maximum power of the devices.

The prior experience questionnaire is composed of the following items:

- ***PExp1***: *How familiar are you with subjective video quality evaluation?* {I am not familiar, I am familiar, I work in the area}
- ***PExp2***: *Do you watch High-Quality movies?* {Never, At least once a month, At least once a week, Everyday}
- ***PExp3***: *How familiar are you with 360° videos?* {I am familiar, I've watched on a few occasions, I watch everyday}
- ***PExp4***: *Have you used a Virtual Reality (VR) headset before?* {Yes, No}
- ***PExp5***: *How familiar are you with VR experiences?* {I am not familiar, I've experienced on a few occasions, I experience everyday}

- ***PExp6***: *How often do you watch videos on the Internet using mobile devices?*
  {Everyday, At least once a week, At least once a month, Never}
- ***PExp7***: *If you are familiar with 360° videos, what device do you use to watch them?*
  {I am not familiar, Home TV, Smartphone or Laptop or Ipad, VR Headset}
- ***PExp8***: *What type of video content are you mainly watching on your mobile device?*
  {Static, Semi-dynamic, Dynamic}

The questions relating to smell sensitivity are based on the Chemical Odor Sensitivity Scale (COSS) [67] and are also expressed on a 5-point Likert scale {Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree}. They are:

- ***SS1***: *When I enter into freshly painted rooms, I easily develop difficulty in breathing.*
- ***SS2***: *Sprays and drying paint give me a feeling of difficulty in breathing.*
- ***SS3***: *Small quantities of smoke make me cough.*
- ***SS4***: *As soon as I smell smoke, I have difficulty in breathing.*
- ***SS5***: *I cannot stay in smoky rooms for a long period of time.*
- ***SS6***: *Strong smell of paint gives me a feeling of nausea.*
- ***SS7***: *Strong smell of paint and smoke makes me feel dizzy.*
- ***SS8***: *I am very sensitive to the smell of petrol at petrol stations.*
- ***SS9***: *I develop difficulty in breathing the smell of detergents.*
- ***SS10***: *I cannot tolerate certain perfumes.*
- ***SS11***: *Exhaust gases are very unpleasant for me.*

QoE, as a dependent variable, is also captured through a questionnaire. which the participants responded to after watching each of the 360° mulsemedia video clips. This questionnaire is based on and adapted from previous ones employed in mulsemedia QoE studies [32, 33, 68, 69, 70] :

- ***QoE1***: *Please rate the overall quality of the 360° video experience.*
  {Bad, Poor, Fair, Good, Excellent}

- ***QoE2***: *The quality of the visual display was appropriate.*
  {Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree}
- ***QoE3***: *I enjoyed the 360° video experience.*
  {Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree}

Questions targeting the QoE of multi-sensory effects complement the above questions, and are also expressed on a 5-point Likert scale {Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree}

- ***QoE4***: *How would you rate the intensity of the olfaction effect?*
  {Too Weak, Weak, Just Fine, Strong, Too Strong}
- ***QoE5***: *How would you rate the intensity of the airflow effect?*
  {Too Weak, Weak, Just Fine, Strong, Too Strong}
- ***QoE6***: *The olfaction effect enhances the sense of reality.*
- ***QoE7***: *The olfaction effect is distracting.*
- ***QoE8***: *The olfaction effect is annoying.*
- ***QoE9***: *I enjoy watching the video with olfactory effects.*
- ***QoE10***: *The scent was mismatched to what I was watching.*
- ***QoE11***: *The airflow effect enhances the sense of reality.*
- ***QoE12***: *The airflow effect is distracting.*
- ***QoE13***: *The airflow effect is annoying.*
- ***QoE14***: *I enjoy watching the video with airflow effects.*

3.5. Participants and procedure

A power analysis was conducted in order to determine the sample size for the experiment. Accordingly, given the experimental design detailed in Section 3.1, a desired power of 0.8, a large effect size of 0.8, and a significance level of 0.05 yields a minimum sample size of 47. In the end, a total of 48 participants (27 male, 21 female) took part in this study. Their age was between 16 and 65 years old (16 between 16 - 25; 15 between 26 - 35; 17 over 35 years old). Participants were recruited from three universities through email advertising. None of them received any monetary compensation for taking part. Invited users who reported motion and altitude sickness, allergy to smells, or colour blindness, were not allowed to proceed with the experiment. Thus, three participants meeting at least one of these conditions were excluded from the initial pool of 51 volunteers.

Participants were informed about the content, the stages, and duration of the experiment. Prior to the start of the experiment, users gave informed consent. Additionally, they were reminded they could withdraw at any time. Each participant was then asked to fill in a set of questionnaires concerning demographic information, prior experience, and smell sensitivity, as detailed in Sections 4.5 and 4.6. The experiment started when participants put on the customised 360° multisensory VR headset (Figure 1) and experienced the selected videos (see Figure 2). After each video, users answered a QoE questionnaire (presented in Section 3.4).

3.6. Analysis

SPSS 25.0 (Statistical Package for Social Science) for Windows was used to perform statistical analyses. Data were analysed with both parametric and non-parametric procedures. Accordingly, t-Tests for independent samples, one-way ANOVA and correlations tests were used to analyse the impact of gender, and smell sensitivity differences on the perceived quality of 360° mulsemedia. A three-way ANOVA was employed to examine the effect of gender, age and type of video on users' QoE. We also used the non-parametric Kruskal-Wallis test to examine the influence of prior experience on 360° mulsemedia QoE. For analysis purposes, responses to the Likert scale 5 point questions presented in Section 3.4 were mapped to the numerical values 1 to 5. The internal consistency of the scale as measured by Cronbach alpha was 0.75, which is considered good [71].

4. Results and Discussion

4.1. Gender

t-Tests for independent samples were conducted to compare differences in male and female users' quality perception of 360° mulsemedia. Results for gender-related differences in QoE evaluations are presented in Table 1.

Regardless of gender, the QoE evaluation of the 360° mulsemedia experience was positive (see MOSs - Mean Opinion Score - for each question in Figure 3). Participants reported similar levels of enjoyment (QoE3, QoE9, QoE14) and tended to disagree with the negative statements related to scents and airflow (QoE7, QoE8, QoE10, QoE12, QoE13). Mean values presented

Table 1: Gender differences in QoE evaluation.

Question	*t*	*p*	*d*	Question	*t*	*p*	*d*
QoE1	-1.28	.20	0.22	QoE8	-1.02	.31	0.18
QoE2	.07	.94	0.02	QoE9	-.08	.93	0
QoE3	.33	.74	0.05	QoE10	1.74	0.84	0.27
QoE4	**-1.99**	**.048**	0.33	QoE11	.26	.79	0.04
QoE5	**-2.96**	**.004**	0.51	QoE12	.19	0.85	0.02
QoE6	.65	.52	0.11	QoE13	-.65	.52	0.11
QoE7	-1.11	.27	0.19	QoE14	.98	.33	0.17

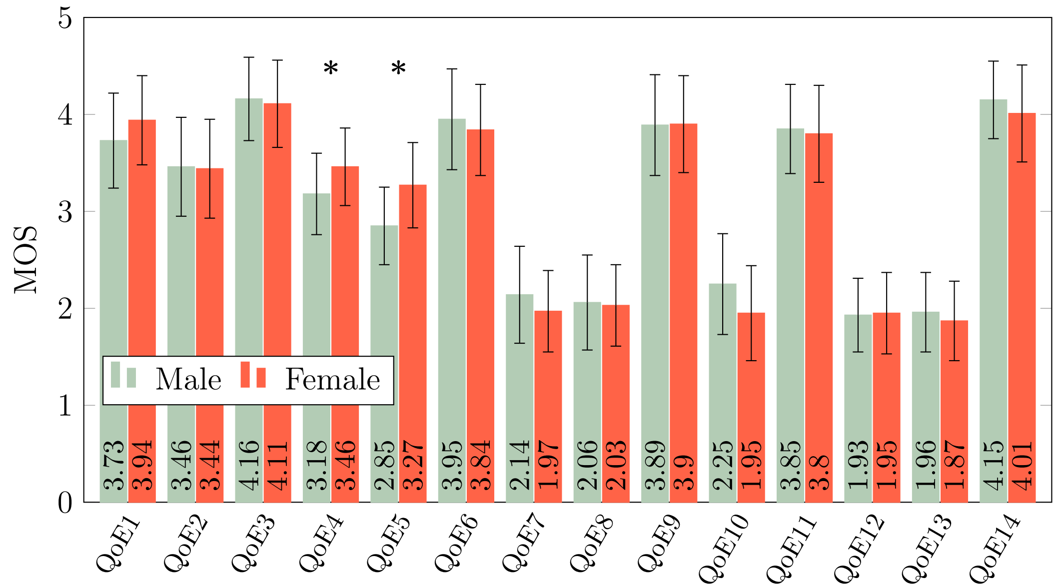

Figure 3: Gender MOS differences in QoE evaluation.

in Figure 3 show that by employing additional sensory cues, we increase the realism of the 360° experience (QoE6, QoE11) for both gender groups.

A statistically significant influence of gender was found with respect to the perceived intensity of scents and airflow (QoE4, QoE5): $t(142) = 0.85$, $p = 0.048$ and $t(142) = 1.53$, $p = 0.004$. Female participants perceived the scents and airflow stronger than male participants, thus indicating certain sensory sensitivity differences between genders.

Existing literature investigated the role of gender in QoE evaluation of multisensory multimedia and games [32, 33, 72] with encouraging results. In [73], Murray et. al propose a model that estimates gender factors have an 8% influence on user QoE in olfaction-enhanced multimedia. Our results extend existing studies to 360° multisensory media setups and show that here, gender influence on QoE evaluation is less significant. This could be explained by the immersive experience this type of media provides - totally different from traditional audio-visual content. Significant differences between genders were found only in the perceived intensity of sensory content (scent and airflow). These results confirm and extend in a 360° digital media setup the findings in [74], which showed that on average women are more sensitive to scent than men.

4.2. Age-group

To understand if people belonging to different age groups evaluate QoE in different ways, we carried out a one-way ANOVA test (age: three levels corresponding to three age-groups). Results are presented in Table 2. Analysis of variance showed that age has a significant effect on *quality evaluation* (QoE1; QoE2): $F(2,141) = 7.51$, $p < 0.005$; $F(2,141) = 4.01$, $p < 0.05$; on the perceived level of *airflow intensity* (QoE5): $F(2,141) = 4.17$, $p < 0.05$; and on the *degree of realism of airflow* in 360° mulsemedia (QoE11): $F(2,141) = 8.81$, $p < 0.005$. To establish what age-groups influence the experience of 360° mulsemedia, we employed pairwise comparisons of the means using Tukey's Honestly Significant Difference procedure.

Table 2: Age-group differences in QoE evaluation.

Question	**F**	***p***	η^2	**Question**	**F**	***p***	η^2
QoE1	**7.51**	**.001**	**0.96**	QoE8	1.43	.24	0.01
QoE2	**4.01**	**.02**	**0.05**	QoE9	0.1	.89	0.02
QoE3	2.53	.08	0.23	QoE10	1.21	.31	0.23
QoE4	.51	.59	0.007	**QoE11**	**8.81**	**.0015**	**0.11**
QoE5	**4.17**	**.017**	**.056**	QoE12	3.08	.051	0.042
QoE6	1.31	.27	0.018	QoE13	1.94	.14	0.027
QoE7	.56	.57	0.01	QoE14	2.99	.053	0.027

Most of the significant differences were observed between the group aged 16-25 years old and the group where participants were between 26-35 years old, with the latter assigning constantly harsher scores than the former - for instance, in the case of *QoE1: Please rate the overall quality of the 360° video experience*: $M_{16-25} = 4.19$, $SD_{16-25} = 0.96$; $M_{26-35} = 3.44$, $SD_{26-35} = 0.84$. Similar differences between the two groups were also found for *QoE2: The* *quality of the visual display was appropriate*: $M_{16-25} = 3.73$, $SD_{16-25} = 1.10$; $M_{26-35} = 3.13$, $SD_{26-35} = 0.89$ (see Figure 4).

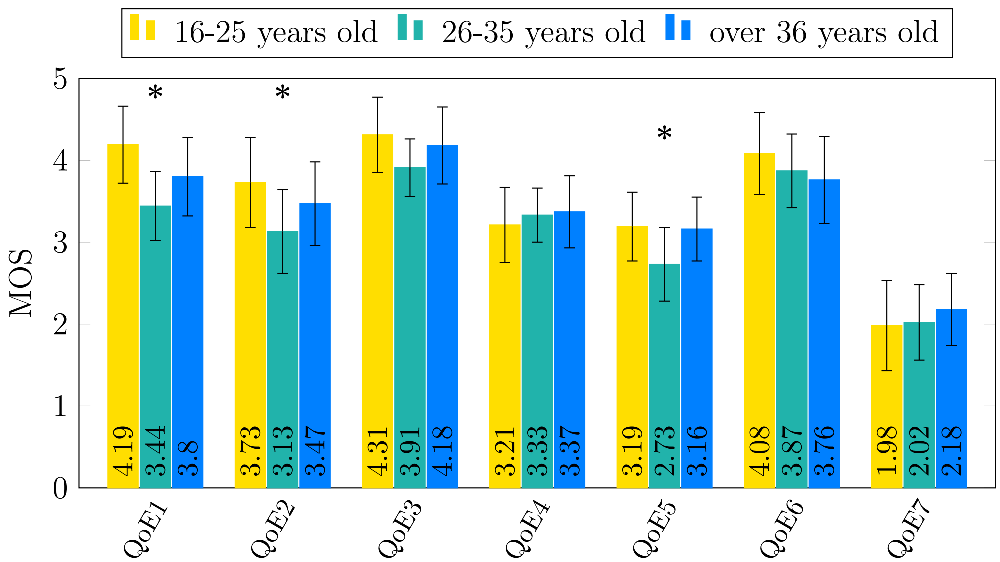

Figure 4: Age-group MOS differences in QoE evaluation (QoE1 - QoE7).

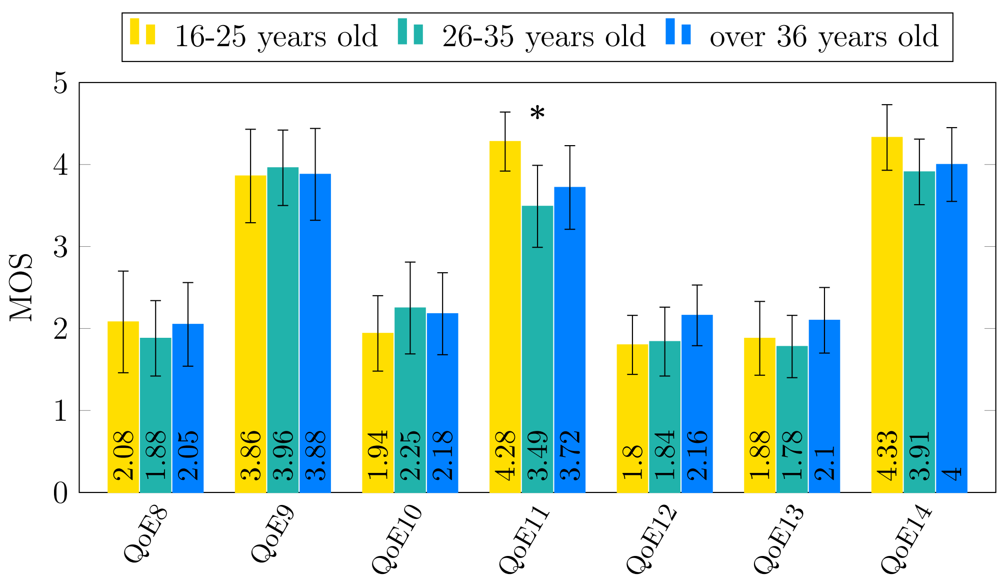

Figure 5: Age-group MOS differences in QoE evaluation (QoE8 - QoE14).

Significant differences between groups were also highlighted for the perception of the airflow content in aspects related to its intensity *QoE5: How would you rate the intensity of the airflow effect?*: $M_{26-35} = 2.73$, $SD_{26-35} = 0.91$, $M_{16-25} = 3.19$, $SD_{16-25} = 0.84$; $M_{36+} = 3.16$, $SD_{36+} = 0.78$, or to the degree of realism provided by airflow *QoE11: The airflow effect enhances the sense of reality*: $M_{16-25} = 4.28$, $SD_{16-25} = 0.74$; $M_{26-35} = 3.49$, $SD_{26-35} = 0.99$ (see Figures 4 and 5).

These results show that age plays an important role in influencing viewers' experience of 360° videos enhanced with multisensory effects. This supports previous findings that presented evidence on the key role played by human factors (e.g., gender, age, personality, culture) in the way perception of multimedia and mulsemedia quality and enjoyment are rated [14, 33, 73]. MOSs presented in Figures 4 and 5 indicated that Generation Z (born in the mid-1990s to the early 2000s) displays a strong engagement with the multisensory content. Overall, users aged 16-25 showed a stronger tendency than their older peers towards awarding better scores to the 360° mulsemedia experience. Their MOSs are the highest in all the important analysed aspects (quality, enjoyment) with highlights related to the wind effect. This preference can be explained by [75], where they looked into assessing the effects of multisensory cues on user engagement in immersive environments and found significant correlations between wind and happiness.

4.3. Gender, age, and type of video

A three-way ANOVA was run to examine the effect of gender, age and type of video on users' QoE. There was no significant three-way interaction between gender, age, and video, and neither was the interaction between age and video or age and gender found to be significant.

4.4. Gender, age and prior experience

To examine the effect of gender, age and prior experience on users' QoE, we conducted a three-way ANOVA and we display the values obtained for the interaction between gender and prior experience in Table 3, the interaction between age and prior experience in Table 4 and the three-way interaction in Table 5.This analysis highlighted the additional potential impact that prior experience could have on QoE, towards which end we conducted further tests as detailed in the next section.

Table 3: Interaction between gender and prior experience on QoE

	Gender*							
QoE_{1-14}	**PExp1**	**PExp2**	**PExp3**	**PExp4**	**PExp5**	**PExp6**	**PExp7**	**PExp8**
QoE1	**.029**	**.015**	.118	.571	.913	.500	.102	**.007**
QoE2	**.018**	**.014**	.427	.745	.644	.111	282	**.015**
QoE3	**.005**	.352	**.025**	.340	**.050**	052	.070	.180
QoE4	.833	.831	.650	.792	.966	.751	.415	**.042**
QoE5	**.023**	**.039**	.654	.756	.442	**.007**	.101	.504
QoE6	.929	.468	.613	.797	.934	.382	.735	.104
QoE7	.213	.339	.715	.857	**.001**	.153	.937	.306
QoE8	.633	.298	.464	.408	.635	.144	**.015**	.527
QoE9	.106	.812	.656	.633	.310	.508	.272	.220
QoE10	.199	.162	.609	.996	.517	.341	.468	.547
QoE11	.423	.456	.264	.095	.308	**.000**	.458	.290
QoE12	.063	.460	**.030**	.169	.081	.172	.311	.924
QoE13	**.013**	.367	**.003**	.387	.383	.142	.197	.380
QoE14	**.033**	.685	.247	.511	.432	**.000**	.304	.122

4.5. Prior experience

In order to gauge the impact of users' prior experience on QoE, we applied the non-parametric Kruskal-Wallis test (and t-test for PExp4). In Table 6, we show the p-values obtained between the different groups. We highlight significant values ($p < 0.05$) that provide very strong evidence of a difference between at least one pair of the groups.

Next, we carried out a series of post-hoc tests to understand the implications of the various dimensions of prior experience on user 360° mulsemedia OoE. Meaningful results are presented next; p-values were adjusted using Bonferroni correction.

4.5.1. How familiar are you with subjective video quality evaluation? (PExp1)

The Kruskal-Wallis test result in Table 6 shows that the difference in responses for **QoE8** ($\chi^2(2) = 16.69$, $p < 0.001$) and **QoE13** ($\chi^2(2) = 7.53$, $p = 0.023$) is statistically significant with respect to participants' level of familiarity with subjective video quality evaluation. Dunn's pairwise tests were

Table 4: Interaction between age and prior experience on QoE

	Age*							
QoE_{1-14}	**PExp1**	**PExp2**	**PExp3**	**PExp4**	**PExp5**	**PExp6**	**PExp7**	**PExp8**
QoE1	.496	.187	.918	.627	.575	**.016**	.238	**.003**
QoE2	.709	.780	.750	.639	.517	**.001**	.381	**.002**
QoE3	.244	**.004**	.193	.063	.078	.504	.061	**.004**
QoE4	.188	.270	.750	.553	.625	.358	.972	.199
QoE5	.977	.058	.792	**.004**	**.032**	.072	**.027**	.079
QoE6	.104	.402	.213	.104	.348	.440	.768	.836
QoE7	**.002**	**.015**	**.033**	.077	.099	.254	**.018**	.241
QoE8	**.027**	**.044**	.348	**.016**	**.029**	.313	**.035**	.430
QoE9	.094	.188	.106	**.021**	.126	.262	.144	.117
QoE10	**.006**	**.015**	**.000**	**.001**	**.005**	.388	**.000**	.009
QoE11	.082	.891	.544	.423	.690	**.006**	.782	.273
QoE12	**.008**	.166	.072	.097	.081	.782	.540	.134
QoE13	**.016**	.356	.055	.185	.192	.451	.213	.288
QoE14	**.033**	.673	.079	**.005**	**.046**	**.000**	.608	.069

carried out for the three pairs of groups (**not familiar**, **familiar**, **working in the area**). Evidence of significant differences between pairs of groups is presented in Table 7 and shows that users who are not knowledgeable about the process of subjective video quality evaluation are significantly less disturbed by the presence of multisensory content that those who are familiar or work in the area.

4.5.2. Do you watch High-Quality movies? (PExp2)

Values in Table 6 show that the differences in responses for **QoE2** ($\chi^2(3) = 9.18$, p = 0.027), **QoE5** ($\chi^2(3) = 14.43$, p = 0.002), **QoE11** ($\chi^2(3) = 8.82$, p = 0.032), and **QoE12** ($\chi^2(3) = 8.14$, p = 0.043) are statistically significant with respect to participants' viewing patterns (**never**, **at least once a month**, **at least once a week**, **everyday**). For QoE2 and QoE12, Dunn's post hoc tests could not provide evidence of the groups between which significant differences exist in the perceived quality of the visual display and in the distraction produced by the airflow effect. The pairs of groups with

Table 5: Three-way interaction between gender, age and prior experience on QoE (for PExp6 this level combination of factors is not observed, thus the corresponding population marginal mean is not estimable.)

	Age*Gender*							
QoE_{1-14}	**PExp1**	**PExp2**	**PExp3**	**PExp4**	**PExp5**	**PExp6**	**PExp7**	**PExp8**
QoE1	.473	**.022**	.342	.124	.664	.	.377	.172
QoE2	**.021**	**.003**	.310	.458	.414	.	.159	.544
QoE3	**.023**	**.014**	.238	.100	.231	.	.372	.135
QoE4	.060	.970	.793	.744	.719	.	.762	.059
QoE5	.345	.178	.073	.114	.233	.	.211	.537
QoE6	.929	.117	.952	.358	.372	.	.344	.106
QoE7	.592	.144	.780	.291	.360	.	.334	.624
QoE8	.549	.371	.735	.077	.183	.	.237	.410
QoE9	.160	.794	.129	.781	.819	.	.131	.145
QoE10	.284	.518	.652	.742	.811	.	.677	.487
QoE11	.396	.276	.598	.290	.658	.	.783	**.014**
QoE12	.335	.366	.357	.432	.413	.	.690	.360
QoE13	.779	.352	.808	**.021**	**.050**	.	.962	.067
QoE14	.125	.264	.172	.509	.492	.	.264	.201

significant different views for QoE5 and QoE11 are detailed in Table 8.

Our results thus show that user viewing patterns are important factors to consider when designing mulsemedia experiences, particularly in respect of perceived sense of reality, quality of display, intensity of airflow, as well as the enjoyment of olfactory effects. Whilst there is evidence [76] that user viewing interests do influence some aspects of multimedia QoE, it seems that this is also the case as far as 360° mulsemedia is concerned.

4.5.3. How familiar are you with 360° videos? (PExp3)

p-Values in Table 6 show that when we consider different degrees of familiarity to 360° videos (**I am familiar, I've watched on a few occasions**, **I watch everyday**), we obtain significant differences in responses for **QoE3** ($\chi^2(2) = 6.11$, $p = 0.047$) and **QoE8** ($\chi^2(2) = 9.31$, $p = 0.01$). When it comes to the enjoyment of the 360° experience (QoE3), post hoc tests did

Table 6: p-Values for Kruskal Wallis test.

QoE_{1-14}	**PExp1**	**PExp2**	**PExp3**	**PExp4**	**PExp5**	**PExp6**	**PExp7**	**PExp8**
QoE1	.223	.423	.066	**.043**	**.005**	.765	.699	.124
QoE2	.392	**.027**	.162	**.011**	.052	**.045**	.194	**.001**
QoE3	.690	.063	**.047**	**.001**	**.045**	0.070	.120	**.001**
QoE4	.117	.561	.558	.071	.509	.384	**.020**	.683
QoE5	.065	**.002**	.950	.877	.557	**.009**	.269	.249
QoE6	.151	.679	.212	.857	**.016**	.325	.059	**.002**
QoE7	.098	.394	.070	.525	.110	.184	**.024**	**.001**
QoE8	**.000**	.787	**.010**	**.022**	**.001**	.472	**.005**	**.001**
QoE9	.206	.108	.557	.911	.107	.946	.588	**.032**
QoE10	.200	.895	.329	.532	.101	.698	.214	**.014**
QoE11	.852	**.032**	.788	.090	.714	.183	.270	**.000**
QoE12	.102	**.043**	.098	.968	**.020**	.116	.167	**.000**
QoE13	**.023**	.493	.168	.390	**.026**	.179	.247	**.000**
QoE14	.287	.096	.293	**.022**	.205	.202	.253	**.000**

Table 7: Dunn's pairwise tests for PEx1: groups presenting significant differences (G1, G2), mean ranks for groups (MR_{G1}, MR_{G2}), p-values.

QoE_{ID}		**G1**	**G2**	**MR_{G1}**	**MR_{G2}**	**p**
8	annoyance caused by olfaction	*familiar*	*not familiar*	91.01	61.99	<0.001
			working - area		67.00	0.042
13	annoyance caused by airflow	*familiar*	*not familiar*	84.93	65.71	0.023

Table 8: Dunn's pairwise tests for PEx2: groups presenting significant differences (G1, G2), mean ranks for groups (MR_{G1}, MR_{G2}), p-values.

QoE_{ID}		**G1**	**G2**	**MR_{G1}**	**MR_{G2}**	**p**
5	perceived airflow intensity	*never*	*once a week*	5.00	78.44	0.008
			once a month		75.17	0.005
11	perceived realism from airflow	*never*	*once a week*	15.67	79.37	0.023

not provide evidence of the groups between which significant differences exist. Results of Dunn's pairwise test for Qo8 are presented in Table 9.

Table 9: Dunn's pairwise tests for PEx3: groups presenting significant differences (G1, G2), mean ranks for groups (MR_{G1}, MR_{G2}), p-values.

QoE$_{ID}$		**G1**	**G2**	**MR**$_{G1}$	**MR**$_{G2}$	**p**
8	annoyance caused by olfaction	*everyday*	*on a few occasions*	131.33	68.21	0.016

Our results show that the user's familiarity with the content being viewed is an important factor to consider in the design of mulsemedia experiences, particularly when it comes to the annoyance due to olfactory effects. This mirrors similar findings in the multimedia arena [77], which have highlighted the importance of content familiarity on QoE.

4.5.4. Have you used a Virtual Reality (VR) headset before? (PExp4)

An independent samples t-test was performed on participants QoE responses (yes, no) with respect to PExp4 as a grouping factor. Mean and SD values are presented in Figure 6. Statistically significant differences were observed between the two groups in answers to **QoE1, QoE2, QoE3, QoE8** and **QoE14**.

These results suggest that participants who did not have previous experience with a VR headset rated significantly higher aspects related to: the quality of the overall experience (QoE1: $t(142) = 2.05$, $p = 0.043$), the quality of the visual display (QoE2: $t(142) = 2.57$, $p = 0.011$), the perceived enjoyment of the 360° mulsemedia experience (QoE3: $t(142) = 3.25$, $p = 0.001$), and the enjoyment produced by airflow effects (QoE14: $t(142) = 2.32$; $p = 0.022$). Moreover, they were less annoyed by the olfactory content added to the experience (QoE8: $t(142) = -2.32$, $p = 0.022$).

Our analysis thus revealed interesting insights into the impact that prior use of VR headsets has on 360° mulsemedia QoE. It is notable to remark, though, that whilst there are significant differences between the two groups, olfactory and airflow effects were still perceived positively by both groups. The same observation holds in respect of the quality of visual display, as well as the overall quality and enjoyment of the 360° video viewing experience.

4.5.5. How familiar are you with VR experiences? (PExp5)

p-Values in Table 6 show significant statistical differences between responses to **QoE1** ($\chi^2(2) = 10.52$, $p = 0.005$), **QoE3** ($\chi^2(2) = 6.19$, $p =$

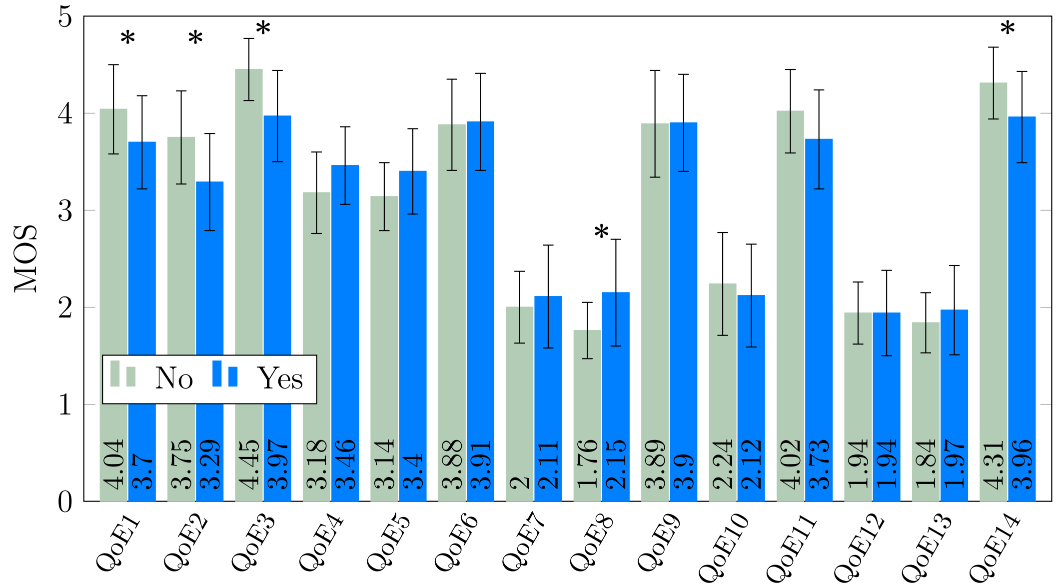

Figure 6: Have you used a Virtual Reality (VR) headset before?

Table 10: Dunn's pairwise tests for PEx5: groups presenting significant differences (G1, G2), mean ranks for groups (MR_{G1}, MR_{G2}), p-values.

QoE$_{ID}$		**G1**	**G2**	**MR**$_{G1}$	**MR**$_{G2}$	**p**
1	overall quality of the 360°experience	*everyday*	*not familiar*	30.00	83.86	0.006
3	enjoyment	*everyday*	*not familiar*	37.75	79.40	0.042
6	realism olfaction	*everyday*	*few occasions*	64.89	77.99	0.043
8	annoyance caused by olfaction	*everyday*	*not familiar*	129.00	66.51	0.001
			few occasions		71.59	0.001
12	distraction caused by airflow	*everyday*	*few occasions*	113.17	68.59	0.019
13	annoyance caused by airflow	*everyday*	*not familiar*	114.17	70.20	0.027
			few occasions		70.90	0.023

0.045), **QoE6** ($\chi^2(2) = 8.27$, p = .016), **QoE8** ($\chi^2(2) = 13.78$, p = .001), **QoE12** ($\chi^2(2) = 7.85$, p = .020) and **QoE13** ($\chi^2(2) = 7.31$, p = .026), when we consider the participants' VR experience (**I am unfamiliar**, **I've expe-**

rienced on a few occasions, **I experience everyday**). Dunn's tests were used to follow-up this finding (see Table 10).

Our results thus show that prior VR experience is an important factor which determines some crucial aspects of a user's 360° mulsemedia experience, particularly in terms of its influence on the effect of olfactory stimuli on enhancing the sense of reality, the effects of airflow and olfactory media on user satisfaction, as well as the overall quality and enjoyment of the 360° mulsemedia viewing experience.

4.5.6. How often do you watch videos on the Internet using mobile devices? (PExp6)

Application of the Kruskal Wallis test (Table 6) highlights that the level of use of mobile devices (**everyday**, **at least once a week**, **at least once a month**, **never**) to watch videos on the Internet significantly determines differences in participants' responses to **QoE2** ($\chi^2(3) = 8.044$, p = 0.045) and **QoE5** ($\chi^2(3) = 11.578$, p = 0.009) as further analysed in Table 11

Table 11: Dunn's pairwise tests for PEx6: groups presenting significant differences (G1, G2), mean ranks for groups (MR_{G1}, MR_{G2}), p-values.

QoE$_{ID}$		**G1**	**G2**	**MR$_{G1}$**	**MR$_{G2}$**	**p**
2	quality visual display	*once a week*	*once a month*	85.73	54.08	0.042
5	perceived airflow intensity	*once a week*	*once a month*	57.80	93.58	0.006

Users who use mobile devices to watch Internet videos more often, evaluate better the quality of the visual display in our multisensory setup. Moreover, they perceive the intensity of airflow closer to 'Just Fine'. The relationship between perceived quality and a hedonic dimension such as enjoyment is a complex one in multimedia QoE [14, 78], and our results seem to indicate that this is indeed the case with 360° mulsemedia.

4.5.7. If you are familiar with 360° videos, what device do you use to watch them? (PExp7)

The Kruskal-Wallis test results in Table 6 revealed significant differences between responses in respect to the device type (**not familiar, home tv, smartphone/ipad/laptop, VR headset**) used to watch 360° videos

(PExp7) for **QoE4** ($\chi^2(3) = 9.794$, $p = .020$) , **QoE7** ($\chi^2(3) = 9.398$, $p = .024$) and **QoE8** ($\chi^2(3) = 12.921$, $p = .005$). These differences are further analysed below.

Table 12: Dunn's pairwise tests for PEx7: groups presenting significant differences (G1, G2), mean ranks for groups (MR_{G1}, MR_{G2}), p-values.

QoE$_{ID}$		**G1**	**G2**	**MR$_{G1}$**	**MR$_{G2}$**	**p**
4	perceived olfaction intensity	*smartphone/ laptop/ ipad*	*VR headset*	61.29	82.13	0.018
7	distraction caused by olfaction	*smartphone/ laptop/ ipad*	*not familiar*	63.04	90.33	0.025
8	annoyance caused by olfaction	*smartphone/ laptop/ ipad*	*VR headset*	58.41	79.96	0.016
			not familiar		86.38	0.018

The fact that the particular access device influences QoE has been demonstrated for traditional audiovisual content [79, 80]; it is edifying to see that it also holds for mulsemedia content. In particular, users who are unfamiliar with 360°content or who access it on traditional devices such as a TV seem to be more distracted and annoyed by olfactory effects than users who use VR headsets.

4.5.8. What type of video content are you mainly watching on your mobile device? (PExp8)

The type of content mainly watched by the users (**static**, **semi-dynamic**, **dynamic**) influences significantly their answers to **QoE2** $\chi^2(2) = 14.889$, $p = .001$), **QoE3** ($\chi^2(2) = 13.529$, $p = .001$), **QoE6** ($\chi^2(2) = 12.096$, $p = .002$), **QoE7** ($\chi^2(2) = 13.220$, $p = .001$), **QoE8** ($\chi^2(2) = 13.129$, $p = .001$) , **QoE9** ($\chi^2(2) = 6.898$, $p = .032$), **QoE10** ($\chi^2(2) = 8.505$, $p = .014$) , **QoE11** ($\chi^2(2) = 18.984$, $p < .001$), **QoE12** ($\chi^2(2) = 17.467$, $p < .001$), **QoE13** ($\chi^2(2) = 17.709$, $p < .001$) and **QoE14** ($\chi^2(2) = 23.427$, $p < .001$) (Table 6.)

Whilst there is substantial evidence that content is king in multimedia QoE (i.e. the particular dynamism - or lack thereof - of multimedia content influences QoE) [81, 18], what we have shown above is slightly different and arguably more subtle. Specifically, what appears to hold is that user viewing behaviour, in terms of content dynamism, impacts a substantial majority (Table 13) of QoE constructs (11 out of 14) in respect of 360° mulsemedia.

Table 13: Dunn's pairwise tests for PEx8: groups presenting significant differences (G1, G2), mean ranks for groups (MR_{G1}, MR_{G2}), p-values.

QoE$_{ID}$		**G1**	**G2**	**MR**$_{G1}$	**MR**$_{G2}$	**p**
2	quality visual display	*semi-dynamic*	*static*	93.64	56.78	<0.001
			dynamic		70.75	0.019
3	enjoyment	*static*	*semi-dynamic*	52.24	75.56	0.038
			dynamic		80.88	0.001
6	realism olfaction	*static*	*dynamic*	55.51	82.41	0.002
7	distraction caused by olfaction	*static*	*dynamic*	88.19	61.41	0.002
8	annoyance caused by olfaction	*dynamic*	*semi-dynamic*	61.39	82.00	0.033
			static		86.94	0.003
9	enjoyment caused by olfaction	*static*	*dynamic*	58.94	79.76	0.027
10	mismatched scent	*static*	*dynamic*	83.01	63.18	0.043
11	realism airflow	*static*	*dynamic*	50.01	84.55	<0.001
12	distraction caused by airflow	*dynamic*	*semi-dynamic*	60.03	80.50	0.035
			static		91.14	<0.001
13	annoyance caused by airflow	*dynamic*	*semi-dynamic*	59.75	82.55	0.014
			static		89.85	<0.001
14	enjoyment airflow	*dynamic*	*semi-dynamic*	86.59	65.91	0.034
			static		49.19	<0.001

Users who regularly watch dynamic content rate significantly better aspects like enjoyment (QoE3, QoE9, QoE14) and realism (QoE6, QoE11) than the other participants. Moreover, multisensory content has less negative effects on these users.

4.6. Smell sensitivity

A Spearman's rank-order correlation was run to determine the relationship between sensitivity to smells and perceived QoE. The correlation test results on responses with respect to participants' smell sensitivity are shown in Table 14. Each of the QoE questions which significantly correlated with an element of the smell sensitivity questionnaire is presented below.

Table 14: Correlation coefficient and p-value for smell sensitivity.

QoE1$_{1-14}$	*Results*	*SS1*	*SS2*	*SS3*	*SS4*	*SS5*	*SS6*	*SS7*	*SS8*	*SS9*	*SS10*	*SS11*
QoE1	r_s	.080	**.177**	-.003	.025	.135	.161	.141	.153	.117	**.337**	.082
	p	.341	.034	.968	.768	.106	.054	.092	.067	.161	.000	.330
QoE2	r_s	-.085	-.124	-.081	.070	.076	**-.209**	-.122	-.097	-.108	**-.296**	.086
	p	.308	.138	.336	.402	.363	.012	.146	.249	.198	.000	.307
QoE3	r_s	.032	.031	.018	-.047	-.006	**-.206**	**-.194**	-.129	**-.178**	-.079	.151
	p	.699	.717	.833	.577	.943	.013	.020	.124	.033	.349	.071
QoE4	r_s	.064	.045	.094	.128	-.011	.123	.135	.158	.098	.013	**.176**
	p	.447	.589	.263	.125	.896	.142	.107	.059	.242	.879	.035
QoE5	r_s	-.052	.018	.144	.044	-.103	.076	.012	.048	.015	.157	.036
	p	.534	.827	.085	.600	.218	.364	.889	.567	.857	.060	.671
QoE6	r_s	**-.172**	-.084	**-.234**	**-.259**	-.077	**-.243**	**-.181**	**-.283**	-.160	-.085	-.016
	p	.040	.320	.005	.002	.356	.003	.030	.001	.055	.309	.847
QoE7	r_s	.000	-.040	-.001	.138	.084	.100	.047	.090	.111	.061	-.040
	p	.998	.638	.988	.100	.319	.234	.578	.282	.184	.470	.631
QoE8	r_s	-.057	-.057	-.081	.106	.102	.085	.042	.050	.105	.039	-.154
	p	.498	.495	.333	.207	.223	.309	.613	.556	.210	.646	.065
QoE9	r_s	.021	.063	-.069	-.101	-.019	**-.206**	**-.183**	**-.295**	**-.175**	.057	.033
	p	.805	.456	.412	.229	.820	.013	.028	.000	.036	.495	.692
QoE10	r_s	.089	.092	.079	.160	**.223**	.160	**.164**	**.277**	.159	.162	.123
	p	.289	.271	.345	.056	.007	.055	.049	.001	.057	.052	.141
QoE11	r_s	-.124	-.146	**-.275**	**-.201**	-.032	**-.257**	-.152	-.138	**-.173**	**-.323**	-.035
	p	.138	.082	.001	.016	.700	.002	.068	.098	.038	.000	.676
QoE12	r_s	**.235**	**.190**	.080	**.215**	.151	**.239**	**.191**	**.239**	.139	.096	.083
	p	.005	.023	.339	.010	.071	.004	.022	.004	.096	.252	.321
QoE13	r_s	.118	.103	-.031	.156	.103	**.209**	**.186**	.125	.103	.068	-.049
	p	.159	.220	.711	.061	.219	.012	.025	.137	.217	.421	.562
QoE14	r_s	-.061	-.047	-.163	-.124	.034	**-.253**	**-.182**	-.118	**-.181**	-.137	.070
	p	.466	.578	.051	.139	.689	.002	.029	.160	.029	.102	.405

- Users who reported that *When I enter into freshly painted rooms, I easily develop difficulty in breathing (SS1)* gave negatively correlated ratings with the enhancement of the sense of reality due to the olfaction effect (QoE6, p=.040). However, a statistically significant positive relationship is found with the level of distraction experienced due to the airflow effect (QoE12, p=.005). So, this category of users tends to perceive negatively the sense of reality introduced by olfactory effects as well as to perceive airflow effects as distracting.

- Positive correlations were observed between users who professed that *Sprays and drying paint give me a feeling of difficulty in breathing (SS2)* and their ratings of the quality of the 360° video experience (QoE1, p=.034). A positive correlation is also observed in this respect with the tendency of users to appreciate the enhancement of the sense of reality due to the airflow effect (QoE11, p=.023).

- Participants who admitted that *Small quantities of smoke make me cough (SS3)* gave negatively - and significant - correlated ratings as regards their perception that the effects of olfaction (QoE6, p=.005) and airflow (QoE11, p=.001) enhance the sense of reality. Thus, it would seem that the potential of multi-sensory effects to enhance the sense of reality is limited for such participants

- Users who reported that *As soon as I smell smoke, I have difficulty in breathing (SS4)* have significant but negatively correlated ratings in respect of their sense of reality being enhanced due to olfaction (QoE6, p=.002) and airflow (QoE11, p=.016) effects. Moreover, such users' ratings showed significant and positive correlations with opinions in respect of the airflow's distracting effect (QoE12, p=.010). This shows that for such users olfactory and airflow effects might be detrimental to their QoE.

- A significant and positively correlated relationship was observed between users who reported that *I cannot stay in smoky rooms for a long period of time (SS5)* and those who said the scent was mismatched to what they were watching (QoE10, p=.007).

- Participants who declared that a *Strong smell of paint gives me a feeling of nausea (SS6)* gave positively - and significant - correlated ratings as regards to their perception of distraction (QoE12, p=.004) and annoyance (QoE13, p=.012) due to airflow effect. However, the ratings correlated significantly - but negatively with respect to their perception on the appropriateness of quality of visual display (QoE2, p=.012), and overall enjoyment of the 360° video experience (QoE3, $p=.013$). Additionally, it significantly - but negatively - correlated with the users' perception of enhanced sense of reality (QoE6, $p=.003$) and enjoyment due to olfactory effects (QoE9, $p=.013$), as well as enhanced of sense of reality (QoE11, $p=.002$) and enjoyment due to airflow effects (QoE14, $p=.002$). It thus seems that airflow and olfactory effects are not suited for this category of participants.

- User ratings to a *Strong smell of paint and smoke makes me feel dizzy (SS7)* significantly - and positively - correlated in regards to their ratings on the mismatch of scent with what was watched (QoE10, $p=.049$), as well as their perception of distraction (QoE12, $p=.0022$) and annoyance (QoE13, $p=.025$) associated with airflow effects. Additionally, their ratings correlated significantly - but negatively - with respect to their perception of the overall enjoyment of the 360° video experience (QoE3, $p=.020$), the enhanced the sense of reality (QoE6, $P=.030$) and enjoyment (QoE9, $p=.028$) due to olfactory effects, as well as enjoyment due to airflow effects (QoE14, $p=.002$). Thus, it seems that introducing multisensory effects is not recommended for users possessing this particular type of smell sensitivity.

- Participants who professed that *I am very sensitive to the smell of petrol at petrol stations (SS8)* had ratings which significantly - and positively - correlated with their perception of mismatched scent (QoE10, $p=.001$) and distraction due to airflow effect (QoE12, $p=.004$). Moreover, correlation analysis highlighted a significant - but negative - relationship with respect to their perception of an enhanced sense of reality (QoE6, $p=.001$) and enjoyment (QoE9, $p<.001$) due to olfactory effects. Multisensory effects do not seem to lead to an enhanced QoE for this category of users, quite the contrary.

- Users who admitted that *I develop difficulty in breathing the smell of detergents (SS9)* gave significantly - but negatively - correlated ratings with respect to their perception of enjoyment due to olfactory (QoE9, $p=.036$) and airflow (QoE14, $P=.029$) effects as well as the overall 360° video experience (QoE3, $p=.033$), and enhanced sense of reality due to airflow effects (QoE11, $p=.038$). Again, multisensory effects would not be recommended for users with this type of smell sensitivity.

- Users who admitted that *I cannot tolerate certain perfumes (SS10)* had ratings which significantly - and positively correlated - with the overall quality of the 360° video experience (QoE1, $p<.001$). However, their ratings significantly - but negatively - correlated with respect to their perception of the appropriateness of the quality of visual display (QoE2, $p<.001$), and enhanced sense of reality due to airflow effect (QoE11, $p<.001$). On balance, 360°mulsemedia experiences are appropriate for this category of users, especially if airflow effects are used sparingly.

- A significant and positive correlation was observed between users' ratings on *Exhaust gases are very unpleasant for me (SS11)* and the intensity of the olfaction effect (QoE4, $p=.035$). Perhaps unsurprisingly, it seems that scent intensity is an important factor in the design of 360° mulsemedia experiences, particularly for this kind of users.

Our analysis has thus shown that, with the possible exception of users who *cannot tolerate certain perfumes* and those who confessed that *Sprays and drying paint give me a feeling of difficulty in breathing*, 360°mulsemedia effects should be used parsimoniously, if at all, for individuals with declared smell sensitivities.

5. Conclusion

360° videos and VR provide a new content experience that goes beyond traditional media. However, in order to understand how they can be used to enhance the audience's experience, it is important to get a deeper insight into viewer behaviour. Our research investigates key aspects related to the influence of various human factors (e.g., age groups corresponding to Generation X, Y, Z; gender; previous experience) on the evaluation of omnidirectional videos enhanced with multisensory effects.

The findings of this research offer novel practical implications (summarised in Figure 7) to consider when designing future interactions with 360° multisensory media for different categories of consumers (e.g., Generation Y, Z, etc.). We showed that today's teenagers - 18 to 26-year-olds (Generation Z) - assess positively certain dimensions of QoE (enjoyment, quality, degree of realism) in 360° mulsemedia setups. Moreover, for the same users, possible negative effects (e.g., annoyance, distraction) are reduced. These observations can benefit and add new dimensions to the high use of video amongst today's teenagers. Generation Z watches (and creates) personalised video content[2]. Their attention span is short, thus creators must focus on bite-sized content that engages them. Mulsemedia might offer Generation Z new tools for creating and shaping media experiences and culture, stimulating their diversity [82]. Based on our findings, enhancing content with multisensory effects can be used to target the engagement of this generation. Moreover, mulsemedia has potential [83, 84] to enrich experiences of Generations Y and X - aged 26 to 60 years - who are interested in entertainment and nostalgia-driven content[3].

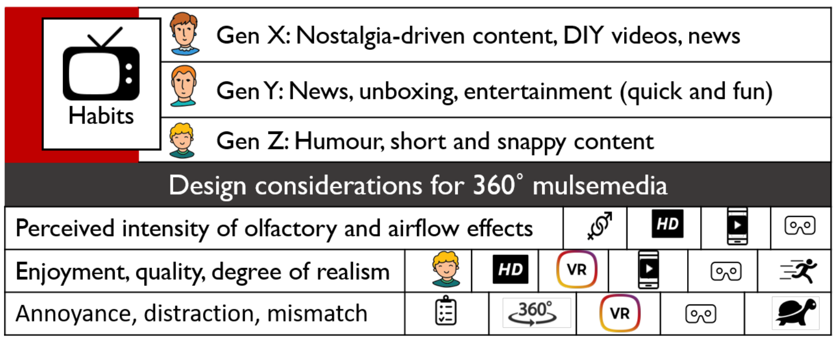

Figure 7: Design considerations for 360° mulsemedia.

Another interesting finding of this study is that gender is an important factor to consider when setting up the intensities of multisensory effects - with women displaying an increased sensitivity compared to men. This dimension is affected also by the previous experience of users in terms of HD videos watching patterns, and usage of VR devices and phones for watching videos.

Overall, the influence of an individual's prior experience on QoE has revealed significant insights into the importance and possibility of incorporating the above-mentioned factors for personalizing the 360° mulsemedia experience in order to achieve an enhanced QoE. These results have to be tempered somewhat by the fact that, in the exploratory study reported herein, we used an *ad hoc* and, as of yet, unvalidated, research instrument to characterise this particular user aspect. With this in mind, our results do nonetheless indicate

[2]How to Create Content that Appeals to Gen Z available at `https://upcity.com/blog/how-to-create-content-that-appeals-to-gen-z/`, accessed on 2020-09-11.

[3]The YouTube Habits of Baby Boomers, Gen X, Millennials, and Gen Z available at `https://www.theshelf.com/the-blog/youtube-habits`, accessed on 2020-09-11.

that users' prior experience regarding the levels of dynamism of the videos they watch is an important factor which determines 360° mulsemedia experience in many aspects. To the best of our knowledge, this is the first time - in a multimedia or mulsemedia context - that the levels of video dynamism predominantly encountered by users in their viewing habits have been shown to influence their QoE. Particularly, participants who watch dynamic video content tend to have a better 360° mulsemedia experience, while those who watch more static content have the lowest.

Our results also showed that the overwhelming majority of QoE questions in our study were significantly influenced by particular characteristics of users' smell sensitivity. Knowledge of a user's particular smell sensitivity is thus instrumental in enhancing their 360° mulsemedia experience and gives mulsemedia designers an important insight into how incorporating it in 360° mulsemedia systems is able to deliver a personalized - and enhanced - experience. It is also worth highlighting that our work, whilst exploratory in nature, could lay the foundation for building theoretical and predictive models incorporating human factors for the betterment of QoE. Indeed, this is valuable future work. Moreover, as an exploratory study, the generalizability of the results and conclusions generated also need further confirmatory work.

In concluding, we remark that multisensory 360° videos and VR are not simply elaborated versions of traditional media. Given that new generations are true digital natives with brains wired to sophisticated, complex visual imagery - they are the ones to benefit from and to exploit this type of new media. In this paper, we offer empirical evidence that human factors should be taken into account in the design of immersive mulsemedia. However, we have explored but a subset of human factors here - future studies might investigate the importance of other dimensions, such as culture, personality and cognitive styles.

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