Quality of Experience in Relation to Wearables

A thesis submitted for the degree of Doctor of Philosophy

By

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ABSTRACT

The purpose of this study is to apply the concept of Quality of Experience (QoE) to wearables. QoE is inextricably linked to the user experience of multimedia computing and, although QoE has been explored in relation to other types of multimedia devices, thus far its applicability to wearables has remained largely ignored. Given the proliferation of wearable devices and their growing use to augment and complement the multimedia user experience, the need for a set of QoE guidelines becomes imperative. The study which forms the focus of this PhD meets that need and puts forward a set of guidelines tailored exclusively towards wearables' QoE.

Accordingly, an extensive experimental investigation has been undertaken to see how wearables impact users' QoE in both multimedia and multiple sensorial media (mulsemedia) contexts. Based on two exploratory studies, the findings have shown that the haptic vest (KOR-FX) enhanced user QoE to a certain extent. In terms of adoption, participants reported they would generally incorporate the heart rate (HR) monitor wristband (Mio Go) into their daily lives as opposed to the haptic vest. Other findings revealed that human factors play a part in user's attitudes towards wearables and predominantly age was the major influencing factor across both of the studies. Moreover, the participants' HR varied throughout the experiments, suggesting an enhanced level of engagement whilst viewing the multimedia video clips. Furthermore, the results suggest that there is a potential future for wearables, if the QoE is a positive one and also if the design of such devices are appealing as well as unobtrusive.

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DECLARATION

The following papers have been published (or submitted for publication) as a direct result of the research discussed in this thesis:

Peer-reviewed Conferences

1. Hussain, N., Mesfin, G., Covaci, A. and Ghinea, G. (2018) 'Towards Augmenting Multimedia QoE with Wearable Devices: Perspectives from an Empirical Study', *IEEE International Conference on Multimedia & Expo Workshops (ICMEW),* San Diego, July, pp.1-6.

2. Mesfin, G., Hussain, N., Covaci, A. and Ghinea, G. (2018) 'Inverse and Transitivity of Cross-Modal Correspondence in Mulsemedia', *IEEE International Conference on Multimedia & Expo Workshops (ICMEW),* San Diego, July, pp.1-6.

3. Covaci, A., Mesfin, G., Hussain, N., Kani, E, Andres, F. and Ghinea, G. 'A Study on the Quality of Experience of Crossmodal Mulsemedia', *The 10th International Conference on Management of Emergent Digital EcoSystems*, Tokyo, Japan, Sep.

Journals

1. Mesfin, G., Hussain, N., Covaci, A. and Ghinea, G. (2019) 'Using Eye Tracking and Heart Rate Activity to Examine Crossmodal Correspondences QoE in Mulsemedia', *ACM Transactions on Multimedia Computing, Communications, and Applications*, 15(2), 34.

2. Covaci, A., Estêvão, S., Mesfin, G., Hussain, N., Kani, E. and Ghinea, G. (2019) 'How Do We Experience Crossmodal Correspondent Mulsemedia Content?', *IEEE Transactions on Multimedia,* pp.1-10.

3. Mesfin, G., Hussain, N., Kani, E., Covaci, A., Estêvão, S. and Ghinea, G. (2019) 'QoE of cross-modally mapped mulsemedia: an assessment using

eye gaze and heart rate’, *Multimedia Tools and Applications*, accepted for publication.

4. Kani, E., Hussain, N., Mesfin, G. and Ghinea, G. (2019) ‘On the Influence of Human-Factors in Cross-Modal Mulsemedia QoE’, submitted under review.

ABBREVIATIONS

ACR	Absolute Category Rating
AI	Artificial Intelligence
ANOVA	Analysis of Variance
APP	Application
APPS	Applications
AR	Augmented Reality
BPM	Beats Per Minute
CAGR	Compound Annual Growth
CG	Control Group
ECG	Electrocardiogram
EDA	Electrodermal Activity
EEG	Electroencephalography
EG	Experimental Group
EKG	Electrocardiography
EMG	Electromyography
GPS	Global Positioning System
GSR	Galvanic Skin Response
HCI	Human Computer Interaction
HMD	Head Mounted Display
HR	Heart Rate
IDC	International Data Corporation
IDT	Innovation Diffusion Theory
IF	Influence Factor
IPTV	Internet-based Protocol Television

LED	Light Emitting Diode
MOS	Mean Opinion Score
Mulsemedia	Multiple Sensorial Media
NFC	Near Field Communication
OLED	Organic light-emitting diode
QoE	Quality of Experience
QoS	Quality of Service
SPSS	Statistical Package for the Social Sciences
SUS	System Usability Scale
TAM	Technology Acceptance Model
TEL	Technology Enhanced Learning
TPB	Theory of Planned Behaviour
TRA	Theory of Reasoned Action
UEQ	User Experience Questionnaire
UX	User Experience
VoD	Video on Demand
VoIP	Voice over IP
VR	Virtual Reality

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Chapter 1: Introduction

1.1 Overview

This is the introductory chapter providing an overview of the research topic that thesis will explore. It is structured as the following: Section 1.2 gives a background of wearables; Section 1.3 discusses the history of wearables whilst Section 1.4 describes the market forecasts of wearables. Section 1.5 details the research problem. Section 1.6 outlines the research aim and objectives. Section 1.7 outlines the thesis structure and lastly the chapter is concluded in Section 1.8. The main purpose of this chapter is to provide an overview of the key issues associated with the subject of study.

1.2 Background

Over the years, wearable technologies have advanced in the digital world and have become more personalized. The most relevant definition of *'wearables'* or *'wearable technologies'* is that they are *"electronics and computers that are integrated into clothing and other accessories that can be worn comfortably on the body"* (Wright and Keith, 2014). Wearables come in the form of watches, glasses, jewellery, headsets, trainers and smart fabrics (Tehrani and Michael, 2014). Wearable devices provide wireless connectivity enabling users to connect to the internet and access or exchange information easily in real-time while moving (Lee et al. 2016).

Wearable technologies have aroused interest across different fields such as entertainment, education and gaming (Kalantari, 2017). However, according to Wright and Keith (2014), wearable technology has its great influence in the fields of health care, medicine, and fitness, as many wearable technologies utilize a wide array of sensors to measure one's wellbeing. Indeed, this has been proven in many studies (O'Loughlin et al. 2013; Iqbal et al. 2016; Bruno et al. 2018; Watt et al. 2019). Moreover, wearables have become prominent and many well-established companies such as Apple, Samsung, and Google have launched wearable products (Kamath, 2018).

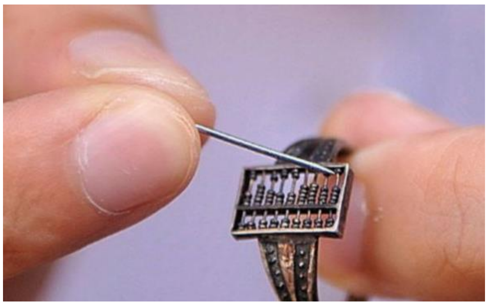
1.3 A Brief History of Wearables

The growth of wearables has evolved immensely since its early days that date back to 1284 when an Italian named Salvino D'Armate invented the first pair of wearable eyeglasses (Glasses history, 2018). Then around 1550 Peter Henlein a German locksmith introduced the Nuremberg egg spring-powered watches to tell the time to users and were typically worn as a necklace or attached to clothing (Ensign, 1948). During the 17th century in China the first Abacus wearable smart ring is thought to be invented by mathematician Cheng Dawei and the ring worked as a counting tool to perform quick calculations (Zolfagharifard, 2014). It was later in 1961 when two mathematicians Thorp and Shannon initially created and tested the first wearable computer to predict the roulette wheels. The cigarette pack sized computer was small and concealed in a shoe, it measured the speed of a roulette wheel and communicated predicted results to an earpiece (Thorp, 1998). However, these traditional wearables only performed simple tasks and were not advanced, as they did not involve computer functionalities and could not be programmed by the user to run various applications (apps). All these wearables can be seen in (Fig.1.1).

In 1968 the first virtual reality (VR) head-mounted display (HMD) system was built by computer scientist Ivan Sutherland. The HMD was designed so that a user can explore a virtual world (Sutherland, 1968). It was not until the mid-1970s when the consumer wearable computer products market began (Page, 2015). In this era wearable computers got smaller in size; it was all about miniaturization and watches were a popular starting point as Hewlett Packard HP-01 released an algebraic calculator watch in 1977 that did more than just tell the time - it included a stopwatch, a timer, alarm and a touchscreen interface (Marion et al. 1977; King, 2011). Similarly, in 1984 Seiko Epson released the RC-20 smart wristwatch with computer technology functionality. The smartwatch featured a touchscreen liquid crystal display (LCD) and users could run apps for scheduling, storing memos, displaying world times and performing calculations with a four-function calculator (Pocket calculator show, 2005). In 1979 Sony introduced the Walkman a commercial wearable cassette player equipped with a set of on-ear foam-pad headphones. Users were able to listen to music at anytime and anywhere with this portable and pocket-sized device. It made a huge success, by the end of 1999 selling 186 million cassette playing Walkman's (Santo, 2018). All these devices mentioned here can be seen in (Fig.1.2).

Salvino D'Armate eyeglasses[1]

Nuremberg egg watch[2]



Abacus ring[3]

Roulette wheel computer[4]

Figure 1.1: Traditional Wearables

[1] https://www.pinterest.co.uk/pin/390616967659135515/

[2] https://en.wikipedia.org/wiki/Nuremberg_eggs

[3] https://www.dailymail.co.uk/sciencetech/article-2584437/Is-wearable-computer-300-year-old-Chinese-abacus-ring-used-Qing-Dynasty-help-traders.html

[4] https://www.engadget.com/2013/09/18/edward-thorp-father-of-wearable-computing/

Ivan Sutherland HMD[5]

HP- 01 Watch[6]

Seiko Epson smartwatch[7]

Sony Walkman[8]

Figure 1.2: Late 1960's and 1970's wearables

During the 1970s and 1980s Steve Mann, hailed as the *'father of wearable computing'*, invented WearComp, an intelligent *"photographer's assistant"* system (Mann, 1997). The same author continued to work and develop a series of wearable systems that he named as WearCam (wearable camera) and WearTech (wearable technology). The wearable systems included a backpack mounted computer with a head-mounted display, audio wearables, surveillance wearable camera, lifelogging, augmented reality (AR) systems and mediated reality wearables (Mann, 2013a, 2013b). Most of his work has revolved around computerized eye wear that would resemble ordinary glasses which can be seen in (Fig.1.3). His best-known wearable device was a digital eyeglass (EyeTap) invented in 1999. The EyeTap is a wearable

[5] https://medium.com/@kaurgagan073/virtual-reality-5a0164a2a3c2

[6] https://www.theledwatch.com/hp_calculator

[7] https://www.wareable.com/smartwatches/the-origins-of-the-smartwatch

[8] https://spectrum.ieee.org/consumer-electronics/gadgets/the-consumer-electronics-hall-of-fame-sony-walkman

camera that projects computer generated content and became the predecessor to Google Glass (Mann, 2012) see (Fig.1.4).

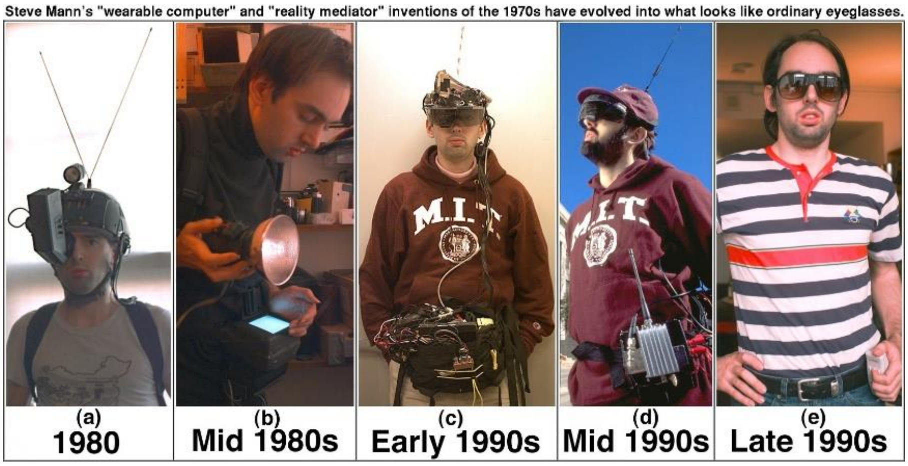


Figure 1.3: Evolution of Steve Mann's Eye Wear[9]

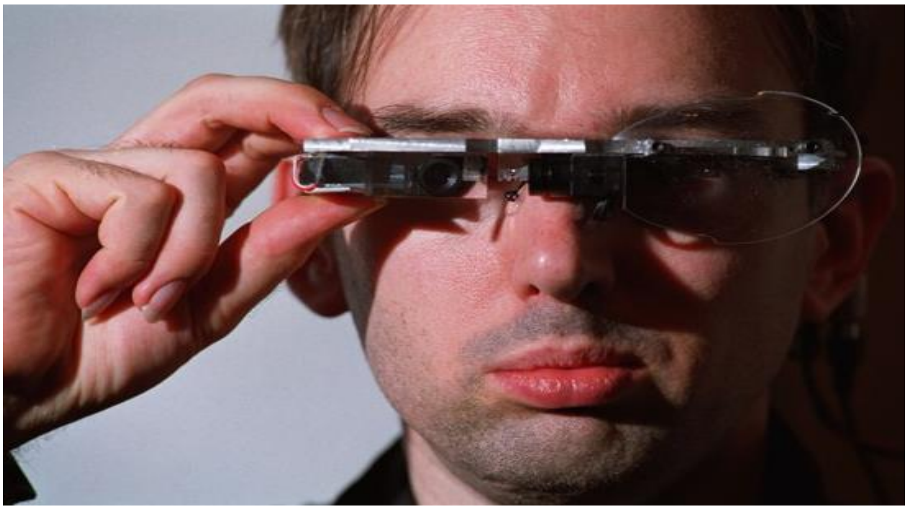


Figure 1.4: EyeTap[10]

In addition, in the year 1999 is when the first consumer Bluetooth a wireless technology headset was released. The small earpiece device transfers data, streams audio and information can be exchanged between multiple devices such as smartphones, computers, headphones, smartwatches and speakers (Medium, 2017).

[9] http://cyborganthropology.com/Steve_Mann

[10] https://www.newyorker.com/tech/annals-of-technology/glass-before-google

It was later in the years 2006 and 2013 that people began to pay attention and became more aware of wearable technologies. The Fitbit Company, founded in 2007 by James Park and Eric Friedman, released the first wireless fitness tracker that included step counts, calories burned, distance walked, sleep and activity intensity. The fitness tracker connects to a smartphone via Bluetooth (Fitbit, 2017). Then in 2012 Nike came up with an activity tracker (Nike+ FuelBand), enabling users to track their calories burned, steps taken and set daily goals to get fitter. Users' can connect and share their fitness information with the Nike+ online community via Bluetooth as well as set their own fitness goals, monitor their activities and engage with others in competition (Phin, 2013). Wearables started to get more advanced with the launch of Google Glass in 2014. Google Glasses connect to the internet enabling users to take pictures, capture information online, record videos and audio via voice commands. Due to the incomplete functionalities the glasses were halted (Techtrends, 2015). These devices can be seen in (Fig.1.5)

Bluetooth[11]

Fitbit[12]

Nike+ Fuelband[13]

Google Glass[14]

Figure 1.5: Modern Wearables

[11] https://en.wikipedia.org/wiki/Bluetooth

[12] https://www.amazon.co.uk/Fitbit-Wireless-Activity-Sleep-Wristband/dp/B00BGO0QEO

[13] https://www.digitaltrends.com/fitness-tracker-reviews/nike-fuelband-review/

[14] https://www.techtrends.co.zm/google-glass-production-halted/

1.4 The Market Growth Forecasts of Wearables

The market for wearable electronic devices has been thriving year after year. A statistics report by IDTechEx (2019) has conveyed that the general wearable market growth has increased steadily and has doubled in revenue since 2014 see (Fig.1.6). The same report predicted that in 2019 the wearables market would be worth $50 billion. Globally the market 2019-2024 is forecast to grow at a compound annual growth rate (CAGR) of 17.66% (Research and Markets, 2019).

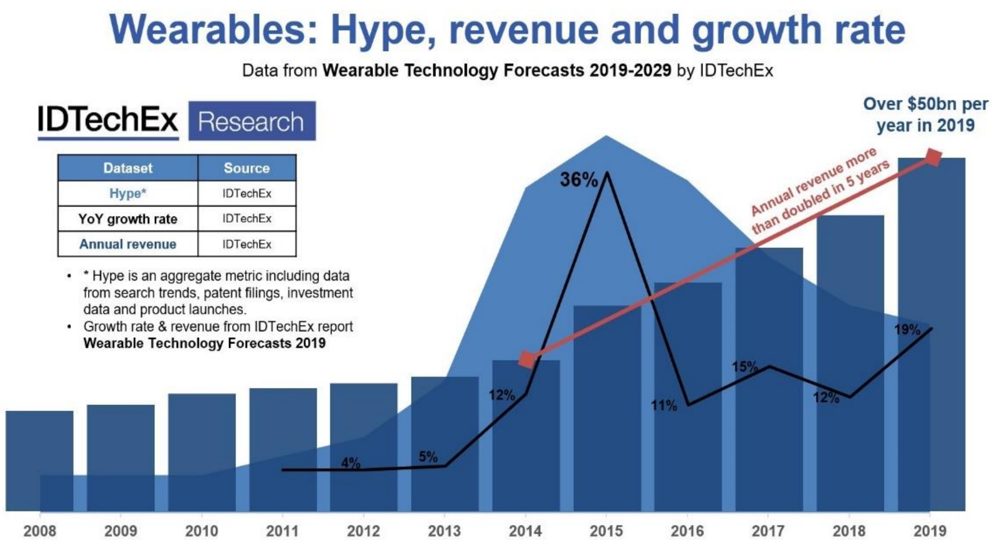


Figure 1.6: Statistics of Wearables[15]

The report by the International Data Corporation (IDC) (2019a) shows the breakdown of the individual wearable categories in terms of product shipment, market share and CAGR from 2019-2023 as seen in (Table1.1). The report shows clearly that wrist-worn devices have a strong market growth, especially the smartwatch category appearing to have a huge success as brands such Apple, Huawei, Samsung, Xiaomi and Fitbit are continuously advancing the wrist-worn devices to meet the user's needs as well as fit into their lifestyle (IDC, 2019b). Smartwatches were the popular wearable product and accounted for 44.2% of the wearables market in 2018. With a huge demand of such wearables, the expected

[15] https://www.idtechex.com/en/research-report/wearable-technology-forecasts-2019-2029/680

growth will reach 47.1% by 2023 (IDC, 2019a). The shipments of wrist-worn devices in 2019 amassed 34.2 million units with 28.8% year-over-year growth. The top five wearable companies for wrist worn devices can be seen in (Table1.2). Wrist-worn wearables are expected to reach 152.7 million units by the end of 2019. A prediction for 2023 is 194.1 million units with a CAGR of 6.2%. However, growth in the wrist-worn category will continue with smartwatches being in the top spot as wristbands will experience flat growth from 41.2% in 2019 to 32.5% by 2023 as China has already dominated the wristband market with brands such as Huawei and Xiaomi, and IDC expects this to continue (IDC, 2019b) see (Table 1.3).

Table 1.1: Wearables Forecast[16]

Worldwide Wearables Forecast by Product Category, including Shipments, Market Share, and 2019-2023 CAGR (shipments in millions)					
Product Category	**2019 Shipments***	**2019 Market Share***	**2023 Shipments***	**2023 Market Share***	**2019-2023 CAGR***
Clothing	3.0	1.5%	8.5	3.1%	30.2%
Earwear	54.4	27.4%	86.5	31.0%	12.3%
Watch	90.6	45.6%	131.3	47.1%	9.7%
Wristband	49.0	24.7%	50.4	18.1%	0.7%
Others	1.7	0.8%	2.3	0.8%	8.2%
Total	**198.5**	**100.0%**	**279.0**	**100.0%**	**8.9%**

Table 1.2: Top 5 Wearable Companies: Wrist-worn devices[17]

Top 5 Wearables Companies, Wrist-Worn Devices Only, by Shipment Volume, Market Share, and Year-Over-Year Growth, Q2 2019 (shipments in millions)					
Company	**2Q19 Shipments**	**2Q19 Market Share**	**2Q18 Shipments**	**2Q18 Market Share**	**Year-Over-Year Growth**
1. Xiaomi	5.9	17.3%	4.2	15.6%	42.2%
2. Apple	5.1	14.8%	4.7	17.8%	7.0%
3. Huawei	4.8	14.1%	1.7	6.6%	175.7%
4. Fitbit	3.5	10.1%	2.6	9.9%	32.0%
5. Samsung	3.2	9.4%	1.1	4.1%	195.1%
6. Others	11.7	34.3%	12.2	45.9%	-4.0%
Total	**34.2**	**100.0%**	**26.6**	**100.0%**	**28.8%**

[16] https://www.idc.com/getdoc.jsp?containerId=prUS44930019

[17] https://www.idc.com/getdoc.jsp?containerId=prUS45521319

Table 1.3: Worldwide Wrist-worn devices by product forecast[18]

Worldwide Wrist-Worn Wearables Forecast by Product, Shipments, Market Share, and 2019-2023 CAGR (shipments in millions)					
Product	**2019 Shipments***	**2019 Market Share***	**2023 Shipments***	**2023 Market Share***	**2019-2023 CAGR***
Smartwatch	66.5	43.5%	105.3	54.3%	12.2%
Basic Watch	23.3	15.3%	25.6	13.2%	2.4%
Wrist Band	62.9	41.2%	63.2	32.5%	0.1%
Total	**152.7**	**100.0%**	**194.1**	**100.0%**	**6.2%**

1.5 Research Problem

So far, there have been many wearables that have revolutionized the technological landscape and lifestyle of individuals. Whilst the popularity and growth of the wearables market has been undeniable, this is not to say that the sector is without its problems. There are many issues and challenges that have arisen and the most addressed were design, privacy, data security and cost. Design issues emerged in the 2000s as wearables appeared to be complex to use and huge to wear creating a negative experience, which alienated users, resulting in rejection (Moen, 2007; Bryson, 2007; Anderson and Lee, 2008; Amft and Lukowicz, 2009; Poslad, 2009; Paradiso et al. 2010). Moreover, other challenges such as privacy and data security concerns have created a barrier in user acceptance as well as adoption, especially in the healthcare domain (Motti and Caine, 2015; Pantelopoulos and Bourbakis, 2010; Ching and Singh, 2016). Price is also an issue with consumer adoption of wearables and has a significant effect on consumer decision-making (Zeithaml, 1988; Lee, 2009; Yang et al. 2016; Preusse et al. 2016).

[18] https://www.idc.com/getdoc.jsp?containerId=prUS45521319

Although researchers and experts have been increasingly discussing the problems associated with consumer acceptance of wearable devices and identified to some extent the underlying influencing factors, there is, however, a lack of studies centered around measuring the users' Quality of Experience (QoE) with wearables. QoE is crucially important as it encapsulates the end user's delight or annoyance towards a product or service (Brunnström et al. 2013). To the best of our knowledge not a single study has looked at the users' attitudes and behaviors towards wearables from the multimedia or multiple sensorial media (mulsemedia) (Ghinea and Ademoye 2012a; Ghinea et al. 2014) point of view which this thesis seeks to explore, these points will be more comprehensively justified in Chapter 2. Accordingly, this thesis will answer the following research question:

"How do wearables affect people's QoE in a multimedia and mulsemedia context?"

1.6 Research Aim and Objectives

In line with the research question, the following research aim for this study is defined below:

"To evaluate QoE of wearable computing devices in multimedia and mulsemedia contexts"

To meet the aim the following research objectives are defined:

- *Objective 1*: Design suitable questionnaires in capturing users' QoE when interacting with wearables. We intend to design questions in relation to the two wearables by incorporating system usability scale (SUS) questionnaire and user experience questionnaire (UEQ).

- *Objective 2*: Evaluate QoE with wearables in the multimedia context. Here we will follow a positivism research methodology and collect quantitative data via subjective measures (questionnaires) and objective measures a physiological metric (HR) to evaluate QoE.

- *Objective 3*: Examine the impact of mulsemedia on user QoE with wearables. Extend upon the first study and incorporate mulsemedia examining the perceptual impact of mulsemedia on wearable devices.

- *Objective 4*: Explore human factors to determine meaningful user requirements for effective interactions, which can then be used as recommendations for multimedia and mulsemedia applications and wearables. We will investigate the impact of age, gender and education on users' perception of both multimedia and cross-modal mulsemedia content with wearables.

- *Objective 5*: Propose a set of guidelines, which can be applied to either new or existing wearables, for evaluating user QoE. Our ultimate goal is to combine the findings from both of our studies (Chapters 4 and 5) into a set of comprehensive guidelines.

1.7 Thesis Structure

The structure of this thesis is as follows: in Chapter 2 we discuss user acceptance models, user experience, wearables, QoE and mulsemedia with the intent of defining research aims and objectives.

In Chapter 3, we describe and justify the research methodology that shall be used in the studies described in Chapters 4 and 5. We also introduce the questionnaires that will be employed in our studies.

In Chapter 4, we evaluate the user QoE using the traditional approach with two wearable devices, namely a haptic vest (KOR-FX) and a heart rate (HR) monitor wristband (Mio Go). Moreover, we examine the impact of these two wearables with the use of 7 multimedia video clips that the users viewed.

In Chapter 5, we use the non-traditional approach and apply mulsemedia to evaluate user QoE of two wearables that were previously used in Chapter 4. We used both subjective and objective measures. The experiment was structured, and participants watched 6 video clips with crossmodally matched smells whilst wearing the two wearable devices.

In Chapter 6, we combine the findings and the results obtained from the device impact evaluation experiments (Chapters 4 and 5) to formulate a set of QoE guidelines for wearables to enhance the user experience. Moreover, previous literature based on wearable guidelines will be discussed.

Finally, we conclude in Chapter 7 by highlighting our research findings and contributions.

1.8 Conclusion

In concluding, we remark that although wearables have had a substantial growth, the user experience, especially in the area of wearable computing, has only been investigated in a fragmented manner. Work has traditionally neglected the initial interaction between wearable devices and the user. Although research has explored the general problems (design, privacy and data security) with wearables, it has not measured the user experience in respect of their enjoyment towards such devices. The research problem highlighted in this chapter will be explored in depth within this thesis in the following chapters.

Chapter 2: Literature Review

2.1 Overview

Technology has had a significant impact across the world and especially the way in which people communicate with one another. There are many technology innovations that have developed rapidly over the years and multimedia is no exception to this. Whilst digital multimedia appeared over two decades ago, constant innovations in respect of communication infrastructure access devices, as well as multimedia rendering and production have meant that multimedia technology has remained at the forefront of innovation. Given the importance of end users in the acceptance and adoption of technology, the term QoE was initially introduced in the late 90s. QoE refers to the *"degree of delight or annoyance of applications or services"* (Brunnström et al. 2013). Although, there has been research done on QoE there is a gap that exists and that is with *'wearables'*. Wearables have known an increasingly popularity of late, becoming progressively affordable and offering a variety of options to the contemporary user. However, user experience is key as far as the adoption of modern technology and adapting QoE to wearables is long overdue, especially as wearable devices branch out into multimedia consumption and multi-sensorial interaction.

Wearable technologies' most evident manifestation is through computerised gadgets that can be worn on or underneath garments. They encompass a plethora of devices, such as watches, fitness trackers, glasses, headsets, clothing, jewellery, and are used in many fields, e.g. gaming, military, healthcare, education, entertainment and leisure (Jhajharia et al. 2014). When it comes down to acceptance, however, users tend to be reluctant to do so, due to privacy and security concerns (Ching and Singh, 2016; Motti and Caine, 2015). The most critical element of technology adoption is getting users to change their habits and precious few studies have discussed the acceptability of wearable devices. Researchers such as Spagnolli et al. (2014) have pointed out that there are issues such as privacy concerns and comfort that lead users to being reluctant to use wearable devices in real contexts. Moreover, as mentioned by Buenaflor and Kim (2013), due to social acceptance, not many users take to wearable computers; besides, human factor and technological considerations impact users in accepting technology. QoE research so far has not dealt with wearable devices - apart from a single study by Hupont et al. (2015) see Section 2.4.3 - as wearables have been mostly in the development phase. However, some are now commercially available and have progressively gained notable attention from users as well as markets.

There is scarcely any research done regarding QoE of wearable devices, notwithstanding the fact that both domains are of importance in the ICT sector. The main contribution of this work is to fill this existing gap, discovering user attitudes and acuities aligned with the interactivity associated with wearables. To this end, clear views will be evident through measuring QoE associated with wearable devices in multimedia and mulsemedia context. Also, a set of guidelines will be formulised to evaluate user QoE of wearables. The use of the guidelines will assist researchers or developers to examine QoE better for existing and future innovations linked to wearable devices. Accordingly, the structure of this chapter is as follows: Section 2.2 is about user experience; Section 2.3 discusses adoption theories whilst Section 2.4 looks at wearables. Section 2.5 discusses the limitations of wearables. Section 2.6 deliberates QoE and related work whilst Section 2.7 details mulsemedia and QoE. Lastly, Section 2.8 concludes this chapter.

2.2 User Experience

QoE is strongly linked to the user experience (UX) field, which focuses on human factors rather than technology itself. UX is based upon a person’s view about their interaction and use towards a system, product or service. Understanding user behaviour has been challenging, since it appears that measuring and evaluating UX is a problem, as this concept is still being debated, defined and explored by researchers as well as practitioners (Law et al. 2008; Lachner et al. 2016; Hussain et al. 2018). Also, many authors such as Dillon (2001), Hassenzahl (2006), Hassenzahl and Tractinsky (2006), Hassenzahl et al. (2006a, 2006b) have accentuated different aspects of UX that are beyond usability, exploring user's reactions, engagement and interaction with systems. Additionally, Vermeeren et al. (2010) have highlighted that people's experiences change overtime and when designing a product their involvement should be throughout the whole development phase during and after an interaction with a product. Along the same lines, Balasubramoniam and Tungatkar (2013) have stated that UX evaluation is much easier with existing products that people have been using for a longer period. However, it can be challenging to evaluate product experiences earlier on amongst users, seeing they are concepts plotted on paper and prototypes. Nonetheless, Petrie and Bevan (2009) have argued that evaluating UX earlier in the process of development will lead a product to be successful.

2.3 Adoption Theories

Modern technologies cannot be effective unless they are accepted. However, users tend to be reluctant in accepting and using contemporary technologies. To tackle this challenge Fishbein and Ajzen came up with Theory of Reasoned Action (TRA) in 1980, which defines relationships between beliefs, norms, attitudes, behaviour and intentions (Ajzen and Fishbein, 1980). Their model has its roots in social psychology and is used to predict and explain behaviour (Fig. 2.1). TRA suggests that behavioural intention is seen as the major predictor to a person's willingness to perform a behaviour. The TRA looks at two factors that determine behavioural intention which are an individual's attitude to the behaviour and subjective norms. Attitude is based around an individual's belief of a certain behaviour that makes either a positive or a negative contribution to their life. Subjective norms relate to a person's beliefs about their social world that could influence whether he/she should engage in the behaviour.

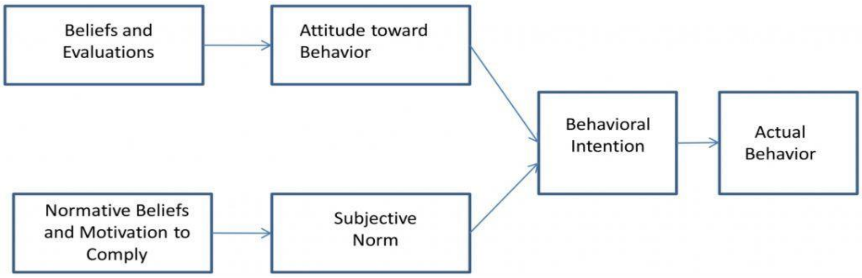


Figure 2.1: Theory of Reasoned Action[19]

The TRA has been used to predict a variety of different behaviours such as for coupon usage (Shimp and Kavas 1984), for nutrition knowledge (Shepherd and Towler 1992), for recycling (Goldenhar and Connell 1993), for dental care (Hoogstraten et al. 1985) and for donating blood (Bagozzi 1981).

Another theory is the Theory of Planned Behaviour (TPB), which is an extension to the TRA and involves a perceived behavioural control variable (Ajzen, 1985) see (Fig.2.2). TPB was developed to predict behaviours in which individuals have incomplete volitional control. According to Ajzen behaviour is controlled by intentions. Intentions are influenced by three constructs, which comprise the theory of reasoned action: attitude, subjective norm and an added construct of perceived behavioural control. The TPB's key contribution is the concept of perceived behavioural control defined as an individual's perception of how easy or difficult it is going to be to perform the behaviour (Ajzen, 1987).

TPB has been used successfully to predict and examine a wide range of behaviours and intentions especially in health studies including: cigarette smoking (Godin et al. 1992), weight loss (Schifter and Ajzen 1985), exercising (Godin et al. 1993), breast feeding (Swanson and Power 2005), and substance use (Connor and McMillan 1999). There are limited empirical studies that analyse the users' acceptance of wearable devices as this market is still in its maturing stage. One study by Turhan (2013) utilized TPB in the context of wearable technologies acceptance. In this study, the author proposed a model based on two wearables a smart t-shirt and a smart bra to understand consumer's acceptance of such devices.

[19] https://www.pinterest.co.uk/pin/300404237629790706/

The findings of the study show that the author incorporated other factors such as normative beliefs, self-efficacy, relative advantage, need compatibility and cost to improve their model.

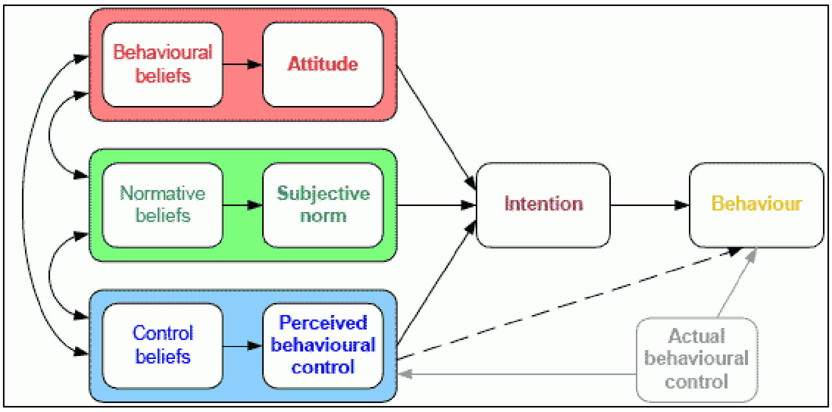


Figure 2.2: Theory of Planned Behaviour[20]

While TRA is a general model it was adapted by Davis in 1989 with a Technology Acceptance Model (TAM), which has its root on cognitive psychology, and it is an intention-based model. Davis (1993) has specified that user acceptance determines the success or failure of any system. He came up with TAM that has been widely used, studied continuously and expanded over the years. The purpose of TAM is to predict user acceptance by looking at two factors perceived usefulness and perceived ease of use (Davis, 1989). Many of the researchers who have investigated consumers' adoption of wearable technologies have utilised the TAM model (Chuah et al. 2016; Lee, 2009; Cheng and Mitomo 2017; Krey et al. 2016; Choi and Kim 2016; Chae, 2009; Hwang, 2016; Kang and Jin 2007). However, these researchers have extended this model by integrating external variables such as perceived comfort, perceived aesthetics and perceived enjoyment.

TAM has been used in many other fields to test user acceptance such as smartphones where Park and Chen (2007), found meaningful results, as perceived usefulness and attitude were the attributes that were professed positively amongst smartphone users. TAM has also been used in health care for telemedicine

[20] https://www.cleverism.com/theory-of-planned-behavior/

technology (Hu et al. (1999) and prototype system for postural assessment with physiotherapists (Schaik et al. (2002). This model has been applied in other studies for example spreadsheet applications (Mathieson, 1991), word processors (Davis et al. 1989), websites (Koufaris, 2002), e-mail (Szajna, 1996), e-collaboration (Dasgupta et al. 2002), web browser (Morris and Dillon, 1997), blackboard (Landry et al. 2006), e-learning (Masrom, 2007) and smart payment card (Diamond et al. 2018). Below in (Fig.2.3) is the illustration of the model:

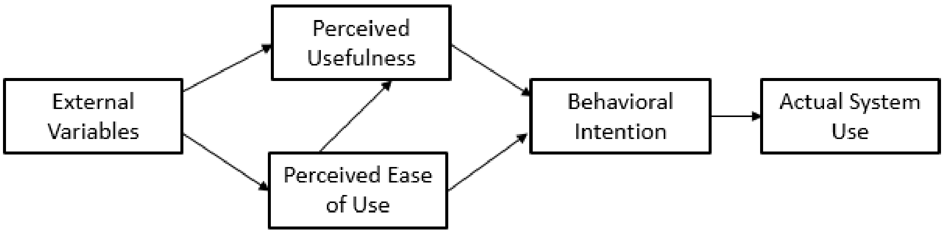


Figure 2.3: Technology Acceptance Model (Venkatesh and Davis, 1996)

Whilst TRA, TPB and TAM look at behaviour and the overall acceptance of technology, Roger's Innovation Diffusion Theory (IDT) explains the reason behind why some innovations fail as opposed to others being adopted. According to Rogers (1995), the characteristics of acceptable technology play a key role and he devised an IDT, which feature five characteristics: compatibility, complexity, relative advantage, trialability and observability see (Fig.2.4).

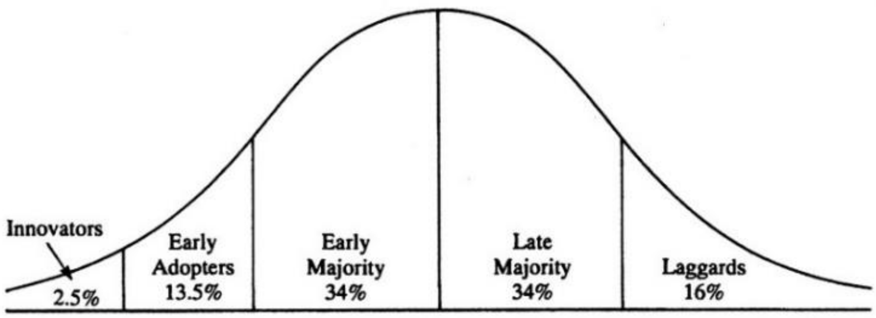


Figure 2.4: Rogers Innovation Diffusion Theory[21]

[21] https://extensionaus.com.au/extension-practice/diffusion-of-innovations-theory-case-studies-and-discussion/

This theory has been applied at both organizational and individual levels of analysis (Zaltman et al. 1973). Innovations are adopted at different rates and Rogers identified five categories of adopters: innovators, early adopters, early majority, late majority and laggards. Roger's theory has been widely used such as online games Cheng et al. (2004), and mobile banking Al-Jabri and Sohail, (2012). In respect to wearables adoption, a study by Wu et al. (2016) explored consumers' intentions to use smartwatches by employing IDT along with TAM. In their model, they added perceived enjoyment to improve its explanatory power.

2.4 Wearables

In recent years, wearable technologies have gained popularity and have attracted wide attention in academia and industry (Kalantari, 2017; Jarusriboonchai and Häkkilä 2019). Billinghurst and Starner (1999) have suggested that wearable devices are new ways of managing information as it is distributed by small gadgets. They have encountered that the combination of devices such as back packs, belts and head mounted displays have improved user performance across applications that include navigation assistance and aircraft maintenance. Hence, wearable devices may have had an impact on user performance, but there is hardly any information as to whether the new and upcoming devices are likely to meet the user requirements in order to give them a good user experience.

2.4.1 Smart Jewellery

The digital trend of smart jewellery has changed rapidly, as rings, necklaces and bracelets are now transformed into smart gadgets and through these accessories, people can access their mobile phone applications. Smart jewellery brings fashion and technology together, and leading jewellery designers of around the world have acknowledged the role of technology in jewellery. Companies such as Ringly and Vinaya specialise in digital jewellery and now well-known organisations such as Fossil and Swarovski have started to adopt technology with their jewellery

(WearableTechDigest, 2016). Some of the favourites include Zenta[22], which acts as a biometric bracelet enabling people to improve upon their wellbeing. There are other pieces of jewellery that are based upon health such as Altruis X[23], Aries[24] and Ear-O-Smart[25] (Charara, 2016; Maslakovic, 2016).

Ju and Spasojevic (2015) have stated that smart jewellery will gradually change the way people interact with mobile phones. An example of this is the Ringly[26] Luxe smart ring, which is a wireless-enabled ring, in which vibrations and light features are used to alert the wearer to notifications that include calls, texts and emails. Although Ringly's design received positive feedback, it has only managed to gather average user reviews (Prasuethsut, 2016; Wearable Tech Reviews, 2016). A digital jewel, such as Ringly, is not just a fashion accessory but also determines functionalities. Such functionalities could be a feedback tool on daily physical activity, a reminder of fluid intake or any other type of activity (e.g. sleep). Fortmann and Heutan (2015) investigated which requirements are deemed important for digital jewellery. From their study, they found that users cared less about the customisability, context awareness and body location requirements but were more interested in the display design, interaction and functionality.

Apart from the requirements of digital jewellery Silina and Haddadi (2015), examined jewellery-like devices and identified that the consumer base involves women of different age groups and tastes. Similarly, Gokey (2016) has discussed that the few pieces of digital jewellery that are available to purchase are mostly aimed at women. This is due to women preferring a discreet yet fashionable wearable technology that gives notifications and fitness in style. Not all-smart jewellery is designed for women, as smart rings can be worn by both genders. These

[22] https://www.wareable.com/health-and-wellbeing/zenta-vinaya-specs-price-features-release-date

[23] https://www.telegraph.co.uk/connect/small-business/story-of-vinaya-a-jewellery-tech-business/

[24] https://ringly.com/products/smart-bracelet

[25] http://thirdwavefashion.com/2015/09/wearable-tech-startup-meet-ear-o-smart/

[26] https://ringly.com/products/smart-ring

include Motiv[27] the iPhone and Android compatible smart unisex ring that comes in three colours silver, rose gold and slate grey. It involves different sizes to fit both men and women. This ring shows that it was possible to put a fitness tracker on a finger that monitors steps, distance, heart rate (HR) and active minutes. Oura[28] is another ring that comes in three colours and has varied sizes. However, it tracks sleep, body temperature as well as the HR and has been worn by Prince Harry (Heathman, 2018). Both Motiv and Oura have been reviewed as being useful (Hartmans, 2017; Caddy, 2017; Caddy, 2018; Bradshaw, 2018).

Many of the smart rings have similar functionalities that involve health and fitness or connect to mobile phones to notify text messages, calls and emails. Still, there are some rings such as Java[29] and NFC[30] (Near Field Communication) that unlock doors, smartphones, computers, and solve forgotten passwords (Johnson, 2018). The Java ring has been tested at a school just outside Orlando where students were provided with the rings that are programmed to unlock doors, store electronic cash to pay for lunches and allow students to check out books (Bonsor, 2018). Other types of jewellery such as necklaces and bracelets are also integrated with functionalities that track and monitor activities that would aid on improving one's health. One of the necklaces that has gained a high praise from its reviewers is the Bellabeat Leaf Urban[31] fitness-tracking pendant, which can be worn in different ways, such as a necklace, a clip or a bracelet. This device is specifically designed for women, and customers who purchased and used this device were pleased with the functionalities and its elegant design (Gokey, 2017; Fiorillo, 2016). However, whilst smart jewellery may be at the forefront of next generation technology but, there are limited amounts of products in this area and not many people have used such devices as they are less common. The smart jewellery can be seen in (Fig.2.5).

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[27] https://mymotiv.com/

[28] https://ouraring.com/

[29] https://electronics.howstuffworks.com/gadgets/home/digital-jewelry3.htm

[30] https://nfcring.com/

[31] https://www.bellabeat.com/products/leaf-urban

Zenta Bracelet | Altruis X Bracelet | Aries Bracelet | Bellabeat Leaf Urban | Ear-O-Smart Earrings

Ringly Luxe Ring | Motiv Ring | Oura Ring | NFC Ring | Java Ring

Figure 2.5: Smart Jewellery

2.4.2 Wrist-Worn Devices

Wearable technology comes in many forms to communicate information to users. There are various types of wearables, of which wrist wearables are popular and have become mainstream. There are two main types of wrist-worn devices: smartwatches and wristbands.

Smartwatches: A smartwatch is a minicomputer designed to be worn on the wrist and is one of the most well-known wearable devices (Bieber et al. 2013). Smartwatches can be worn for either general or for fitness purposes. Most are smartphone-dependent and feature a touchscreen, voice controls, global positioning system (GPS), run apps and display notifications. Smartwatches paired with smartphones can playback digital media for instance audio tracks enabling the user to change volume with Bluetooth wireless headphones. In addition, many of these devices emulate fitness trackers focusing on health and activity monitoring like HR, calories burned, and steps taken (Chuah et al. 2016; Silbert 2019).

The Apple watch as an example connects to an iPhone displaying notifications on a wrist enabling a wearer to respond to phone calls, texts, emails, calendar appointments and social media updates (Dempsy, 2015). The watch will serve to not only tell time and date, but it tracks a user's health and HR showing metrics on its watch face. Moreover, the watch enables a wearer to carry out numerous activities such as make contactless payments using Apple Pay, stream music or podcasts and use Siri to get quick information. In addition, the watch is water resistance, being suitable to wear for swimming or surfing (Apple Inc. [US], 2018a). The overall impressions from the reviewers were varied as some were enthralled whilst others were critical (Rosenfield, 2017). Despite Apple's best efforts, some people were sceptical about the accuracy of the data in relation to HR and other physical tracking features. To validate the accuracy Kirk (2016), examined three wrist-worn activity monitors in which Apple watch was one of them and was found to be the most accurate. Studies by Dooley et al. (2017) and Abt et al. (2017), also tested the Apple watch and confirmed that the validity of measuring the HR was more accurate compared to other wrist-worn devices.

Other related research by Bai et al. (2017), Fokkema et al. (2017) and Veerabhadrappa et al. (2018), have revealed that the validity and reliability of the watch has proven to be most accurate when assessing the energy expenditure, daily step counts and distance (walking speed). Although these studies have already shown a good accuracy of HR measurement according to Wallen (2015) and Dooley et al. (2017), the accuracy of the energy expenditure was found generally poor in relation to weight loss. No device will show perfect results as each device differs when used for different purposes and it depends upon the intensities of the workout or an activity that is carried out by a user. Regardless of a range of reported accuracies from these studies, consumers continue to show a great deal of interest in them especially the wrist-worn devices.

Apple continue to develop and redefine their smartwatches. The newer version Apple watch series 4[32] has a larger display screen and there are life saving features to improve a user's wellbeing. These features include a fall detection, an electrocardiogram (ECG) for heart readings, low and high HR notifications, emergency services and a breathing application (app) to remind users to breathe throughout the day (Apple Inc. [US], 2018b). Many users have complimented the design and have found the device to be useful (Snelling, 2018; Hall, 2018). Also, there are other smartwatches such as Samsung Galaxy[33] , Fitbit Versa 2[34], Mobvoi TicWatch E2[35] and Fossil Sport[36] that share similar functionalities as the Apple watch. Most of the smartwatches have built-in GPS to track user's location, monitor users health and users can reply to messages as well as receive calls. All these smartwatches can be seen in (Fig.2.6).

32 https://www.apple.com/uk/apple-watch-series-4/

33 https://www.samsung.com/uk/wearables/smart-watch/

34 https://www.fitbit.com/uk/shop/versa

35 https://www.mobvoi.com/us/pages/ticwatche2

36 https://www.fossil.com/en-gb/smartwatches/explore/sport/

Figure 2.6: Smart Wrist-Worn Devices

Wristbands: Wristbands often called *'fitness trackers'* focus on health and activity monitoring of one's wellbeing (Becker et al. 2017). These devices are mostly designed for athlete and gym goers to help them improve upon their health. Also, fitness trackers can be worn by anyone who's looking to advance and monitor their general health. Whilst some have basic fitness tracking others have more features such as built-in GPS, smartphone compatible, and a range of physical activities giving a user valuable insight on their physical and mental state (Gabrielson, 2016). Fitness tracking devices have various types of sensors embedded that do more than just provide data about a user's physical activities (e.g. steps, calories and distance). Many of these wearable devices measure biometrics data from HR monitoring, body temperature to tracking sleep quality (Coorevits et al. 2016). With this data, individuals can obtain intuitions about their body and lifestyle as they are reminded of their health status.

Garmin Vivosmart 4[37] is an example everyday wear tracker that is named as one of the top fitness bands in the Independent (Alger, 2019), Techrader (Peckham, 2019) and The Telegraph (Rear, 2018). This device has a slim monochrome organic light-emitting diode (OLED) touch screen; it is waterproof and has a battery life that lasts up to 7 days. The device has an accompanying smartphone app called *'Garmin connect'* where users can view detailed data of their health. Vivosmart 4 has fitness sensors that track a user's daily activity such as calories burned, steps taken, floors climbed intensity minutes and sleep cycles. Other health monitoring tools comprise continuous HR monitoring, relaxation breathing timer, all-day stress tracking, pulse oximeter, body battery energy monitor and activity timers. The activity timers are

[37] https://buy.garmin.com/en-GB/GB/p/605739

for runs, pool swims and walks. The pulse oximeter monitors a wearer's blood oxygen saturation levels at night giving them a better understanding of their sleep. Not only that, the body battery measures the energy levels throughout the day letting a wearer know the optimal time for activity and rest. In addition, just like smartwatches, this tracker receives notifications, along with vibration alerts such as calls, texts and calendar events via mobile (Garmin, 2018).

The Garmin Vivosmart 4 has been reviewed as an affordable yet easy to use wearable device and users have praised the long battery life (O'Connor, 2019; Song, 2018 and Carnoy, 2018). However, a few people have found the display screen of the device narrow and would have preferred if there was a built-in GPS to track the location when running or cycling (Munn, 2018; Tan, 2018 and Langley, 2018). Examples of other wristbands mostly include GPS and share similar functionalities such as Fitbit Charge 3[38], MOOV[39] , Xiaomi Mi band 4[40] and Huawei Band 2 Pro[41] see (Fig.2.7). Generally, the use of wrist-worn devices, both smartwatches and wristbands, are used for two different purposes such as smartphone notifications and fitness tracking. These two types of products have an accompanying smartphone app displaying advanced analytics. With a huge popularity of these devices amongst consumers, companies tend to refine and release newer versions every year with added features to make them more desirable.

Figure 2.7: Fitness Trackers

[38] https://www.fitbit.com/uk/charge3

[39] https://store.moov.cc/products/moov-now

[40] https://www.mi.com/global/miband

[41] https://consumer.huawei.com/uk/wearables/band2-pro/

2.4.3 Virtual and Augmented Reality Devices

There are a whole raft of virtual reality (VR) headsets available from high-end ones like Oculus Rift[42], PlayStation VR[43] and the HTC Vive[44] to mobile experiences such as the Samsung Gear VR[45], Google DayDream View[46] and Google Cardboard[47] see (Fig.2.8) (Greenwald, 2017), (Porter, 2018). VR is one of the modern technologies, which was introduced a few decades ago and has taken a vital role in the field of technology in a very short time. VR enables the user to interact with artificial environments that are created with software giving a sense of reality. This is captured through 3D environments being generated and 3D objects that are overlaid with computer graphics where users completely immerse themselves in the VR world (Silva et al. 2003).

Figure 2.8: Various VR headsets

There have been a few studies that have explored the use of VR headsets amongst users. Hupont et al. (2015) looked at QoE and compared the VR head mounted display *'Oculus Rift'* with 2D PC screens in relation to gaming. They found that Oculus Rift did increase the sense of immersion in the virtual world with users as well as the QoE. Also, their results conveyed that the perceived usability of the

[42] https://www.techspot.com/products/audio-video/oculus-rift-s.202520/

[43] https://www.playstation.com/en-ca/explore/playstation-vr/buy-now/

[44] https://www.vive.com/us/

[45] https://www.samsung.com/global/galaxy/gear-vr/

[46] https://arvr.google.com/daydream/

[47] https://arvr.google.com/cardboard/

Oculus Rift received positive feedback than the 2D PC screen. The only downfall was that many users reported feelings of nausea after wearing the headset.

Similarly, Tan et al. (2015) linked Oculus Rift and a desktop computer to explore user's experiences in playing a shooting game. From their study, they found that the Oculus Rift heightened the overall experience, as users' felt immersed in the game as compared to the desktop computer. Whilst some of the users suffered cyber sickness after wearing the device, it did not affect most user's experiences. Also, Amin et al. (2016), compared immersion between three platforms the Oculus Rift, Cardboard VR and a desktop display. The users (patients) played a game for pain management that is designed to help distract their physical pain. The results were very close, but the Cardboard VR provided an acceptable amount of immersive experience than the Oculus Rift. VR technologies are being adopted by many consumers who have started to acknowledge and use them especially when playing games.

As well as VR, the momentum that has gained popularity in the human computer interaction field (HCI) is called *'Augmented Reality'* (AR). AR was pioneered by Mizell and Caudell in the 1990's (Krevelan and Poelman, 2010). AR is used to simplify 2D and 3D computer graphics which are based upon real objects that can be visualized by users. The interfaces of AR involve 3D objects that appear in front of a user's face. This technology is the fusion of real and virtual reality combined with the physical world.

AR is widely used in the medical and the gaming industry, though it is now being adopted in the other industries because of its uniqueness (Billinghurst and Kato, 2002), (Blecken, 2009). There are many AR glasses that have been developed including Google Glass[48], Magic Leap Goggles[49], Microsoft Hololens 2[50], Vuzix

[48] https://www.techtrends.co.zm/google-glass-production-halted/

[49] https://www.magicleap.com/magic-leap-one

[50] https://www.microsoft.com/en-us/hololens

Blade AR[51], Optinvent Ora-2[52], and Everysight Raptor[53] smart glasses system see (Fig.2.9). These glasses contain similar functionalities such as battery, internet-enabled computer, camera, speaker, voice and touch controls in an eyeglass form factor (Diaz, 2019).

Figure 2.9: Various AR Glasses

One of the smart glasses that has been mostly studied is Google Glass. Leue et al. (2015), for instance, found that the device enhanced majority of the visitor's knowledge and understanding of paintings within the art gallery. Another study by Vorraber et al. (2014) reveals that the utilisation of Google Glass enhanced concentration with tasks in hand by reducing neck and head movements, as usually a surgeon would need to view several remote monitors during surgery. Correspondingly, Moshtaghi et al. (2015), found the Google Glass to be beneficial in the medical field amongst surgeons who can communicate with one another more efficiently from remote locations. Also, it appears from this study that the Google Glass is a teaching mechanism to medical students as the surgeon can stream the video of a surgical procedure to any computer in real time. This enables the students to visualise the operation outside of the operating room as well as gaining an immersive learning experience. On the other hand, both studies have highlighted that although Google Glass has been helpful, it has drawbacks that involve data privacy, low battery capacity and the fact that heat is generated due to multiple tasks running on the device. Likewise, Brusie et al. (2015), assessed the usability of both

[51] https://www.vuzix.com/products/blade-smart-glasses

[52] http://www.optinvent.com/

[53] https://everysight.com/product/raptor/

Google Glass and Vuzix M100 and encountered that both devices have problems. It was known that Google Glass has overheating, connectivity and voice control problems whereas, Vuzix M100 has problems with focusing a user's eyes onto the screen due to obstruction of view in the display eye, as well as lack of an expansive library for voice recognition. These problems have been addressed and are in the process of being rectified by developers.

Whilst AR eyewear is mostly used in the medical, military and gaming fields, it has not come in the view of being used for everyday purposes for everyday routines or tasks. The glasses usually come with high costs, being exorbitant for consumers to purchase. In addition, the developments of AR glasses are not being launched enough. This could be due to not many people being aware of AR technologies or because they appear to look complex to use and the trend of wearing smart glasses on the street has not been visible.

2.4.4 Smart Clothing

Smart clothing has become appealing to many people and is defined as *"a new garment feature which can provide interactive reactions by sensing signals, processing information, and actuating the responses"* (Suh et al. 2010). However, its origins can be traced to the last century, as in 1990 smart clothing was introduced and used for military purposes in European countries and the U.S. During the years, smart clothing has evolved as fashion and textile sectors joined in product development. The demand of smart clothing started to increase, and high fashion brands started to apply technology to their fashion pieces (Suh et al. 2010). The usage of smart textiles ranges from fashion, sports, health and fitness that can monitor and transmit biomedical information on wearers.

2.4.5 Fashion

There are aesthetic applications for smart fabrics that light up in patterns, can change colour and even display pictures or video. Fashion is a trend that constantly changes and what has become obvious amongst designers are light-emitting diode lights (LED) which are being integrated into garments. Dalsgaard and Sterrett (2014) have stated that fashion designers use LEDs (colour changing technology) to enhance garments for stage performances. In addition, smart textiles are being designed with inbuilt solar panels. Designers such as Moritz Waldemeyer[54] showcased at the closing ceremonies of Olympics in London 2012 with lighted garment displays. The carnival costumes were embedded with 140 LED lights that were made to pulse at the rhythm of Brazilian drummers. Another designer, Rainbow Winters designed sound reactive Thunderstorm dress[55] in 2012. She used interactive textiles in her garments where the pattern and colour change and light up in response to sound as the volume rises; the dress illuminates (Dalsgaard and Sterrett, 2014).

One of the most talked about smart clothing was designed by fashion designer Pauline van Dongen who created a wearable *'solar dress'*[56] in 2013 (Dalsgaard and Sterrett, 2014). The dress became successful and in 2015, she designed a *'solar shirt'*[57]. Smelik et al. (2016), tested two pieces of smart clothing from Pauline's collection the solar dress and shirt amongst participants. From their study, they found that participants felt uncomfortable in wearing the dress and would not wear it daily whereas the solar shirt is much more comfortable but still has some flaws. As well as other designers such as Mary Huang and Hussein Chalayan, companies such as Philips Lightening, Moon Berlin and Cute Circuit have all produced outfits that assimilate technology. A specific company that stood out was Studio Xo[58] with their interactive clothes such as the *'Volantis'* dress which made pop star Lady Gaga levitate (Fales, 2015).

[54] http://www.waldemeyer.com/olympic-ceremonies

[55] https://qeprize.org/createthefuture/redefining-fashion-interactive-textiles/

[56] http://www.paulinevandongen.nl/project/wearable-solar/

[57] http://www.paulinevandongen.nl/project/wearable-solar-shirt/

[58] https://fashioningtech.com/2013/12/19/gagas-flying-hovercraft-dress-volantis-by-studio-xo/

Moreover, the University of Manchester's National Graphene Institute has collaborated with a wearable technology company Cute Circuit[59] and produced an innovative graphene dress that recognises and changes colour of a wearer's breathing pattern (Cute Circuit, 2018; Halliday, 2017 and Distor, 2017). Cute Circuit have also started to integrate phones and cameras into their clothing pieces where famous faces such as Katy Perry, Ellie Goulding and Nicole Scherzinger have worn to events (Walker, 2015). Smart clothing is emerging as fashion designers have started to branch out and be creative with their garments. The smart fashion wear can be seen in (Fig.2.10).

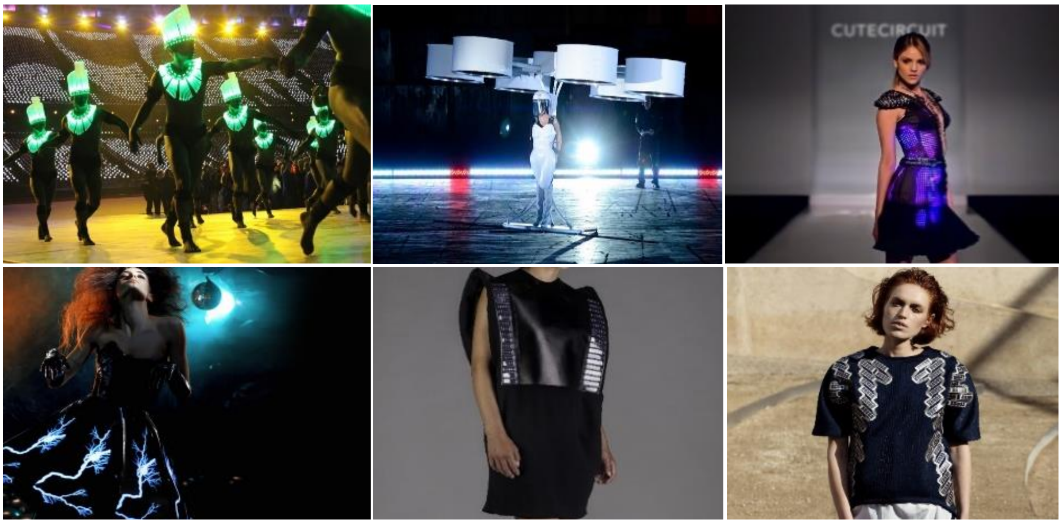


Figure 2.10: Smart Fashion Clothing

2.4.6 Healthcare and Fitness

Smart health and workout gear are becoming widespread in athletic apparel that monitor a wearer's physical condition. Shirts, pants, shorts and under garments have sensors weaved into them that can track many aspects of one's performance. These include monitoring HR, calories burned, breathing rate, temperature, muscle tension, speed, distance, location and other physiological functions aiding the workout to be more efficient (Qiu et al. 2018; Vagott and Parachuru 2018; Ahmadi

[59] https://cutecircuit.com/graphene-dress/

et al. 2015). Smart clothes are designed to look like regular clothes making them more appealing as they have invisible bio-metric sensing technologies integrated in them making the garments seamless than looking like tech. Start-up brands like Athos[60], Hexoskin[61], and Myontec[62] have biometric-sensing technologies integrated in their fabrics and market their products to athletes. These brands have HR, pulse rate and temperature sensors built in their smart apparel.

One brand such as Hexoskin have designed garments that track muscle output and form. Specifically, the Hexoskin smart shirts measure ECG, sleep, lungs, stress, fatigue, respiration rate and activity (steps, calories and cadence). These garments are connected to a smartphone app and the data is transmitted via Bluetooth in real time (Hexoskin, 2018). Hexoskin's smart shirts have been reviewed by end users as being comfortable and most accurate when measuring heart and breathing rate but the prices are quite high (Bort, 2016; Duffy, 2014). One study by Phillips et al. (2017), examined the validity and reliability of Hexoskin shirt. From their results, the shirt was found to be reliable yet valid when carrying out moderate to dynamic activities. Another example, workout gear such as Physiclo's[63] leggings and shorts have built in resistance bands designed to help an athlete burn more calories and provide substantial training benefits to their muscles.

Physiclo's clothes can be used for many types of athletic training such as jogging, cycling, jumping, hill sprints and many more (Physiclo, 2017). The garments are designed for both genders and have received positive reviews in terms of functionalities, as some have highlighted that they found the garment to be very effective. Nonetheless, some did point out that the garment is rather uncomfortable to wear as well as the design doesn't fit properly on the body (Laurence, 2017; Weidaw, 2017). There are many other brands who have developed similar garments

[60] https://www.shop.liveathos.com/products/mens-upper-body-kit

[61] https://www.hexoskin.com/

[62] https://performbetter.co.uk/product/myontec-mbody-pro-portable-emg/

[63] https://physiclo.com/

in relation to fitness such as Ralph Lauren with their Polo Tech smart shirt[64] (Spears, 2014) and Polar Team Pro[65] see (Fig.2.11).

Figure 2.11: Smart wearable fitness clothing

In addition to the smart garments mentioned above, there are socks, shoes and insoles that are embedded with sensors to improve a runner’s training. Smart footwear provides runners actionable information from artificial coach built-in sensors that feed data via Bluetooth to a user’s smartphone app. Taking the Sensoria[66] fitness socks as an example, are designed for runners to run fast and avoid injuries. The smartphone-compatible running socks interact with the user through an automated coaching assistant. The socks have integrated pressure and force sensors that detect a user’s activity, distance tracking, speed, cadence, foot landing and running style. Also, the sock connects to an anklet that is worn on the cuff of the sock and wirelessly relays data in real-time from the sensors which is sent to the user’s smartphone via Bluetooth. Although these socks have been designed by developers to be as conventional as possible, there have been some users who were not keen on the cost and usability of these socks. The users have

[64] https://www.designboom.com/technology/ralph-lauren-tech-polo-biometrics-us-open/

[65] https://www.polar.com/uk-en/b2b_products/team-pro

[66] https://www.sensoriafitness.com/smartsocks/

reported in the reviews that the anklet was irritating to wear and that the socks are expensive to purchase (Ferenstein, 2014; Dolcourt, 2015; Hunley, 2016).

Besides socks, there are smart shoes that have built in sensors to track gyroscope, magnetometer, accelerometer and more to provide a detailed information to runners about their running form. Brands such as Under Armour HOVR[67] and Altra IQ[68] have designed digitally connected smart shoes for fitness tracking. One pair of shoes that have stood out amongst users are the Under Armour HOVR shoes. Under Armour designed a line of running shoes that have been deemed to be stylish, comfortable and lightweight to wear by users and experts (RunRepeat, 2018; Believe in The Run, 2017). Their smart shoes are fitted with a chip that detects several key running metrics of a user's run. The sensors within the shoes connect to the smartphone app called MapMyRun that displays data collected from the run as well as capturing real-time location via the phone's GPS (Under Armour, 2018).

Correspondingly, there are smart insoles developed by Digitsole[69] and Arion[70] that share comparable fitness tracking functionalities as the shoes and socks. Both insoles can be used in any type of shoe by either slipping or replacing the original insole. The insoles are designed to improve a user's running or pedalling technique to minimise risk of injury. Digitsole and Arion insoles are connected and controlled via smartphone. Both insoles feature artificial intelligence (AI) where audio feedback is based on the metrics that coaches a user as they run (Arion, 2017 and Digitsole, 2017). As well as tracking a user's run, Digitsole's innovative foot product has heating capabilities where a user can adjust the temperature of their shoes by connecting to the mobile app enabling them to have warm feet when carrying out activities in winter (Digitsole, 2017). Besides the eight sensors, Arion insoles have foot pods that attach to the shoe and feature Bluetooth, GPS, accelerometer and gyroscope to track the movement of the user's body. Also, the

[67] https://www.underarmour.com/en-us/mens-ua-hovr-infinite-running-shoes/pid3021395

[68] https://www.altrafootwear.co.uk/torin-iq

[69] https://www.digitsole.com/

[70] https://www.arion.run/product/arion-smart-insoles-2-0/

foot pods have LEDs for safe running at night. The one aspect of Arion that is different among other footwear is that the real-time feedback of data is displayed in the form of live heat-maps giving a user a detailed insight of their running technique (Arion, 2017). These insoles have received mixed reviews (Beavis, 2017; Easton 2017). Most users have been pleased with Digitsole in keeping their feet warm but were unhappy with the design of the insole being bulky (Roberts, 2017 and Kastrenakes, 2015). Footwear can be seen in (Fig.2.12).

Figure 2.12: Smart socks, shoes and insoles

2.5 Limitations

Wearable technologies are not always accepted due to people’s views and opinions which are always changing, and this is a challenge but, finding out how they feel in wearing the wearables is something that could aid developers in improving upon their designs or functionalities to meet their needs. To this end, many factors are perceived as being influential in accepting wearables. For instance, Ariyatum et al. (2005) highlighted that the physical appearance of a wearable plays a key role when it comes to acceptance. Moreover, the wearable device should fit the user’s personality and lifestyle, and indeed the device’s usability, functionality and price are also crucial factors when it comes to the device’s acceptance. Similarly, Bodine and Gemperle, (2003) claim that the acceptance of wearables is based on perceptions of comfort and functionality; and that these dimensions should be considered by the developers early in the development phase. However, developers tend to not always involve users in the early development stage and test wearables in iterations, which ultimately causes problems when it comes to using a device regularly and acceptance of the device (Marcus, 2014).

Users' involvement is critical, as their experience confirms the success or failure of a product (Interaction Design Foundation, 2017). Accordingly, Stickel et al. (2009), and Hassenzahl (2001) have pointed out that user satisfaction is an important feature that determines whether the product has met a user's expectation. From this review of related work, it becomes clear that the potential of using wearable devices to enhance user QoE of viewing multimedia content has largely been ignored by the literature. In this context, a deeper understanding of user QoE is what inevitably would close the gap between designers and developers, helping them understand what users need and want from the product.

2.6 Quality of Experience

There are many definitions for *'quality'* that have been proposed in the literature. For instance, Parasuraman et al. (1985), have said of quality that it is an indescribable and diverse concept, whilst Martens and Martens (2001) have defined *'quality'* as an individual's judgement or perception of an outcome that could be from either a product or service (Brunnström et al. 2013). As well as *'quality'* in the ICT environment, *'experience'* has become obvious, as they both have a distinct meaning. Experience is defined as an individual's interaction with a service or system and their perception of events that occur (Brunnström et al. 2013). Event is defined in the literature as a place where something imperative happens that is organised by someone. This includes the location and the time the event will occur and involves observations (Brunnström et al. 2013).

The term QoE was introduced in various white papers such as Qualinet (2013), Nokia (2006), and Sandvine (2006) and there are different definitions that have been proposed in the literature that share a similar meaning. The concept of QoE is based on understanding human behaviour/attitudes, as well as users' needs, perceptions and acceptance of products. The international telecommunication union (ITU) defines QoE as *"the overall acceptability of an application or service, as perceived subjectively by the end-user"* (ITU, 2007). As defined here the ITU addresses that QoE includes the complete end-to-end system effects (client, terminal, network, services infrastructure, etc.), where overall acceptability may be influenced by user expectations and context. According to Kim and Choi (2010) and Staelens et al. (2010), this definition of QoE is user-centric and is particularly relevant for multimedia streaming type of services that are linked to quality of service (QoS) which includes Internet-based Protocol Television (IPTV), Video on Demand (VoD), streaming media and broadband data services where large volumes of audio-visual data are delivered to the end-users in real-time. Similarly, Li-yuan et al. (2006), define QoE: *"The function of quality of experience (QoE) evaluation includes two aspects: to monitor the experience of user on-line, then to control and justify the service based on the QoE to ensure that the quality of service can highly meet the requirements of the user"*. This definition of QoE is also associated with the QoS concept as it assesses how the end user perceives the value of the service.

In contrast Laghari et al. (2012), define QoE as a blueprint encapsulating experiences and human objective, subjective, hedonic and aesthetic needs focusing upon a person and their interaction towards technology. According to them, understanding human desires requires incorporating cognitive science, engineering science, social psychology, and economics. This definition is different compared to the one proposed by the ITU that explicitly refers to QoE as a subjective measure whereas objective human factors are considered equally as important in this definition. Zapater and Bressan, (2007) defines QoE as *"the characteristics of sensations, perceptions and views of people about a particular service or product; these characteristics can be good, fair or bad"*. Sensation and perception are an area in psychology and this definition emphasizes these two characteristics that will determine the user's QoE. In relation to this definition Rodriguez et al. (2016) have stated that other criteria such as human cognitive process, sensory processing and psychological approaches would complement the perceived quality of multimedia services.

Although, the term QoE has various definitions, it all depends on the context it is used. For our research we applied a recent (working) definition from the Qualinet paper- *"QoE is the degree of delight or annoyance of the user of an application or* *service. It results from the fulfillment of his or her expectations with respect to the utility and / or enjoyment of the application or service in the light of the user's personality and current state"* (Brunnström et al. 2013). Here QoE is defined entirely from the user's perspective- *"…the degree of delight or annoyance of the user…"* and includes a hedonic component as well *"...utility and/or enjoyment..."*. Furthermore, *'application'* refers to- *"A software and/or hardware that enables usage and interaction by a user for a given purpose. Such purpose may include entertainment or information retrieval, or other"* (Brunnström et al. 2013). We used this definition of QoE because it is relevant to an exceptionally large array of application fields. Also, it is the most common and well-established definition used by researchers for different scenarios. This definition was deemed appropriate to use as we wanted to demonstrate the relevance of QoE concept with wearables and its applicability in two contexts (multimedia and mulsemedia).

The key success of any product or service is determined by the end users' satisfaction whilst interacting with it. To this end, the QoE concept has played an important role in the fields of multimedia and telecommunications. QoE has gradually become widespread being employed in several areas and there has been a significant increase in the research efforts around this concept both in academia as well as the industry (Kilkki, 2008). The most common application areas of QoE concept include the following: communication and multimedia services, medical applications, business models, entertainment services, among others (Rodriguez et al. 2016). However, with time QoE has become relevant in the areas of human computer interaction (HCI), systems design and UX (Brunnström et al. 2013). There are many factors that influence the users QoE including human (psychological), system (technical) and context (social) (Ebrahimi, 2009; Reiter et al. 2012). Brunnström et al. (2013) define an influence factor (IF) as *"any characteristic of a user, system, service, application, or context whose actual state or setting may have influence on the Quality of Experience for the user"*. The human IF is a characteristic of a human user and describes the user's physical, emotional and mental state as well as the demographics and socio-economic background of an individual. Accordingly, Laghari and Crespi (2012), have expressed that human IFs contain physiological, psychological and demographic factors. They have detailed that the physiological factors involve the user's health, emotion, anxiety and fatigue states. Whereas psychological factors involve the user's mood, beliefs, attitudes, curiosity and demographics include age, gender, education, ethnicity, occupation and so forth. System IFs are characteristics that are technical oriented and control the quality of an application or service that is delivered to a user (Jumisko-Pyykkö, 2011). Lastly, the context IFs describe the users environment along with the time and space in which a service is used with the characteristics of physical, social, temporal, economics and many more (Jumisko-Pyykkö et al. 2010; Jumisko-Pyykkö, 2011; Floris et al. 2014).

2.6.1 Quality of Experience vs Quality of Service

QoE has initially been explored in the telecommunications and multimedia sectors aligned with Quality of Service (QoS) concept. In the past years' network operators and service providers have relied on QoS parameters (throughput, delay, jitter, packet loss, bandwidth, latency and error rates) to define how well a network performs, up until now they have started to integrate the concept of QoE (Varela et al. 2014; Kim et al. 2008). According to the ITU, (2008) QoS is defined as *"the totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service"*. As opposed to QoE, the concept of QoS does not focus on the end-users perceived experience from a service nor does it reflect on their satisfaction rather concentrates on the performance of the network (Varela et al. 2014; Chen et al. 2009). More notably, a number of studies have been carried out on QoS this concept is deemed important for supporting multimedia applications such as video-conferencing, media streaming, Voice over IP (VoIP) and online gaming that require higher bandwidth (Kaur and Grewel, 2016; Amin, 2005; Agrawal et al. 2007; Zander and Armitage, 2004).

Traditionally, multimedia providers have used the network-centric quality metrics based on QoS parameters rather than focusing on user centric QoE when meeting the needs of its users and applications (Song et al. 2016). Although, QoS parameters have been long employed in evaluating the multimedia services nonetheless these parameters lack sufficient consideration in capturing a real user's perceptions and experiences (You et al. 2010; Staelens et al. 2010). Unlike QoS the QoE provides insights of how the user is likely to feel at the time of using a particular product, application or service assessing their perceptions and emotions (Laghari et al. 2011). Inevitably QoE has become significantly important amongst network operators and service providers who deliver their services over the internet. Subsequently multimedia service providers are more drawn into assessing the users QoE than focus on the traditional evaluation methods (QoS) seeing as user perception, expectations and satisfaction have become the crucial determinants for the success of a product and service (Geerts et al. 2010; Kilkki, 2008).

2.6.2 Measures

QoE involves metrics when measuring the quality of content and performance. A metric is defined as *"a system of related measures that facilitates the quantification of some particular characteristic"* (Serral-Graci`a, 2010). Within the QoE concept there are two distinct measurements- perception based (subjective) and instrumental (objective) (Fiedler et al. 2010; Brooks and Hestnes, 2010; Takahashi et al. 2004; Moor et al. 2010; Li-yuan et al. 2006 and Wu et al. 2009).

Subjective: Subjective user studies are the foundation of QoE research focusing on user's perceived quality as well as their overall experience and interaction with an application or service. The most valid way to assess the QoE is represented by subjective methodologies that require human evaluators. In the QoE domain the most commonly used method to perform subjective tests is the Mean Opinion Score (MOS) that was introduced by the standardization bodies such as the ITU-T in its ITU-T P.800 recommendation (ITU, 2003). The MOS is used to find out users' opinions on the perceived quality of the media received to them using a 5-point rating scale (Fiedler et al. 2010). The response scales use anchors such as 1 = "poor", 2 = "fair", 3 = "good", 4 = "very good" and 5 = "excellent" this is referred to as Absolute Category Rating (ACR) (Takahashi and Yoshino, 2004; Moreno-

Roldán, 2017). MOS has been used for decades in telecommunications (voice, audio and video quality) and subjective tests are deemed more reliable as they are usually carried out by a test panel of real users (Flanagan, 1965).

Consequently, there are drawbacks as authors Menkovski et al. (2010), Zhang and Ansari, (2011), Kuipers and Kooj (2010) and Laghari et al. (2012), have stated that although QoE is mostly subjective nevertheless these tests are time consuming and costly. This is because subjective tests require a large sample size of real users to get reliable results which is not feasible and such tests are hard to organise.

Objective: In the context of multimedia objective tests are based on user performance measures - accuracy of user task completion, user errors, success rate, user inputs and so forth (Brookes and Hestnes 2010). Such tests do not consider the users' opinions and are carried out on behalf of a real user using automated algorithms where user's perceptions are predicted using key properties of the process or outcome of user behaviour (Fiedler et al. 2010). Objective methods are a quicker alternative to use because they are cost effective. Although the traditional approach has been effective to use however, these measures do not comply in the new era of digitalisation. Hence, researchers in the human factors domain have carried out objective tests using the physiological measures as indicators of behaviour, mental effort and stress of an individual (Engelke et al. 2007; Mandryk et al. 2006; Vicente et al. 1987). The physiological measures used are HR, ECG, electromyography (EMG), electroencephalography (EEG), electrocardiography (EKG), galvanic skin response (GSR) and eye tracking (Mandryk et al. 2006; Wang et al. 2005; Hanson et al. 2010). The physiological metrics have also been used in the HCI field as Egan et al. (2016), employed HR and electrodermal activity (EDA) to evaluate user QoE for virtual environments. In the same line Mandryk et al. (2006), used physiological data in gaming and collaborative play environments. The potential and benefits of using these objective metrics as indicators of user QoE for immersive experiences were shown also for AR applications in (Keighrey et al. 2017). The use of such objective measures in these studies have shown great results to some extent.

2.7 Mulsemedia and QoE

In recent years, QoE has been applied in mulsemedia, which extends beyond the traditional multimedia applications (video, audio, text and graphical images) (Ghinea et al. 2011; Ghinea et al. 2014). Mulsemedia enriches traditional audio video content with new media types such as olfaction (smell), haptic (touch) and gustatory (taste) to enhance users' QoE and to explore novel methods for interaction (Ademoye and Ghinea, 2009; Narumi et al. 2011; Murray et al. 2017). Also, mulsemedia brings new opportunities for the development of immersive technologies and opens new perspectives in real world applications including medicine, education, advertising and communication (Ghinea et al. 2014; Sulema, 2016). There are various explorations on the practicality and possibility of incorporating different media types into applications focused mainly on the digital representation of sensing, storage and display, and less on its impact on QoE (Cingel and Piper 2017; Ghinea and Ademoye 2012a, 2012b; Murray et al. 2017). Users exposed to multisensory experiences have reported a noticeable increase in QoE (Jalal et al. 2018; Monks et al. 2017; Murray et al. 2017; Rainer et al. 2012; Waltl et al. 2010; Yuan et al. 2014, 2015).

Given the mechanisms behind multisensory integration, we hypothesize that an important factor in enhancing QoE could be the crossmodal mappings between the various media dimensions, as played out in the digital world. Thus, as part of this thesis, we focus on determining how selected crossmodal associations impact the users' perceived QoE with wearables see Chapter 5.

2.8 Conclusion

This chapter explored and took a closer look into literature in regards to wearables as well as QoE. The chapter highlighted that, whilst considerable work has been done in relations to wearables' such as adoption, user experience and general problems, nonetheless there is a paucity/absence of studies examining wearables' QoE. Consequently, the research gap addressed in this PhD has been highlighted.

The next chapter will now present the methodology adopted towards the accomplishment of the identified research objectives.

Chapter 3: Research Methodology

3.1 Overview

In the previous chapter, five main objectives were identified for this study. In the current chapter, a research methodology will be described and justified as it will be used throughout this study to achieve the objectives defined in Chapter 2. In addition, we will address the first objective and design suitable questionnaires in association to wearables.

This chapter starts by defining positivism in research and describes its major assumptions and perspectives. In Section 3.2, the use of a positivist research approach for this study is justified based on the definition provided. In Section 3.3, the research design that is used in the course of this study is identified and justified. Section 3.4 explains instrumentation of this research in line with positivism. In section 3.5 the validity, randomization and generalisability for positivist research are described. Section 3.6 discusses the structure of the experiments. Sections 3.7 to 3.10 describe the questionnaires, content, analysis software, and the devices that are used in this study. Section 3.11 describes the sampling method used to recruit participants for this study. Finally, section 3.12 concludes this chapter.

3.2 Research Perspective: Positivism

Positivism - the paradigm adopted in this study- is regarded as a scientific method that can be applied to social sciences. It was coined in the 19^{th} century by Auguste Comte who interprets it *“as a doctrine that defines observation and reason as a means of understanding behaviour”* (Crotty, 2003; Cohen et al. 2007; Mertens, 2005; Sarantakos, 1993). He maintains that the only way to obtain true knowledge of the world derives from sensory experience and testing theories or hypotheses through experimentation, observation and verification (Acton, 1951; Cohen, et al.

2007). Positivists believe that scientific knowledge is the only kind of factual knowledge that is trustworthy. Positivists see reality as being objective and to uncover truth a researcher is required to be objective and collect facts using scientific methods, statistical analysis and generalisability of results to prove or disprove a hypothesis (Alakwe, 2017; McEvoy and Richards, 2006). Usually the results obtained from data collection are quantifiable and observable.

A summary of the fundamental themes of positivism and its major assumptions are the following:

- Ontology (nature of reality): can be defined as *"the science or study of being"* as positivists believe that there is a single objective reality (Hudson and Ozanne, 1988; Crotty, 1998; Blaike, 2010).

- Epistemology (nature of knowledge): is the study of the nature of knowledge, belief and truth, and questions how knowledge is created, acquired, interpreted and communicated (Guba and Lincoln, 1994; Cohen et al. 2007).

- Methodology (approach to systematic inquiry): is a strategy with a use of particular methods that are used to collect and analyse data that can be either quantitative or qualitative (Crotty, 1998; Scotland, 2012). Also, methodology is concerned with curiosity as to what, when, why, from where and how data is composed, analysed and manipulated (Crotty, 1998; Scotland, 2012).

- Deductive logic: allows the researcher to work from the so called *'top down'* approach, when one begins with a theory then narrows that down into more specific hypotheses that are tested with specific data to confirm or contradict the theory (Creswell and Plano Clark 2007). This form of research starts from the general and then works its way down to the particular.

However, much critique exists about positivism philosophy as there has been much debate on whether it is entirely suitable for the social sciences (Hirschheim, 1985). The main themes of positivism will be more detailed throughout the sections of this chapter, and they will be described in terms of the methodology of this study.

3.2.1 Positivistic paradigm and this study

The main aim of the present study was to investigate the user QoE with wearable devices. Positivism is primarily a quantitative type of research that relies on measurement and analysis. Most QoE measures lie under the positivistic paradigm as questionnaires are used to measure users experience with a product or service.

For this study questionnaires are designed to measure the users' feeling towards wearable devices as well as measuring their usability. Also, most usability research accepts the use of the positivistic paradigm. In line with this study only views gathered informally would not provide enough evidence for variables that affect users' experiences. Hence, positivism has been deemed appropriate to utilise in this study as it is the predominant paradigm used in QoE research and it aligns well when measuring the effects of wearables with users. Although there are shortcomings of positivism, it benefits more than outweigh any identified downsides. One of the drawbacks is that most positivism studies prefer to use quantitative methods for data analysis, and this limits the researcher to other data collection methods. The most common research designs linked to the positivist approach are surveys and experimental design (Neville, 2007; Dudovskiy, 2019). Also, this method is inflexible as inaccuracy in scientific data should be reviewed as it is likely to change the end-results of the hypothesis. This can happen because the participants may choose random answers instead of giving authentic responses or they do not have the flexibility to provide answers based on their personal cases (Pham, 2018). As Johnson, (2014) has stated- *"Some scholars believe that since positivists believe everything can be measured and calculated, they tend to be inflexible. Positivists see things as they are and tend to disregard unexplained phenomenon"*.

Another downside of positivism is it holds that valid source of knowledge is based on experience. That is not always the case as other concepts are not based on experience these include time, cause and space (Dudovskiy, 2019). The positivist approach has been criticised by Bryman (2008), who has mentioned that positivism deals with human beings like natural objects and this method fails to segregate people from natural sciences and social sciences. Besides some of the most common limitations we have discussed there are many other setbacks with positivism that have been addressed in the following studies (Guba & Lincoln, 1994; Smith, 1987; Fisher, 2010).

Positivism is based on scientific study of the social world and researchers use the traditional quantitative methods however there are other alternatives for data collection using the triangulation approach in other words (mixed methods) where two or more methods are used such as qualitative and quantitative (Heale and Forbes, 2013). Generally, positivists use quantitative methods however to examine the context of human experience researchers have used constructivism or qualitative research as an alternative to the positivist form of inquiry (Schwandt, 2000). Also, qualitative methods can be used on the ground where quantitative is dominant. Slootman (2018), has argued that quantitative methods can be used within a more interpretivist perspective in positivism.

Drawing the line on everything we still decided to use positivism in our research because in the QoE domain the most commonly used method to collect subjective data is through surveys which is a quantitative type of method. To assess QoE researchers conduct experiments. As mentioned by Möller and Raake (2014), that subjective assessments are carried out via experiments that aid researchers to understand the influence on the QoE when a user is viewing multimedia content. In measuring QoE positivism fits well with our research because we have two experimental studies as defined by Blakstad (2008)- *"The experimental method is a systematic and scientific approach to research in which the researcher manipulates one or more variables, and controls and measures any change in other variables".* Seeing that our research revolves around experimentation of two wearable computing devices we wanted to ensure our results are reliable and positivists claim quantitative data is more reliable, valid and trustworthy than other methods of data collection (McNeill and Chapman, 2005). By following the positivism approach, exact numeric output supports to compare our results in easy and systematic way (Creswell, 2009).

Additionally, research can either be descriptive, explanatory or exploratory (Vaus, 2001; Robson, 1993; Brown, 2006). Descriptive studies provide a picture of a phenomenon or a subject (Hedrick et al. 1993). According to Borg and Gall (1989), descriptive studies are concerned with finding out *'what is'*, therefore one can gather data through observational and survey methods which are commonly used to study a particular subject. However, explanatory research is a type of quantitative research that focuses on *'why'* questions of a phenomenon and explains it rather than describes it (Vaus, 2001). It is one of the many types of research that is detailed-oriented, and a researcher can understand the phenomena and its causes more accurately. This type of study can be correlative in nature as it discovers causal relationships between variables as well as explain relationships between them (Gray, 2001).

Lastly, exploratory research is commonly conducted to investigate a problem that has not been clearly defined yet (Singh, 2007). Also, Brown (2006) has stated that exploratory research *"tends to tackle new problems on which little or no previous research has been done"*. This type of research does not provide conclusive results instead it enables a researcher to gain a better understanding of the existing problem (Saunders et al. 2012). As mentioned by Singh, (2007) *"exploratory research is the initial research, which forms the basis of more conclusive research. It can even help in determining the research design, sampling methodology and data collection method"*. Exploratory research focuses on qualitative research to collect data such as interviews, observations, focus groups or case studies (Singh, 2007). However, survey research is also used in exploratory research for data collection (Kerlinger, 1986).

In this study exploratory research was deemed appropriate as it has been mentioned already, this research addresses the gap in knowledge that has not been explored before and that is with wearables. Exploratory research will help gain insights into the extent of users' QoE with wearables as well as their views on the adoption of such devices. It is crucial to conduct an exploratory study to get a better understanding of end users' QoE with wearable devices. Yin (1994) has mentioned that using exploratory research one is able to obtain adequate insight into the basic issues being investigated. In the case of our studies exploratory research will be conducted via survey research (questionnaires) that will be presented to users' during and after the experiments. Survey research is a quantitative type of research and aligns well with our studies hence it was selected for data collection. As Kerlinger, (1986) has stated that the purpose of the exploratory survey would enable a researcher to become more familiar with the topic. It is highlighted by Malhotra and Grover (1998) that exploratory surveys are applicable for the early stages of research and are beneficial in identifying the concepts and the basis for measurement. In line with our work survey research will be employed to gather data about end users' QoE with wearables.

3.2.2 Measurement, and systematic empiricism

Positivism includes the following underlying themes (Kane and O'Reilly-De Brun, 2001):

- There is a value-free, objective research for studying the world.
- Only objective, observable, trustworthy, generalizable data and proven facts are science.
- Causes in both social and natural worlds can be studied in the same manner with the use of experimental procedures.

Positivistic paradigm is in correspondence with methodology and methods that have the same underlying aims and assumptions. Such a methodology has been named *'systematic empiricism'*. Empiricism refers to the belief that knowledge is gained through objective observation and experience based on the senses (Graziano and Raulin, 1993).

Systematic empiricism is defined as *"the practice of relying on observation to draw conclusions. The phenomena studied in science must be objective and observable"* (Leary, 1995). Empiricism alone is not enough as it does not lead to scientific knowledge. The observations must be made systematically such as those in controlled experiments to test a hypothesis and to develop a theory. Systematic empiricism is structured in a way that allows researchers to draw more valid and reliable conclusions and study more precisely the world (Jackson, 2009). As stated by Myers and Hansen (2002) *"we could observe end-less pieces of data, adding to the content of science, but our observations would be of limited use without general principles to structure them"*. In an empirical investigation the researcher conducts experiments to observe and measure a phenomenon. Rosenthal and Rosnow (1991) define it as *'descriptive research'* while Robson (2002) defines it as *'fixed research design'* as he highlights that relational as well as experimental research are part of *'fixed research design'* that will be elaborated further.

3.3 Fixed Research Design

Typically, there are three types of research designs- quantitative (fixed), qualitative (flexible) and mixed methods (Creswell, 2009). In association with the positivistic paradigm, it was deemed appropriate to utilise a fixed research design in our study as it aims in *'objectivity'* and can be used with specific variables to test hypothesis. Sahni, (2017) has defined fixed research design as: *"In fixed designs, the design of the study is fixed before the main stage of data collection takes place"*. Fixed designs are theory driven and the variables are measured quantitatively. According to Burns and Grove (2001), quantitative research is the *"formal, objective,* *systematic process in which numerical data are used to obtain information about the world".*

Within the fixed research design there are three quantitative designs- experimental, semi-experimental and quasi experiment (Sahni, 2017). The one method used in positivism which was selected for this study is experimental design. The experimental method enables a researcher to determine whether the variables of interest have a cause-and-effect relationship (Jackson, 2015).

The basic requirements that every experiment must meet are the following (Jones, 1995):

- Manipulation: in the experimental research design the researcher will manipulate, change or control at least one or more variables, these are independent variables (referred to as explanatory) that determine the value of a dependent variable.

- Measurement: in a scientific experiment there should be at least one dependent variable (referred to as outcome) which is tested and measured that depends on the values of independent variables and delivers the outcome of the experiments.

- Control: usually in an experiment, variables are controlled except the one that is manipulated, but there are other factors as well as independent variables that could influence the outcome of the experiment called *'extraneous variables'*.

In line with the basic requirements we intend to manipulate one or more variables in our second experiment. In terms of measurement we will have dependent variables that will be tested with independent variables as we will have two groups and experimental one and a control one as discussed in Chapter 5. Finally, this study is comparative, as it does examine and compare the groups, devices and sensory modalities as can be seen from the objectives of this study in Chapter 2.

3.4 Instrumentation

Within the positivistic paradigm, instrumentation is considered very important (Kane and O'Reilly-De Brun, 2001).

- The questions are designed carefully so that they address the variables that interest the researcher.

- The questions are pre-tested on people to make sure that they provide the required information.

- Measurement is standardised, it is carried out in the same way by using the same instruments with all the participants. Measurement can be compared with different groups by repeating the same procedures (Kane and O'Reilly-De Brun, 2001).

- Also, measurement can be repeated using the same procedures to make comparisons with different groups.

In the positivistic paradigm the research techniques used by researchers are usually quantitative and associated with numbers, as the variables are clearly measured and defined (Kane and O'Reilly-De Brun, 2001). The quantitative methods comprise of experimental and non-experimental approaches (Guba and Lincoln, 1994). The methodology of this study reflects the themes and tools described below.

3.5 Internal - External Validity - Randomization and Generalisability

Positivism comprises the following underlying themes:

- Results have high internal validity (valid in the fixed setting), but not essentially high external validity (valid in external setting) as the experimental setting is artificial within positivistic research since it does not use natural settings (Mertens, 1998; Kane and O'Reilly-De Brun, 2001).

- As the laws of cause and effect are identified, predictions can be made, as long as the same conditions apply (Graziano and Raulin, 1993; Kane and O'Reilly-De Brun, 2001).

To test cause-and-effect relationships two types of validity need to be considered: internal and external validity. Internal validity is defined as a *"concern with the question of whether a finding that incorporates a causal relationship between two or more variables is sound"* (Bryman, 2008). Leary, (1995) maintains that experiments with tighter experimental control yield high internal validity of the experiment in question. High internal validity leads to stronger and conclusive conclusions that can be drawn about the causal effects of the independent variable. However, the experiments are often conducted under conditions in an artificial environment. As a result, it is difficult to generalise the findings in real life situations which decreases the external validity.

External validity refers to the extent to which results can be generalised to other populations, procedures and research settings (Campbell and Stanley, 1963). Also, defined by McDermott, (2011) *"external validity refers to the generalizability of findings from a study, or the extent to which conclusions can be applied across different populations or situations".* Fraenkel and Wallen, (1993) have stated that in most experimental research the random selection of participants is an important aspect and researchers are expected to assign participants into groups randomly to improve external validity as well as eliminate bias. Random sampling is the key in ensuring the results are generalizable and increases the external validity.

Randomization was introduced by eminent statistician R.A. Fisher, whereby participants are allocated to experimental conditions via a random procedure, (Fisher, 1935). It is one of the most important statistical techniques. According to Cohen et al. (2010) *"Randomization, then, ensures the greater likelihood of* *equivalence, that is, the apportioning out between the experimental and control groups of any other factors or characteristics of the subjects which might conceivably effect the experimental variables in which the researcher in interested".* Random assignment is a process of allocation as participants are assigned to either experimental or control groups and this usually takes place before the actual experiment begins. Also, random assignment of subjects is not always possible in some research areas, especially when asking for volunteers to participate in the experiment. Nonetheless researchers are still required to use randomization as much as they can.

The findings of this study will need replication if they are to be generalised. Many researchers include an initial study in empirical research and then organise one or more follow up studies that repeat the same procedures from the initial study but with some amendments to see if they are any differences in the results. Also, regarding internal and external validity two or more variables will be examined to see whether there are differences between two groups an experimental one and a control one as detailed in Chapter 5. Participants will be assigned randomly into two groups so that the results are not biased.

3.6 Structured and Unstructured Experiments

Experiments can be either structured or unstructured depending upon one's study. Structured experiments are those that follow a logical approach, with the aim of measuring changes in pre-ordained experimental factors. In structured experiments relevant information is extracted from questionnaires to identify particular outcomes or results. However, unstructured experiments are the opposite since there is no need to follow a pre-defined order. Unstructured experiments are not consistent in measurement or content and interpretative methods are commonly used to analyse the results. Interviews and observations are the techniques used to obtain meaningful and rich information (Gulliver, 2004). Our experiments are structured as we want to collect quantitative data via questionnaires which is in line with the positivism methodology.

3.7 Experimental Questionnaires

In this study, questionnaires were employed to evaluate the user QoE with two distinct wearable devices (KOR- FX haptic vest and Mio Go HR wristband) as shall be described in section 3.11 as well to gauge olfactory experiences with the Exhalia SBi4. These questionnaires were structured and contained closed- ended questions.

3.7.1 System Usability Scale (SUS) Questionnaire

There were two questionnaires designed to measure the users' QoE- one during the experiment based on the haptic vest (see Tables 3.1 and 3.2) and one after the experiment based on both devices (see Tables 3.3 and 3.4). In keeping with good questionnaire design, the questionnaire contained a roughly equal split of positive and negative statements. The System Usability Scale (SUS) developed by Brooke (1996) was used in this study for users to express their opinions. SUS is a tool that quickly measures perceived usability of a product or system obtaining subjective feedback from users. It is the most well-known assessment tool that has continuously proved to be valid and reliable therefore, we decided to employ it in our questionnaires (Bangor et al. 2008; Kortum and Bangor, 2013). Accordingly, SUS is a 10-item questionnaire with a 5-point Likert scale which feature five response options see (Appendix A).

The questions were based on the SUS questionnaire but modified accordingly to the device type. We designed a certain number of questions intended to capture user's perceptions of the two wearables. We wanted to ensure the set of questions were measurable, clear, and concise. Amongst the 10-items in the SUS questionnaire we applied between 5-7 items as not all of them were applicable for our study. The following questionnaires (Tables 3.1 and 3.2) were directly designed for the haptic vest to gain insights into the user's views about the wearable device, as well as whether it had either a positive or negative effect on one's experience. Additionally, two after questionnaires (Table 3.3 and 3.4) explored the applicability, comfort and acceptability of the two wearable devices.

Table 3.1: Online Self-Reported QoE Questions Multimedia

Q1: I enjoyed watching the video clip whilst wearing a Haptic Vest.
Q2: The Haptic Vest effects were relevant to the video clip I was watching.
Q3: The vibration was distracting.
Q4: The vibration was annoying.
Q5: The Haptic Vest effects enhanced the sense of reality whilst watching the video clip.
Q6: The Haptic Vest effects were necessary when watching a video clip.
Q7: The Haptic Vest effects enhanced my viewing experience.

Table 3.2: Online Self-Reported QoE Questions Mulsemedia

Q1: I enjoyed watching the video clip whilst wearing a Haptic Vest.
Q2: The Haptic Vest effects were relevant to the video clip I was watching.
Q3: The vibration was distracting.
Q4: The vibration was annoying.
Q5: The Haptic Vest effects enhanced the sense of reality whilst watching the video clip.
Q6: The Haptic Vest effects enhanced my viewing experience.
Q7: Overall, I enjoyed the multisensorial experience.

Table 3.3: End of Experiment Questionnaire: Haptic Vest

Q1: The Haptic Vest is comfortable to wear.
Q2: I found the Haptic Vest bulky to wear.
Q3: The Haptic Vest starts to heat up after wearing it for a long time.
Q4: I found that the Haptic Vest has a range of functions that are well incorporated.
Q5: I would be confident wearing the Haptic Vest in public.
Q6: I would wear the Haptic Vest at work.
Q7: I would wear the Haptic Vest in my leisure time.

Table 3.4: End of Experiment Questionnaire HR Monitor Wristband

Q1: Do you think Mio Go (wearable band) is a comfortable device to wear?
Q2: I think the activities available on the Mio Go band are helpful.
Q3: I would be confident wearing the HR monitor wrist band in public.
Q4: I would wear the HR monitor wrist band at work.
Q5: I would wear the HR monitor wrist band in my leisure time.

3.7.2 User Experience Questionnaire (UEQ)

The experiments undertaken employed the user experience questionnaire (UEQ) which was adapted to suit the needs of this study and incorporated into the last part of the extended questionnaire for experiment 2 which will be described in Chapter 5. The UEQ short version (Schrepp et al. 2017) measures users' impressions and experiences towards a product. The short version of the UEQ contains 8 items with a 7-point Likert scale. The 8 items are split into two categories such as pragmatic and hedonic quality which are the two meta-dimensions that the short version focuses upon see (Table 3.5). Half of the items in this particular questionnaire start with the positive term whilst the other half start with the negative term (Schrepp et al. 2017). The UEQ data is to be analysed on Microsoft Excel that we follow accordingly.

Table 3.5: User Experience Questionnaire (UEQ)

1	obstructive	o o o o o o o	supportive	**Pragmatic**
2	complicated	o o o o o o o	easy	
3	inefficient	o o o o o o o	efficient	
4	confusing	o o o o o o o	clear	
5	boring	o o o o o o o	exciting	**Hedonic**
6	not interesting	o o o o o o o	interesting	
7	conventional	o o o o o o o	inventive	
8	usual	o o o o o o o	leading edge	

3.8 Analysis of Results

To analyse the results of the four questionnaires statistically, the IBM Statistical Package for the Social Sciences (SPSS) was used in this study. Throughout this study a significance level of $p<0.05$ was adopted for the analysis. SPSS includes descriptive statistics such as frequencies, bar charts, lists, scatter plots and involves measures of central tendency (mean, median, and mode), as well as measures of dispersion (range, standard deviation, variance, minimum and maximum) and measures of kurtosis and skewness. Also, it comprises inferential and multivariate statistical procedures like factor analysis, cluster analysis, analysis of variance (ANOVA) and categorical data analysis (IBM, 2017).

SPSS is particularly well-suited to survey-based (questionnaire-based) research, which is the main reason for using it in our analysis. ANOVA, suitable to test the significant differences of three or more categories, as well as one sample and independent sample t-test, suitable to check whether a sample mean is statistically different from a hypothesized population mean, and, respectively, to identify significant differences between two categories were applied to analyse the participants' responses (Stephen and Hornby 1997).

3.9 Experimental Material

3.9.1 Video Clips

In experiment 1 detailed in Chapter 4, participants watched 7 multimedia video clips, and 6 video clips for experiment 2 see (Chapter 5) each of 120s duration. The view area was 1000x700 pixels. The resolution for each video clip was 1366 x 768 pixels and the frame rate 30 frames per second. The original sound was generated from the original video content. The clips were chosen based on visual features: colour, shape, spatial relations and texture. Accordingly, in 3 of the clips, the predominant colour was blue, yellow, and red, respectively, a further 2 clips were chosen because one was mainly bright and the other dark, while the last 2 contained shapes that were almost exclusively angular or round, respectively (Table 3.6). These clips were chosen because they are based on natural scenes and contain low-level information that would offer a more interactive and engaging experience. These videos are detailed below:

- **Beach clip** – a relaxing tropical beach scene with blue sky and white sand. The clip also features the ocean waves (Lounge V Films, 2016).

- **Dallol Ethiopia volcano clip** – features the unearthly scenery of Dallol in Ethiopia showing the volcanic landscapes (Amazing Places on Our Planet, 2014a).

- **Desert clip** – this clip presents a close up shot of the red Sahara Desert sands in Morocco (Amazing Places on Our Planet, 2014b).

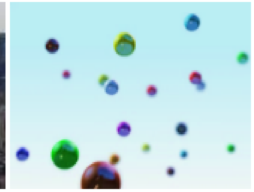
- **Solar eclipse clip** – shows a blend of all phases of the solar eclipse during the night (Serginson, 2015).

- **Sunrise upon the arctic clip** – gives a view of the beautiful arctic mountains with a relaxing sound effect playing in the background (Clifford, 2009).

- **Skyscrapers clip** – this shows a number of breath-taking tall buildings in San Francisco various shots where some are zoomed in to give a detailed image (LemonDrone, 2016).

- **Bouncing balls clip** – this clip presents colourful bouncing balls that bounce up, down and across the screen with a playful audio (AApV, 2014).

Table 3.6: Video Clips Description

V1	V2	V3	V4	V5	V6	V7
						
Theme: Beach	Theme: Dallol in Ethiopia	Theme: Desert	Theme: Solar eclipse	Theme: Sunrise upon the arctic	Theme: Skyscrapers	Theme: Bouncing balls
Visual Cue: Colour- Blue	Visual Cue: Colour- Yellow	Visual Cue: Colour- Red	Visual Cue: Dark	Visual Cue: Bright	Visual Cue: Shape- Angular	Visual Cue: Shape- Round

The video clips were associated with six scents: bergamot, lilial, clear lavender (low intensity), lavender (high intensity), lemon and raspberry. The accompanying olfactory content was modified in line with principles of olfactory-visual crossmodal correspondences that were previously discussed in the literature. The video with dominant blue images (V1) was watched with lilial odor, while the one dominantly yellow (V2) with the bergamot odor (Gilbert et al. 1996). In V3, where brightness was considered the dominant visual cue, low intensity lavender odor was delivered concurrently to the users, while in V4, where the brightness was high, the olfactory content of high intensity lavender, was employed (Gilbert et al. 1996). Finally, V5, the video displaying angular shapes, was matched with lemon odor, whilst V6, where the dominant shape was round, was delivered with a raspberry odor (Hanson-Vaux et al. 2012; Spence, 2011).

3.10 Experimental Devices

3.10.1 Wearable Devices

Two distinct types of wearable devices were used in our experiments see (Fig.3.1 and 3.2). The first was a KOR-FX gaming haptic vest. This device was chosen for this study because a user can get engaged with what they are seeing on the screen, enabling them to have an immersive experience. Also, the haptic vest connects to the audio coming from any media content such as movies or games (KOR-FX, 2014). Applying the KOR-FX device in the experiment would provide different perceptions from users, because the vest has sensors that are meant to immerse the user and enhance the sense of reality as well as giving a better experience overall. The second device used in our study was a wearable HR monitor band *'Mio Go'* (Mio Go, 2017). The Mio Go wearable band was chosen because it would help in monitoring the HR of a participant, especially seeing how fast or slow the heart beats for each video clip in relation to the haptic vest's vibrations. Mio Go has received positive reviews online from people who have purchased this product and use it regularly (Hawkins, 2014).

Figure 3.1: KOR-FX Gaming Vest[71]

Figure 3.2: Mio Go HR monitor wristband[72]

3.10.2 Other Devices

Exhalia- the Exhalia device diffuses scents through cartridges from each of its four small fans see (Fig.3.3 and 3.4). The olfactory emitting device was the Exhalia SBi45 which was considered by previous research more reliable and more robust than existing devices (Murray et al. 2014). The cartridges contain scented polymer through which air is blown (through four built-in-fans). The synchronized presentation of the olfactory data was controlled through a program built using Exhalia's Java-based SDK. The SBi4 can store up to four interchangeable scent cartridges at a time, but we used a single slot in our experiments to prevent the mixing of scents (Exhalia, 2013-2019).

[71] http://www.korfx.com/

[72] https://uk.pcmag.com/heart-rate-monitors/9505/mio-link

Figure 3.3: Exhalia scent diffuser

Figure 3.4: Scent cartridge

Laptop- For this study, a lightweight business laptop Lenovo ThinkPad L460[73] was utilised, which ran Microsoft Windows 10, with 8GB RAM powered by an IntelCore i5 processor. It had 16GB of RAM, 512GB storage and Intel HD Graphics 620 see (Fig.3.5).

Figure 3.5: Lenovo ThinkPad Laptop

[73] https://www.lenovo.com/gb/en/laptops/thinkpad/l-series/ThinkPad-L460/p/22TP2TBL460

Headphones- The iShine[74] stereo headphones were worn by participants throughout the experiments see (Fig.3.6). These headphones were chosen based on comfort and the high sound quality enabling the users' to hear the audio clearly (iShine-trade, 2017).

Figure 3.6: i-Shine Headphones

Smartphone- a Samsung Galaxy S6[75] mobile phone was used to send the HR data via Bluetooth with Mio Go app see (Fig.3.7). The mobile had the following features: dimension 143.4 x 70.5 x 6.8 (mm), weight 238g, display screen 5.1-inch Quad HD Super AMOLED, camera the front 5MP and rear 16MP, operating system is on Android 5.0, memory 3GB RAM and battery 2550mAh. The whole setup of the devices that we have discussed can be seen in (Fig.3.8).

Figure 3.7: Samsung Galaxy S6

[74] https://www.ishine-trade.com

[75] https://www.samsung.com/uk/smartphones/galaxy-s6-g920f/SM-G920FZKABTU/

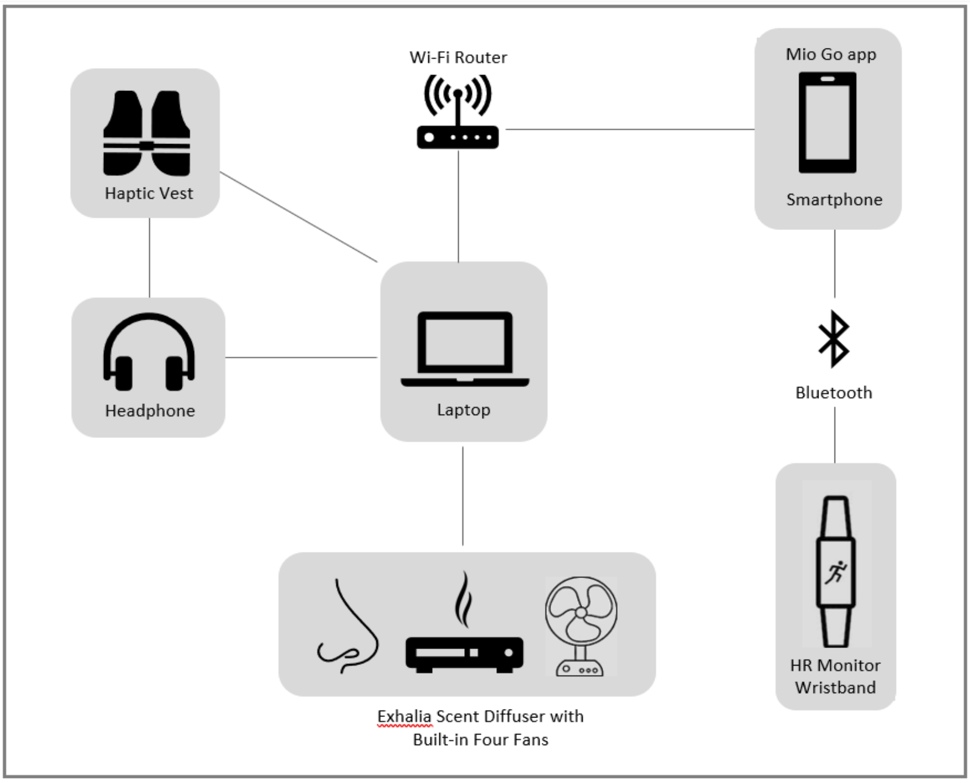


Figure 3.8: Device system set-up

3.11 Sampling

Convenience sampling is a non-probability strategy we used to recruit participants because we had limited resources to reward people in participating in our experiments which were quite lengthy in time (30-40 minutes). This Convenience sampling is defined as *"a type of nonprobability or non-random sampling where members of the target population that meet certain practical criteria, such as easy accessibility, geographical proximity, availability at a given time, or the willingness to participate are included for the purpose of the study"* (Etikan et al. 2016). We chose to use convenience sampling as it was relevant to our studies because it is a quick and easy method to recruit participants in short space of time. We reached out to people who were available from both Brunel University, Department of Computer Science and University of West London, School of Computing and Engineering via email and word of mouth. The participants gave informed consent and could withdraw at any time without giving a reason, and that they were not compensated for taking part in the experiments. The data was anonymised strictly kept confidential.

3.12 Conclusion

In this chapter, we introduced, elaborated upon and justified the research methodology that will be followed throughout in this study. We also considered and explained the reasons for using structured experiments. Moreover, we described and justified the use of the experimental questionnaires, the experimental material and analysis method that shall be used, in order to achieve the defined research aim and objectives. Chapters 4, 5, and 6 will explore and evaluate, respectively, the user QoE when mediated by two different wearable devices (haptic vest and HR monitor wristband), olfaction and multimedia content in a controlled settings environment.

Chapter 4: Multimedia and QoE

4.1 Overview

In this chapter we address the second and fourth objectives of our research and focus on the traditional approach of QoE, as highlighted in Chapter 2, it represents an important side of the initial user experience of wearable computing devices. Specifically, we explore the QoE using both subjective and objective measures, asking users to express their views and opinions in wearing computer devices whilst viewing multimedia content. We also explore the human factors in relation to the self-reported QoE.

This chapter is structured as follows: Section 4.2 provides an introductory background to the current state-of-art of wearables. Section 4.3 discusses previous studies that have employed wearables as well as discussing the human factors. Section 4.4 gives an overview of the participants recruited for this study. Section 4.5 and 4.6 details the methodology followed by our experiments, while results of self-reported QoE are presented and analysed in Section 4.7. Section 4.8 discusses the results for the post questionnaires. In section 4.9 we discuss the results of the human factors (age, gender, education). Section 4.10 presents the HR results, whilst Section 4.11 is the discussion and lastly conclusions are drawn in Section 4.12.

4.2 Background

In recent years wearables have grown and expanded. These gadgets do not only sense but communicate much more to a user (Rachana, 2014). Wearable devices - including watches, glasses, clothing, jewellery, and shoes - are used in many fields, such as healthcare, gaming, military, entertainment, education, commercial fields and leisure (Jhajharia and Verma, 2014). Wearing a computerized device involves many factors that include ease-of-use, how it looks (appearance) whether it is fashionable, lightweight, colour and so forth. What is also important are the functionalities and what the device does, as is personal comfort since the design, material and weight of the device are also factors considered by users (Knecht et al. 2016). However, there has been limited amount of research done exploring the user's experience of the usability of wearable devices. This is surprising, since investigating the ease of use and learnability of a device from a user's point of view would give developers insights into how users feel about the usefulness of such new devices, so they can meet their needs. Indeed, although usability has been applied in many fields (Holzinger, 2005; Kaikkonan et al. 2005; Gosbee et al. 2001), the perceived usability with wearables when experiencing multimedia has, to the best of our knowledge, not been explored and there is a gap which exists between the two concepts.

4.3 Related Work

Wearable technologies are continuously being developed. Whilst devices themselves have been mostly aimed at expert wearers, it is in recent years that wearables became available to consumers and have been used in various fields as detailed in Chapter 2.

Wearables have long been employed in the healthcare sector to assist people and make their life easier. One example of this is the work of Matthews et al. (2015) who looked at the usability of a wearable camera system amongst family caregivers of persons with dementia. From their study it was evident that caregivers found the device useful, easy to learn and accepted it despite having some concerns of privacy, and the device being perceived as obstructive and cumbersome. The system's usability of this device required enhancement, but the functionalities were viewed positively. In related work, Claudio et al. (2015) investigated the use of wearable sensor-based systems in emergency departments. The authors were interested in obtaining user feedback in terms of their attitudes towards wearable systems to predict the success of the technology. They found that both patients and nurses had positive responses and that the perceived usefulness of wearable sensor systems was higher than the ease-of-use. Also, patients' perceptions were more favourable as opposed to the nurses in terms of both ease-of-use and perceived usefulness. Wearable camera systems have a greater acceptance amongst the general population when used for lifelogging purposes, as Ali et al. (2016), have shown, but still have drawbacks in terms of privacy and comfort. Moreover, the same study suggested that the functions and quality of the images need to be improved to give a better satisfaction as well as acceptance.

Although wearable technologies have been on the rise and are trending in the consumer market nonetheless, some wearable technologies have proven to be more successful and better received than others. The reasons behind this could be how users feel about the functionalities, features, aesthetics of wearables and their overall experience that are rarely considered. To address this, we present the results of an empirical study in which the QoE and perceived usability of two wearable devices - a haptic vest and a HR monitor band – whilst watching multimedia content are explored.

Also, as shown in the Qualinet paper (Brunnström et al. 2013) human factors are essential and are one of the three pillars that play an important role in QoE. However, human factors have been overlooked in terms of wearable computing devices. To this end, we will also explore the human factors and whether they impact the quality of user experience of wearable computing devices. Towards this goal, the focus of the experiment reported in this chapter was twofold: to understand the user experience with wearable devices whilst viewing multimedia and to find out whether the users would incorporate wearables in their daily lives.

4.4 Participants

The sample size of our experiment is based on a study by Brunnström and Barkowsky (2018). These authors have emphasised that in QoE experiments planning the sample size depends upon the statistical significance testing one will use for their study. They have also highlighted that the experimenter must distinguish the type of test design they intend to use whether it is a within-subject design or between-subject design. Within-subject design refers to- *"a type of experimental design in which all participants are exposed to every treatment or condition"* (Cherry, 2020). On the hand between-subject design is when participants of an experiment are split into two or more groups and each group has different conditions (Budiu, 2018). For our experiment we used within-subject design because we wanted to test the effect of wearable devices on users QoE with multimedia content using only one group. According to Brunnström and Barkowsky (2018) the sample size for within-subject design with alpha 0.05 needs to involve at least 23 test subjects for one comparison as that would be sufficient to reliably discover a statistical difference.

Our study involved 24 participants (15 males and 9 females). Participants were aged between 18-41+ years of age and hailed from a range of diverse backgrounds, nationalities, and education (undergraduate to postgraduate students and academic staff). All participants spoke English and were computer literate.

4.5 Experimental Preamble

The experiment took place in a quiet room, where the actual time of the experiment lasted between 30-40 minutes. The experiment had received ethics clearance from the local committee and each participant was asked for their consent in taking part in the experiment. Before the experiment, every participant was introduced to the experiment with an explanation of the process and tasks involved. Each participant was then provided with the previously described KOR-FX haptic vest, Mio Go HR monitor wristband and iShine headphones to wear. Once participants confirmed that wearing the devices was comfortable (e.g. not too tight/loose, in an awkward position) they then proceeded to view the multimedia video clips as shown in (Fig. 4.1).

4.6 Experimental Process

Participants viewed 7 multimedia video clips as described in Chapter 3 on a laptop whilst wearing the haptic vest and the HR monitor wristband. The video clips were shown in a random order to ensure that order effects are minimized. After viewing each video clip, participants were asked to complete a short online questionnaire based on the haptic vest, indicating their views on a 5-point Likert scale (1= strongly agree, 2= agree, 3= neutral, 4= disagree, 5= strongly disagree) in respect of a number of statements concerning the device's usability as presented in Chapter 3 (Table 3.1).

When all 7 clips had been watched, participants were required to complete an extended paper questionnaire. The paper questionnaire consisted of questions split into two categories one targeting the haptic vest KOR-FX and the other Mio Go wearable wristband, respectively see Chapter 3 (Tables 3.3 and 3.4). The questions were designed to capture a user's thoughts and their experience of wearing the devices. The widely used SUS was incorporated when developing the questions to gather information and learn about a user's views of the product (Bangor et al. 2009). Once they had completed the experiment, participants were thanked for their time and effort.

Figure 4.1: Experimental setup. The users were wearing: (1) a pair of iShine headphones, (2) the KOR-FX haptic vest, while their HR was measured with (3) Mio Go wristband.

4.7 Analysis of Self-Reported QoE

The analysis of self-reported QoE was carried out to see whether the use of a haptic vest would have an impact on a user's experience against the 7 multimedia video clips. To check the effect that device type (haptic vest) has QoE, we wanted to test the following hypothesis:

- Users will have a positive experience whilst viewing multimedia when wearing a haptic vest

In order to test our hypothesis IBM SPSS was used to undertake a one-sample t-test. A significance level of 0.05 was adopted for the analysis. Our results indicate that specific multimedia content for the video clips significantly influences participants' QoE (Table 4.1).

Throughout most video clips for question, 1 there was no significant difference between participants' level of enjoyment. This suggests that participants' responses were balanced for most of the clips but clips 3, 4, and 6 were the ones that they enjoyed most. The results for question 2 show that most participants felt that the haptic vest effects were only relevant to a certain extent to the video clips they were watching. However, some participants did feel that the effects were more relevant to video clips 1 and 3. This could be due to the video content or the audio.

The results for the following two questions (3 and 4), whilst not statistically significant across the board (only responses for clips 3 and 7 for question 3 and video clips 1, 3, 4, 6 and 7 for question 4 were statistically significant), nonetheless show that users did not perceive the haptic vest's vibrations to be distracting or annoying. The results for question 5 show that in roughly half of the time, participants felt that the haptic vest effects did enhance the sense of reality whilst watching the video clips 3, 4 and 7, with responses being statistically significant. However, responses to this question for the rest of the video clips were not statistically significant, showing that not all participants felt that there was much difference with the effects enhancing the sense of reality; this could well be because of the video content. In respect of haptic effects being necessary to accompany video content, although for most video clips (except for video clip 5) responses were not statistically significant, participants' responses did however reveal a slightly negative attitude here.

Lastly, responses to question 7 reveals that the use of the haptic vest did have an influence on the user viewing experience but only to a limited extent. Participants did, however, feel that the use of the haptic vest effects for video clip 4 were pleasing, with statistically significant responses being obtained in this case. Rounding up, what these experiments highlight is that the use of the haptic vest to impact QoE should be done judiciously and not across the board, considering the viewed content. Indeed, this is in keeping with previous research, which has highlighted the importance of the content itself on user QoE (Interaction Design Foundation, 2017).

Moreover, by applying the QoE concept, we got an insight to the user's experience as well as learning which video clips were of interest to them and which ones were not it is something to consider in the future. However, whilst devices did enhance the overall QoE for most of video clips, the fact that this did not happen across the board could be due to users not being acquainted with wearables whilst viewing multimedia or the content itself not matching up to their needs. Summarizing the results, our hypothesis can be confirmed as users had a positive experience for some of the video clips whilst wearing a haptic vest. However, not all video clips made a positive impact on the user's experience so further work is needed to conclusively approve or disprove the hypothesis.

4.8 Analysis of Post Questionnaires

In this study we wanted to see whether participants would incorporate the two wearable devices a haptic vest and a HR monitor wristband into their daily lives therefore we tested the following hypothesis:

- Users would incorporate wearable devices into their daily lives

In order to test the hypothesis, we analysed the end of the experiment questionnaires using IBM SPSS to undertake a one-sample t-test and a significance level of 0.05 was adopted for the analysis. The results can be seen in (Table 4.2). The results revealed that the perceived comfort of the haptic vest reported by participants had a statistically significant mean value of 2.38, emphasizing that participants found the haptic vest comfortable to wear. Moreover, the perceived comfort of the HR monitor wristband reported by participants, displays an even stronger positive bias, with statistically significant responses' and a mean value of 1.17 (refer to figures 4.2 and 4.3.) Although not statistically significant, results show that participants did not perceive the vest to feel bulky when worn. Statistical significance was, however, obtained in user responses which highlighted that the device did not come across overly warm. Also, the perceived usability of the functions and activities in the vest by the participants was positive. It is also to be remarked that, on average, participants preferred the wristband more than the haptic vest. Participants' statistically significant opinions of wearing the haptic vest in public were average, demonstrating that they were not so keen. Moreover, the results highlighted that users preferred to wear the wristband in public rather than the haptic vest, with expressed opinions again being statistically significant. The same could be said for wearing the devices at both work and during leisure time. Our statistically significant results also highlight that participants are keen on wearing the wristband daily at work.

Lastly, we wanted to know whether participants are likely to wear the devices in their leisure time. Here, the results for both work and leisure of the haptic vest were very similar. The statistically significant results for the wristband had a mean of 1.79, which leans towards a categorical value of 'agree'. Again, the results for both work and leisure of the wristband were very similar. Participants were more comfortable wearing a wristband than the haptic vest in their daily lives. These results confirm our hypothesis as users would incorporate the wearables devices into their daily lives to some extent especially the HR monitor wristband which the users preferred more than the haptic vest.

Table 4.1: Results of the Haptic Vest from the online questions (The cells in bold contain statistically significant results)

Haptic Vest	Video Clip 1	Video Clip 2	Video Clip 3	Video Clip 4	Video Clip 5	Video Clip 6	Video Clip 7
Q1	Mean: 2.63 Std: 1.13 *t* value: -1.619 *p*-value: .119	Mean: 2.66 Std: .868 *t* value: -1.881 *p*-value: .073	**Mean: 2.42** **Std: .776** ***t* value: -3.685** ***p*-value: .001**	**Mean: 2.50** **Std: .978** ***t* value: -2.505** ***p*-value: .020**	Mean: 2.92 Std: .974 *t* value: -.419 *p*-value: .679	**Mean: 2.25** **Std: .847** ***t* value: -4.338** ***p*-value: .000**	Mean: 2.63 Std: 1.10 *t* value: -1.676 *p*-value: .107
Q2	**Mean: 2.46** **Std: 1.02** ***t* value: -2.600** ***p*-value: .016**	Mean: 2.79 Std: 1.14 *t* value: -.894 *p*-value: .380	**Mean: 2.33** **Std: .637** ***t* value: -5.127** ***p*-value: .000**	Mean: 2.58 Std: 1.10 *t* value: -1.856 *p*-value: .076	Mean: 3.29 Std: 1.08 *t* value: 1.320 *p*-value: .200	Mean: 2.71 Std: 1.16 *t* value: -1.232 *p*-value: .231	Mean: 2.58 Std: 1.06 *t* value: -1.926 *p*-value: .067
Q3	Mean: 3.46 Std: 1.28 *t* value: 1.748 *p*-value: .094	Mean: 3.08 Std: 1.06 *t* value: .385 *p*-value: .704	**Mean: 3.46** **Std: .884** ***t* value: 2.541** ***p*-value: .018**	Mean: 3.46 Std: 1.10 *t* value: 2.037 *p*-value: .053	Mean: 3.00 Std: 1.22 *t* value: .000 *p*-value: 1.000	Mean: 3.29 Std: 1.23 *t* value: 1.159 *p*-value: .258	**Mean: 3.58** **Std: 1.10** ***t* value: 2.598** ***p*-value: .016**
Q4	**Mean: 3.58** **Std: 1.14** ***t* value: 2.509** ***p*-value: .020**	Mean: 3.29 Std: 1.04 *t* value: 1.372 *p*-value: .183	**Mean: 3.67** **Std: .817** ***t* value: 4.000** ***p*-value: .001**	**Mean: 3.67** **Std: .817** ***t* value: 4.000** ***p*-value: .001**	Mean: 3.29 Std: 1.16 *t* value: 1.232 *p*-value: .231	**Mean: 3.50** **Std: 1.18** ***t* value: 2.077** ***p*-value: .049**	**Mean: 3.58** **Std: 1.10** ***t* value: 2.598** ***p*-value: .016**
Q5	Mean: 2.63 Std: 1.01 *t* value: -1.813 *p*-value: .083	Mean: 2.75 Std: 1.07 *t* value: -1.141 *p*-value: .266	**Mean: 2.46** **Std: .658** ***t* value: -4.033** ***p*-value: .001**	**Mean: 2.46** **Std: .977** ***t* value: -2.716** ***p*-value: .012**	Mean: 3.00 Std: 1.22 *t* value: .000 *p*-value: 1.000	Mean: 2.54 Std: 1.14 *t* value: -1.967 *p*-value: .061	**Mean: 2.38** **Std: .824** ***t* value: -3.715** ***p*-value: .001**
Q6	Mean: 2.92 Std: 1.21 *t* value: -.377 *p*-value: .739	Mean: 3.04 Std: 1.23 *t* value: .166 *p*-value: .870	Mean: 3.04 Std: .908 *t* value: .255 *p*-value: .824	Mean: 2.67 Std: 1.05 *t* value: -1.556 *p*-value: .133	**Mean: 3.46** **Std: .932** ***t* value: 2.410** ***p*-value: .024**	Mean: 2.88 Std: 1.15 *t* value: -.531 *p*-value: .601	Mean: 2.92 Std: 1.02 *t* value: -.401 *p*-value: .692
Q7	Mean: 2.63 Std: 1.21 *t* value: -1.519 *p*-value: .142	Mean: 2.79 Std: 1.14 *t* value: -.894 *p*-value: .380	Mean: 2.67 Std: .817 *t* value: -2.000 *p*-value: .057	**Mean: 2.21** **Std: .588** ***t* value: -6.953** ***p*-value: .000**	Mean: 3.13 Std: 1.12 *t* value: .549 *p*-value: .588	Mean: 2.58 Std: 1.02 *t* value: -2.005 *p*-value: .057	Mean: 2.75 Std: .989 *t* value: -1.238 *p*-value: .228

Table 4.2 Results of both wearable devices after the experiment (Boldface figures contain statistically significant results)

Haptic Vest	Mean	Standard Deviation	*T*	*p*-value
Q1	**2.38**	**1.01**	**-3.021**	**.006**
Q2	3.21	1.10	.926	.364
Q3	**3.63**	**1.24**	**2.460**	**.022**
Q4	2.75	.676	-1.813	.083
Q5	**3.54**	**1.10**	**2.407**	**.025**
Q6	3.29	1.08	1.320	.200
Q7	2.88	1.30	-.473	.641
Heart rate monitor band	**Mean**	**Standard Deviation**	***T***	***p*-value**
Q1	**1.17**	**.565**	**-15.906**	**.000**
Q2	**2.25**	**.532**	**-6.192**	**.000**
Q3	**2.00**	**.722**	**-6.782**	**.000**
Q4	**1.96**	**.624**	**-8.177**	**.000**
Q5	**1.79**	**.658**	**-8.996**	**.000**

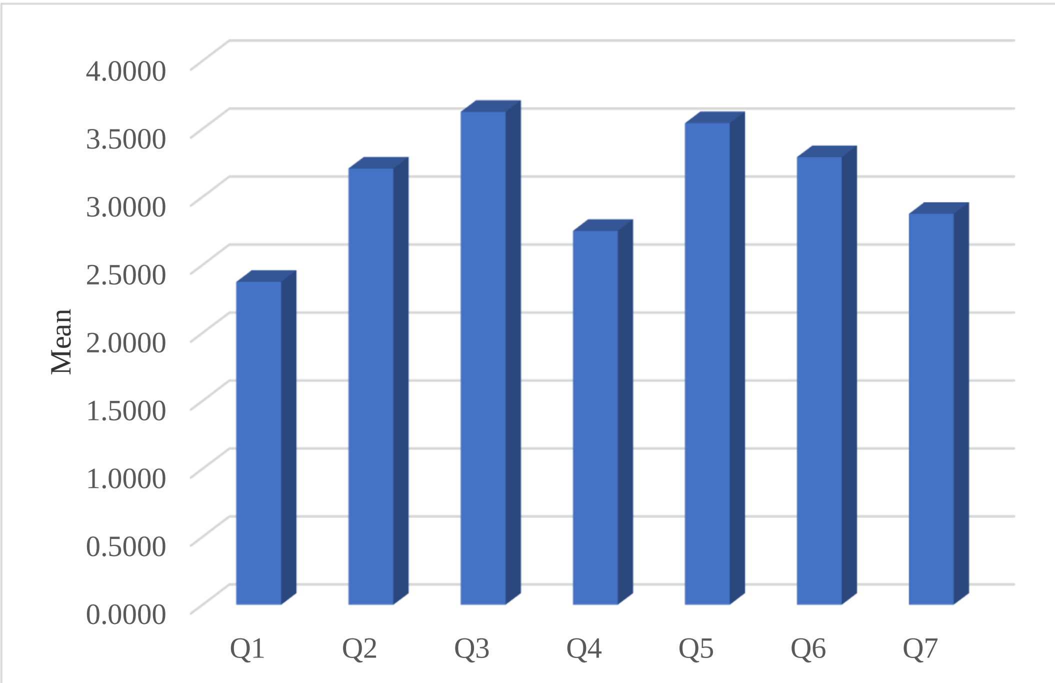


Figure 4.2: End of Experiment Questionnaire: Haptic Vest

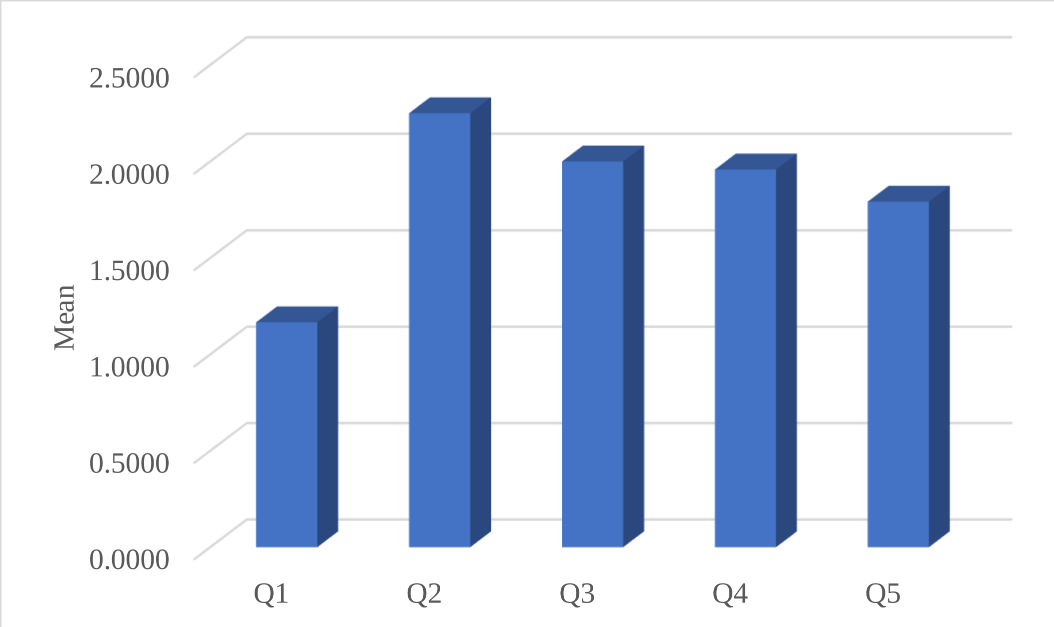


Figure 4.3: End of Experiment Questionnaire: Wrist Band

4.9 Human Factors

We further examined human factors to see whether there is a significant difference in responses obtained from the online questions based on demographics (age, gender and educational level). We wanted to test the following hypothesis:

- Human factors will influence the users QoE with wearables in a multimedia context

To test the hypothesis the analysis was determined using a factorial ANOVA (Table 4.3) and the descriptive statistics can be seen in (Table 4.4). The results illustrated a highly significant main effect of age ($p = .000$) on Q1 whilst there were no differences amongst gender and education. This indicates that the age of participants does considerably influence the responses. Majority of the participants reported a moderately more favourable attitude towards wearing the haptic vest apart from (26-30 years old). With regards, to haptic vest effect (Q2) there were no significant results for gender and education apart from age ($p = .000$). Participants of 26-30 years old found the effects to be relevant to the video clips at a certain degree (M= 3.46). However, the other age groups mean values as shown in (Table 4.4) disclosed that they believed the effects were related to the video clips.

The ANOVA revealed a highly significant main effect of age (p = .000) and gender (p = .034) on Q3. The younger generation (26-30 years old) were more distracted with the haptic vest vibrations as compared to the older generation whose responses were neutral but the age group 41+ years old mean value (3.77) leans towards a categorical value of *'disagree'*. This suggests that participants in this age group did not find the haptic vibrations much of a distraction. Moreover, the mean value for males (M= 3.47) leans towards a categorical value of *'disagree'* as they found the vibrations of the haptic vest less distracting than the females (M= 3.09). Similar results were found for Q4 where gender (p= .042) and education (p= .001) were significant. Males were slightly less annoyed (M= 3.63) with the vibrations than females (M= 3.30). Also, PhD students' responses were neutral (M= 3.31) as opposed to postgraduate and academic staff who did not find the haptic vest vibrations annoying.

The responses to Q5, Q6 and Q7 are significantly determined by age. The two other factors (gender and education) had insignificance effect for these three questions. Q5 shows that majority of the age groups apart from (36-40 years old) agreed that the haptic effects had enhanced the sense of reality. For Q6 users between (31-35 years old) believed more than the other age groups that the haptic vest effects were necessary.

Lastly, in terms of Q7 results showed that users in two age categories (31-35, 41+ years old) confirmed that haptic vest effects did enhance their overall viewing experience. The other two age groups (26-30 and 36-40) responses were neutral, suggesting that the haptic vest partly improved their viewing experience.

These results confirm our hypothesis as human factors did indeed influence users QoE. Age was predominantly the influencing factor on the users QoE as the results exposed that the older generation had a slightly more positive attitude towards the haptic vest than the younger generation.

Table 4.3: Demographic Results (Boldface figures contain statistically significant results)

Questions	Age		Gender		Education	
	F	Sig.	F	Sig.	F	Sig.
Q1: I enjoyed watching the video clip whilst wearing a Haptic Vest	7.343	**.000**	.245	.621	3.95	.675
Q2: The Haptic Vest effects were relevant to the video clip I was watching	8.924	**.000**	.013	.911	2.071	.129
Q3: The vibration was distracting	11.336	**.000**	4.569	**.034**	2.222	.112
Q4: The vibration was annoying	1.827	.144	4.217	**.042**	7.577	**.001**
Q5: The Haptic Vest effects enhanced the sense of reality whilst watching the video clip	3.703	**.013**	.019	.890	1.580	.209
Q6: The Haptic Vest effects were necessary when watching a video clip	7.763	**.000**	.034	.855	1.738	.179
Q7: The Haptic Vest effects enhanced my viewing experience	4.196	**.007**	.002	.969	.361	.697

Table 4.4: Descriptive Statistics

	Age								Gender				Education					
Questions	**26-30**		**31-35**		**36-40**		**41+**		**Male**		**Female**		**Postgraduate**		**PhD**		**Academic Staff**	
	M	Std.	M	Std.	M	Std.	M	Std.	M	Std.	M	Std.	M	Std.	M	Std.	M	Std.
Q1	3.2143	.78680	2.3247	.89504	2.9286	1.07161	2.4898	.96009	2.5429	1.05638	2.6190	.79166	2.6857	1.18251	2.5294	.93721	2.6429	.49725
Q2	3.4643	.92224	2.3636	1.01189	2.4286	1.15787	2.7959	.95698	2.6857	1.12073	2.6667	.96720	2.3714	1.13981	2.7395	1.06931	2.9286	.61573
Q3	2.3571	1.06160	3.4026	1.06696	3.3571	.92878	3.7755	1.0051	3.4762	1.12741	3.0952	1.10299	3.3429	1.25892	3.2605	1.13841	3.9286	.26726
Q4	3.1071	1.03062	3.5584	1.01946	3.7143	.82542	3.6122	1.09576	3.6381	1.04811	3.3016	.99409	3.9714	.89066	3.3193	1.08090	4.0000	.00000
Q5	2.9643	1.03574	2.3766	.88910	3.0714	1.14114	2.6122	1.03715	2.6095	1.03306	2.5873	.96110	2.3429	1.30481	2.6555	.92459	2.7857	.69929
Q6	3.4643	.88117	2.5974	1.07923	3.5714	.75593	3.1633	1.06745	3.0000	1.05612	2.9683	1.13547	2.9714	1.24819	2.9328	1.07144	3.5000	.51887
Q7	3.0714	.85758	2.4026	.97683	3.0000	1.10940	2.7959	1.04042	2.6762	1.06062	2.6825	.94741	2.7714	1.33032	2.6723	.94877	2.5000	.65044

4.10 HR Results

In this study a Mio Go heart rate (HR) monitor wristband was worn by participants whilst viewing the multimedia clips. This wearable was used to identify if there were any differences in the participants HR against each of the selected video clips based on the haptic vest vibrations. We wanted to test the following hypothesis:

- The users HR will not be the same across all the multimedia video clips

To test our hypothesis a one-sample t-test was used via SPSS (Table 4.5). The test value in this context was (80) as the average HR of an adult is (60-100) beats per minute (BPM) (MacGill, 2017).

The findings reveal the HR for the blue clip is significant (p= .000) and the mean was slightly above the value of 80. Perhaps the content or the pressure of the vibrations prompted the participant's HR to rise. The average (BPM) for the yellow and red clip reveals a much higher result (M= 91.26), (M= 91.30) and there was a significant difference both resulting the same (p= .000). This shows there was an increase in the HR whilst participants viewed the clips. The HR could have been affected by the audio that is transmitted via haptic effects. The spinning motors of the haptic vest vibrating against the user's chest could have come across strong enhancing the video content for some participants. The results were significant and same for both dark and bright clips (p= .000). This could be because of the different types of audio that were used in these clips feeding back different vibration intensities on the user's chest. Also, the results for angular and round clips were significant (p= .000). This shows that many users' HR amplified significantly especially in viewing the angular clip (M= 94.30). The shape associated clips featured attractive music as compared to the other clips that had softer music, maybe that caused the BPM to increase as the heartbeat changes depending on the type of music one listens to (Ellis and Brighous, 1952; Zimney and Weidenfeller, 1963). Additionally, some music may have made the participants stressed or equally it could have left them feeling excited making their HR go up. These results confirm our hypothesis as there were differences in the users HR throughout all the video clips.

Table 4.5: HR Results One- Sample T-Test

Video clips	M	Std.	T-value	Sig.
Blue	83.13	41.101	4.101	**.000**
Yellow	91.26	40.753	14.888	**.000**
Red	91.30	41.274	14.675	**.000**
Dark	89.81	31.280	16.855	**.000**
Bright	88.92	36.378	13.129	**.000**
Angular	94.30	36.660	20.913	**.000**
Round	91.07	40.093	14.878	**.000**

4.11 Discussion

The aim of the experiment reported in this study was to provide insights into users experience with wearable devices whilst viewing multimedia content. Although, the scale of our study was small from our results it appears that many users had a satisfying overall experience with the wearables. Both devices studied – a haptic vest and a HR monitoring wrist band - were perceived positively when it came to their comfort and usability. However, in respect of whether the users would incorporate these devices daily the results revealed that the HR monitor wrist band seemed more appropriate to be worn in public, work and leisure as opposed to the haptic vest. This could be because the wrist band is lightweight, small, compact, can be hidden and more appealing whereas the haptic vest is quite cumbersome and would be noticeable to wear. In respect of user QoE, results show that the use of wearables whilst viewing the video clips did increase QoE. Also, it enhanced the enduring nature of the experience, at an average level. The user's interests in video content multimedia in most of the video clips varied as they had different expectations. Nonetheless, some video clips were more enjoyed, and this reinforces the primacy of content in multimedia QoE as evidenced by previous work (Ghinea and Chen, 2006).

Furthermore, the results of the demographics exposed that age had a substantial impact on the haptic vest as certain age groups either agreed or disagreed with the statements in the questionnaire. Most of the age groups responses were near enough positive apart from the younger generation (26-30 years old) as their attitudes towards the haptic vest were quite negative. However, the haptic vest was perceived more positively by the age groups (31-35 and 41+ years old). This could be because this particular age group had an exciting experience and were more engaged as compared to the age groups. Also, females found the haptic vest vibrations a little annoying and distracting than the males this could be because of the video audio coming across loud making the vibrations beat stronger on the participants' chest making them feel uneasy. In terms of the HR it varied throughout all the video clips seeing that the content and the audio were different for each clip and contributed in the HR to either go up or go down all depends on a user's mood something that can be explored in the future.

4.12 Conclusion

In this chapter we have described and discussed the experiment methodology as well as the analysis of the two wearables in accordance to QoE measures (subjective and objective). From the subjective point of view, it can be said that to some extent the users' QoE increased with the use of the wearables. On the other hand, the objective results have shown that the participants' HR varied between the video clips as some had more impact than others. Also, the human factors highlighted that age predominantly influenced users QoE. Building on these results, Chapter 5 will explore and evaluate the QoE of mulsemedia and wearable devices.

Chapter 5: Mulsemedia and QoE

5.1 Overview

In this chapter we address the third and fourth objectives of our research and focus on the non-traditional approach of QoE, as highlighted in Chapter 2. We explore QoE with mulsemedia by employing olfaction and haptic effects. Also, we delve into the human factors to see whether they impact user QoE with mulsemedia in relation to wearables.

The structure of this chapter is as follows: in Section 5.2 we describe mulsemedia and olfaction used in previous literature. Section 5.3 discusses the human factors used in multimedia and mulsemedia setups. Section 5.4 describes the methodology and materials used. In section 5.5 the analysis of self-reported QoE is justified, whilst Section 5.6 describes the analysis of the results from the paper questionnaires for both wearables employed in our study (KOR-FX and Mio Go). Section 5.7 explores the human factors that influence mulsemedia QoE as well as the wearables. Section 5.8 analyses the UEQ questionnaires followed by a discussion in Section 5.9 and conclusions are drawn in Section 5.10.

5.2 Previous Work

With the recent rapid development in technologies underpinning smart and wearable devices human senses beyond the audio-visual can now be included in digital applications. These new multisensory technologies are now more affordable and accessible for all people, hence including other senses such as smell, and touch is an increasingly realistic proposition which has the potential to enhance a user's QoE. Accordingly, there have been a proliferation of studies exploring user QoE of mulsemedia applications incorporating non-traditional media types such as haptics (Iwata et al. 2003), gustatory (Narumi et al. 2011), olfactory (Ghinea and Ademoye, 2012a, 2012b; Murray et al. 2013) or indeed, a combination thereof, such as haptic-olfactory (Hoshino et al. 2011).

QoE has been comprehensively investigated in and considered to be a very important aspect of mulsemedia (Yuan et al. 2014), with several potential application areas being identified. For example, Nakamoto et al. (2008) applied olfaction in a gaming context with results showing an increased QoE. In terms of multisensory interaction and design many studies have demonstrated that using this phenomenon in practice has brought many benefits. Accordingly, Hancock et al. (2013) used a multisensory concept in their study and found it improved the performance of visual searches and reduced the amount on mental workload. Covaci et al. (2018) proposed a multisensorial educational game named Fragrance Channel and looked at how the learning engagement, performance and QoE can be improved with olfactory stimulation. The findings highlighted that multisensory setups in educational games engage users and can increase the performance as well as the learning process.

Speaking of education, Zou et al. (2017) used mulsemedia in Technology Enhanced Learning (TEL) to improve the learning process and experience. The authors developed a testbed to play video content enhanced with olfaction, haptic and airflow effects. The results showed that most users are open to (TEL) as it would increase their learning experience to a great extent. Gustavo, (2018) proposed a model named '*Multisensorial Electronic Books'* combining enhanced e-books with mulsemedia to improve the readers learning process and the QoE. The author also developed a prototype that integrated olfactory, auditory and haptic effects. The prototype was a notable success and opened avenues for future research. Also, in the context of learning e-books enriched with mulsemedia content have shown positive results as seen in several studies (Alam et al. 2013; Borgstrom, 2011; Lin et al. 2016 and Sánchez-Azqueta et al. 2016). It is fair to say that multisensory digital learning experiences that involve olfaction can enhance the users' QoE.

Additionally, the benefit of olfactory media to enrich QoE has also been proven in several other studies (Ghinea and Ademoye, 2011; Ghinea and Ademoye, 2012a, 2012b; Jalal and Murroni, 2017; Murray et al. 2013a; Murray et al. 2014; Tortell et al. 2007; Yuan et al. 2014; Yuan et al. 2015; Zhang et al. 2016). All these studies strengthen the belief that multisensory integration in a digital context will enhance QoE when using interactive systems. Although QoE has been studied with mulsemedia this has been without looking at the cross sensorial interaction. Nonetheless, over the last decade, there has been incipient work which has started to explore crossmodal correspondences between olfactory and visual stimuli. We shall now turn our attention to these.

Crossmodal correspondences have been addressed mainly in the field of cognitive science and this phenomenon is defined as *"a tendency for a sensory feature, or attribute, in one modality, either physically present or merely imagined, to be matched (or associated) with a sensory feature in another sensory modality"* (Parise and Spence, in press; Spence, 2012; Spence and Parise, 2012). Experiencing a stimulus in a sensory modality is often associated with experiences in another sensory dimension (e.g., pitch in audition and brightness in vision). Crossmodal correspondences between audition and vision have long been explored and extensively documented (Marks, 1975). However, researchers have shifted towards mapping olfaction and vision- an area that had not been studied before.

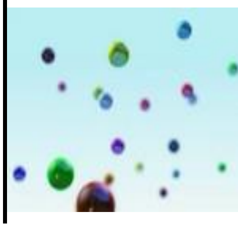
There are few studies that have mapped more than one sensory modality as Gilbert et al. (1996), provided one of the first examples of olfactory-visual correspondences, showing that there are strong correlations between odours and colours. Accordingly, bergamot smell was associated with yellow, cinnamon with red, pine with green, etc. Other studies investigated various smells associated with colours as seen in the works of (Kemp and Gilbert, 1997; Sakai et al. 2005; Streeter and White, 2011; Demattè et al. 2006). Specifically, Gilbert et al. (1996), presented a study on colour odour linkages that showed that blue colour matches lilial scent, yellow colour- bergamot scent, red colour- cinnamon scent and so forth. Part of these matches are illustrated in (Table 5.1). Correspondingly, Kemp and Gilbert

(1997), found that strong smells were found to be associated with darker colours. Other studies focused on the shape - colour correspondences and found that odours of pepper and lemon are significantly related with the angular shape, whereas the odours of raspberry and vanilla are relevantly linked with round shapes (Hanson-Vaux et al. 2012). Crossmodal correspondences were documented between several pairs of sensory modalities such as: vision and touch (Simner and Ludwig, 2009), audition and touch (Yau et al. 2009), flavours and sounds (Crisinel and Spence, 2009), flavours and vision (Gal et al. 2007). Even though the focus of this study is on wearables, we decided to incorporate different smells that were crossmodally matched with the six video clips to enhance user QoE and to explore the user experience of wearables in such a context. To this end we designed an experiment to explore whether the cross-modally mapped multisensorial effects (olfaction and auto-generated haptic) from visual features of videos enhance the users' QoE see (Table 5.1). We hypothesize that considering crossmodal mappings whilst creating mulsemedia systems could lead to more immersive and effective experiences for the users.

5.3 Human Factors

Numerous studies in the multimedia field have shown that human factors such as age, gender and personal interests influence user QoE (Scott et al. 2015; Zhu et al. 2015 and Zhu et al. 2018). Scott et al. (2016) investigated the influence of personality and cultural traits on the perception of multimedia quality. They reported that human factors play an important role in perceptual media quality as well as user enjoyment. Although, these studies are in the context of multimedia applications, very little research has been done on human factors in perceptual mulsemedia quality apart from a single study by Murray et al. (2013b). They investigated how age and gender influence users' perception of the temporal boundaries within which they perceive olfactory data and video to be synchronized. Moreover, whilst there has been previous work on mulsemedia QoE discussed in Section 5.2, there is a paucity of research that has looked at the influence of human factors on wearables QoE, and this adds an extra dimension to our investigation.

Table 5.1: Snapshots from the six videos used during the experiment with their themes, dominant visual cues and the conditions for the EG in each case. The CG experienced only visual content, without olfactory, auditory or vibrotactile content.

Video Snapshot	Description	Video Snapshot	Description
V1 	**Theme.** Beach **Visual cue.** Color: Blue **EG.** Olfactory: Lilial **CG.** Only visual content	**V2** 	**Theme.** Dallol in Ethiopia **Visual cue.** Color: Yellow **EG.** Olfactory: Bergamot **CG.** Only visual content
V3 	**Theme.** Solar eclipse **Visual cue.** Brightness: Low **EG.** Olfactory: Lavender (low intensity) **CG.** Only visual content	**V4** 	**Theme.** Sunrise upon the arctic **Visual cue.** Brightness: High **EG.** Olfactory: Lavender (high intensity) **CG.** Only visual content
V5 	**Theme.** Skyscrapers **Visual cue.** Shape: Angular **EG.** Olfactory: Lemon **CG.** Only visual content	**V6** 	**Theme.** Bouncing balls **Visual cue.** Shape: Round **EG.** Olfactory: Raspberry **CG.** Only visual content

5.4 Methodology

The experiments we designed are aimed to investigate the potential influence of using crossmodal mulsemedia correspondences concepts on user QoE with wearables. More specifically, we used 6 videos characterized by dominant visual features: colour (blue, yellow), brightness (low, high), and shape (round, angular). Participants viewed these videos enhanced with crossmodally matching smells while wearing a haptic vest and a HR monitor wristband. We chose to use the vibrotactile display because literature has shown that participants exhibit an increased emotional response to media with haptic enhancement (Réhman et al. 2014).

5.4.1 Participants

As discussed in Chapter 4 the sample size depends upon the test design an experimenter undertakes for their study which could be either within-subject design or between-subject design. In this experiment we decided to use between-subject design to see if there is statistically significant difference between two unrelated groups. A study by Brunnström and Barkowsky (2018) have shown that the sample size for within-subject design with alpha 0.05 generally requires at least 42 subjects or more. Higher number of subjects would be sufficient for a significant difference and the results would be more reliable with greater power as well as precision. However, these authors have observed that a significance difference of alpha 0.05 can be found with a sample size of 24 subjects. Their study has proved that small sample size can be used as long as it meets the significance level.

We recruited 24 participants (14 males and 10 females) who were randomly allocated into two groups: an experimental group (EG) with 18 participants and a control one (CG) with 6 participants. The crossmodally matched smells and wearables of the two groups can be seen in (Table 5.2). The Participants were aged between 18-41+ years and came from various nationalities and educational backgrounds. The gender and age of the participants were roughly matched across in the experiment. All participants spoke English and self-reported as being computer literate.

Table 5.2: Stimuli assortments and wearables for the two groups

Group	Olfactory	Wearables
G1 Experimental Group	All videos- V1- Lilial, V2-Bergamot, V3-Clear lavender, V4-Lavender, V5- Lemon, V6-Raspberry	Haptic vest and HR monitor wristband
G2 Control Group	All videos- No smell	Haptic vest without effects present and HR monitor wristband

5.5 Experimental Preamble

Our experiment was focused on the cross-modal correspondence between olfactory and haptic effects, and their impact on user QoE. The experiment was carried out in a noiseless laboratory and lasted for approximately 40 minutes. The Exhalia SBi4 device was placed at 0.5m in front of the participant, letting him/her to detect the smell in 2.7 – 3.2s (Murray et al. 2017). All participants were explained the procedure and tasks involved in this experiment. Participants were seated behind a table, facing the 15.6-inch Lenovo Windows 10 laptop screen. Each participant was then provided with headphones (iShine), a haptic vest to wear (KOR-FX) and HR monitor wristband (Mio Go) as shown in (Fig. 5.1). When participants confirmed that wearing the haptic vest and HR monitor wristband were comfortable as well as being satisfied with the whole setup, they then continued to view the video clips. The experiment was approved by the Ethical Committee of Brunel University.

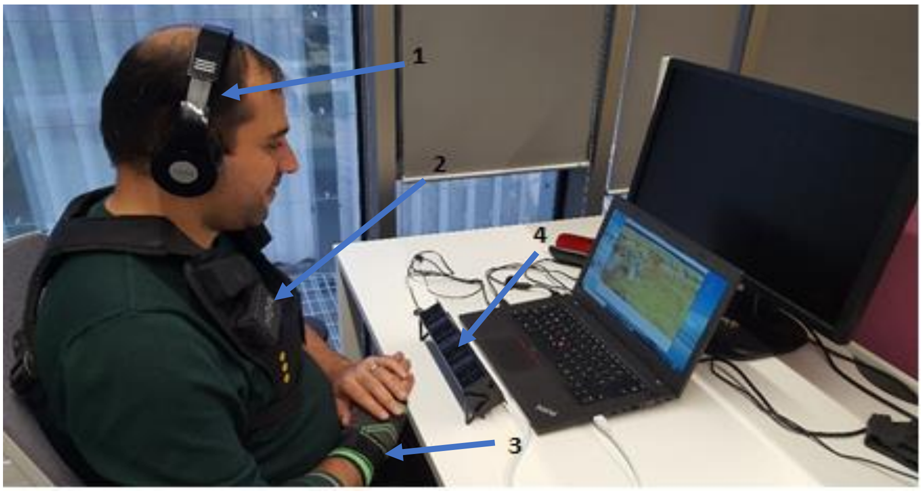


Figure 5.1 Experimental setup. The users were wearing: (1) i-Shine headphone, (2) the KOR-FX haptic vest (3) Mio Link (4) olfactory effects were diffused using Exhalia.

5.5.1 Experimental Process

The experiment involved 6 video clips that were accompanied by olfactory and vibrotactile contents. Video clip 7 (red) was eliminated from this study because there was no cross modal found in association to this colour in the literature. Videos were viewed in a random order so that order effects were minimised. Olfactory content was emitted using Exhalia's SBi4 four built-in-fans blowing through cartridges that contain scented polymer balls. A program employing Exhalia's Java-based SDK was used to emit olfactory content throughout the duration of the video clips.

Accordingly, scents were emitted for 10s at 30s intervals throughout the video clip (i.e. starting at 0s, 30s, 60s, and 90s). When the Exhalia SBi4 was not emitting scents, the scent's lingering effect ensured that it was still noticeable for the next 20s, after which the SBi4's fans were switched back on to emit for the next 10s. Alongside odours, vibrotactile effects were provided throughout the whole duration of the clips, vibrating according to the associated audio soundtrack. After each video clip, participants were asked to complete a subjective questionnaire with a set of 7 questions in relation to QoE, designed to capture users' views and their overall experience of this experiment as detailed in Chapter 3 (Table 3.2). Each question was answered on a 5-point Likert scale with positive questions anchored at one end with *"strongly agree"* and with *"strongly disagree"* at the other end. These questions were developed based on the SUS, widely used amongst researchers and by a variety of industries (Bangor et al. 2009). Once the experiment was over, participants' were further asked to complete paper questionnaires that featured SUS see Chapter 3 (Tables 3.3 and 3.4) and UEQ based questions (Table 3.5).

5.6 Analysis of Self-Reported QoE

We decided to investigate whether wearing a haptic vest with cross-modally mapped olfaction is more effective in enhancing user QoE. We tested the following hypothesis:

- Users will have a positive experience whilst viewing multimedia with olfactory and haptic vest effects

We used IBM SPSS software to run our statistical analysis. To check the effect that device type (haptic vest) has on QoE, we performed an independent sample t-test with group as independent variable and the responses to the 7 self-reported QoE questions as the dependent variables. A significance level of 0.05 was adopted for the analysis and the results are presented in (Tables 5.3 and 5.4). Before analysing the data, we converted the scores of each negatively phrased question (Q3 and Q4) to the equivalent score associated with a positively phrased counterpart. As previously stated, participants self-reported the QoE by answering 7 Likert scale questions.

In Q1, there were no statistically significant results between the EG and the CG for all 6 video clips. This means that the participants' responses do not differ significantly, as the haptic effects which were automatically generated out of the content-original sound have contributed to the enjoyment. Throughout most of the video clips for Q2 there were statistically significant results between the EG and the CG, with the only exception being video clip 2. This suggests that participants' in the EG have noticed the relevance of the haptic effect for these respective videos (1, 3, 4, 5 and 6), whereas in the CG the participants did not notice any effects. This is because no smell and effects were present in this group. On a positive note, in Q3 there were insignificant differences between both groups (EG and CG) revealing that the haptic vest effects were not distractive but rather pleasant. The same can be said for Q4 also showing insignificant differences as the haptic effects were generally not perceived annoying.

In Q5 there were statistically significant differences between the EG and the CG in video clip 3 ($p= .007$), video clip 5 ($p= .002$) and video clip 6 ($p= .007$). This indicates that these clips made a positive impact enhancing the sense of reality for some participants' in the EG however, the same does not apply for the CG who scored a higher mean across these video clips. In respect of Q6 there were statistically significant results in both EG and CG for video clips 1, 3, 5 and 6. In the EG the participants found the haptic vest enhanced their viewing experience to a certain extent, whereas in the CG some participants had a negative view and disagreed, whilst others had a neutral response. Lastly, in Q7 there were insignificant results in both the EG and CG implying that overall, the participants' enjoyed the multisensorial experience. The results confirm the hypothesis as the use of olfaction and haptic effects enhanced the users QoE as seen in the EG.

Table 5.3: Descriptive statistics haptic vest

Haptic Vest	Video Clip 1	Video Clip 2	Video Clip 3	Video Clip 4	Video Clip 5	Video Clip 6
Q1	(EG) M: 2.76 Std: 1.09 (CG) M: 2.66 Std: 1.21	(EG) M: 2.72 Std: 1.01 (CG) M: 2.66 Std: 1.21	(EG) M: 2.37 Std: 1.25 (CG) M: 3.00 Std: 1.54	(EG) M: 2.33 Std: .970 (CG) M: 2.83 Std: 1.32	(EG) M: 2.50 Std: 1.09 (CG) M: 2.83 Std: 1.32	(EG) M: 2.38 Std: .978 (CG) M: 3.00 Std: 1.26
Q2	(EG) M: 2.77 Std: 1.00 (CG) M: 4.00 Std:1.09	(EG) M: 3.05 Std: 1.05 (CG) M: 3.66 Std: .816	(EG) M: 2.41 Std: 1.32 (CG) M: 4.33 Std: .816	(EG) M: 2.83 Std: 1.15 (CG) M: 4.16 Std: .983	(EG) M: 2.27 Std: 1.01 (CG) M: 4.16 Std: .752	(EG) M: 2.88 Std: 1.02 (CG) M: 4.00 Std: .894
Q3	(EG) M: 2.83 Std: 1.04 (CG) M: 3.66 Std: .816	(EG) M: 2.88 Std: 1.02 (CG) M: 3.83 Std: .983	(EG) M: 3.37 Std: 1.31 (CG) M: 3.83 Std: .983	(EG) M: 3.22 Std: 1.26 (CG) M: 3.66 Std: .816	(EG) M: 3.17 Std: 1.07 (CG) M: 3.66 Std: .816	(EG) M: 3.35 Std: 1.11 (CG) M: 3.50 Std: .836
Q4	(EG) M: 2.88 Std: 1.23 (CG) M: 3.50 Std: .836	(EG) M: 3.05 Std: 1.16 (CG) M: 3.83 Std: .983	(EG) M: 3.52 Std: 1.28 (CG) M: 3.83 Std: .983	(EG) M: 3.38 Std: 1.19 (CG) M: 3.50 Std: 1.04	(EG) M: 3.33 Std: .970 (CG) M: 3.50 Std: 1.04	(EG) M: 3.50 Std: 1.09 (CG) M: 3.50 Std: 1.04
Q5	(EG) M: 2.82 Std: 1.07 (CG) M: 3.66 Std: .816	(EG) M: 3.05 Std: .899 (CG) M: 3.83 Std: .983	(EG) M: 2.47 Std: 1.12 (CG) M: 4.00 Std: .894	(EG) M: 3.22 Std: 1.11 (CG) M: 4.00 Std: .894	(EG) M: 2.44 Std: .855 (CG) M: 3.83 Std: .752	(EG) M: 2.88 Std: .963 (CG) M: 4.16 Std: .752
Q6	(EG) M: 2.23 Std: 1.03 (CG) M: 3.66 Std: .516	(EG) M: 3.27 Std: .826 (CG) M: 3.83 Std: .983	(EG) M: 1.82 Std: .727 (CG) M: 4.00 Std: .632	(EG) M: 3.38 Std: 1.09 (CG) M: 3.83 Std: .983	(EG) M: 1.94 Std: .872 (CG) M: 4.00 Std: .632	(EG) M: 1.94 Std: .747 (CG) M: 3.66 Std: 1.03
Q7	(EG) M: 2.23 Std: 1.03 (CG) M: 3.50 Std: .836	(EG) M: 3.11 Std: .758 (CG) M: 3.83 Std: .983	(EG) M: 1.82 Std: .727 (CG) M: 3.66 Std: 1.03	(EG) M: 2.22 Std: .942 (CG) M: 3.50 Std: .836	(EG) M: 1.94 Std: .872 (CG) M: 3.33 Std: .816	(EG) M: 1.94 Std: .747 (CG) M: 3.83 Std: 1.16

Table 5.4: Independent Sample T-Test Self-Reported QoE

Haptic Vest	Video Clip 1	Video Clip 2	Video Clip 3	Video Clip 4	Video Clip 5	Video Clip 6
Q1	F: .085 *t* value: .184 *p*-value: .856	F: .427 *t* value: .111 *p*-value: .913	F: .949 *t* value: -.977 *p*-value: .340	F: 2.591 *t* value: -.988 *p*-value: .329	F: 1.100 *t* value: -.612 *p*-value: .547	F: .557 *t* value: -1.234 *p*-value: .230
Q2	**F: .617** ***t* value: -2.530** ***p*-value: .019**	F: .067 *t* value: -1.288 *p*-value: .211	**F: 2.593** ***t* value: -3.307** ***p*-value: .003**	**F: .257** ***t* value: -2.538** ***p*-value: .019**	**F: .686** ***t* value: -4.157** ***p*-value: .000**	**F: 1.213** ***t* value: -2.369** ***p*-value: .027**
Q3	F: .413 *t* value: -1.775 *p*-value: .090	F: .005 *t* value: -1.976 *p*-value: .061	F: .669 *t* value: -.774 *p*-value: .448	F: 1.125 *t* value: -.801 *p*-value: .431	F: .852 *t* value: -1.013 *p*-value: .323	F: .950 *t* value: -.293 *p*-value: .772
Q4	F: 1.449 *t* value: -1.124 *p*-value: .273	F: .162 *t* value: -1.468 *p*-value: .156	F: .374 *t* value: -.526 *p*-value: .604	F: .128 *t* value: -.203 *p*-value: .841	F: .008 *t* value: -.358 *p*-value: .724	F: .040 *t* value: .000 *p*-value: 1.000
Q5	F: .852 *t* value: -1.743 *p*-value: .096	F: .093 *t* value: -1.733 *p*-value: .091	**F: 1.516** ***t* value: -2.998** ***p*-value: .007**	F: .813 *t* value: -1.544 *p*-value: .137	**F: .608** ***t* value: -3.536** ***p*-value: .002**	**F: 1.168** ***t* value: -2.947** ***p*-value: .007**
Q6	**F: 3.673** ***t* value: .563** ***p*-value: .004**	F: .254 *t* value: -1.363 *p*-value: .187	**F: 1.411** ***t* value: -6.491** ***p*-value: .000**	F: 1.234 *t* value: -.882 *p*-value: .387	**F: 1.217** ***t* value: -5.291** ***p*-value: .000**	**F: .861** ***t* value: -4.407** ***p*-value: .000**
Q7	**F: .709** ***t* value: -2.692** ***p*-value: .014**	F: .006 *t* value: -1.880 *p*-value: .073	**F: .812** ***t* value: -4.787** ***p*-value: .000**	**F: .419** ***t* value: -2.947** ***p*-value: .007**	**F: .021** ***t* value: -3.425** ***p*-value: .002**	**F: 1.798** ***t* value: -4.598** ***p*-value: .000**

5.7 Analysis of Post Questionnaires

We compare results obtained after experiencing mulsemedia interaction in the presence and absence of olfactory, haptic vest feedback from users' and HR monitor wristband. We tested the following hypothesis:

- Users exposed to haptic effects and olfaction would incorporate wearable devices into their daily lives

Accordingly, an independent sample t-test was used to compare the responses obtained from the end of experiment paper questionnaires for the EG and the CG. The results are displayed in (Table 5.5).

In respect of Q1, there were insignificant results between the EG and the CG. This implies that both groups found the haptic vest comfortable to wear. In Q2, insignificant results were found between both groups, (EG and CG). This suggests that both groups did not find the haptic vest bulky to wear. There were also insignificant results in Q3, as both the EG and CG did not find the haptic vest heat up in the duration of viewing the video clips. In Q4, there were statistically significant results ($p = .036$) amongst the EG and the CG, as participants' responses show that not all of them agreed that the functions within the haptic vest were well incorporated. Mostly the EG participants have a positive attitude ($M = 2.38$) and found the functions very useful.

In Q5 there were statistically significant results ($p = .035$). The participants responses in the EG were neutral ($M = 3.44$) implying that they would not mind wearing the haptic vest in public as opposed to the CG who were less keen ($M = 4.50$) this could be due to its appearance (design). Similar results were shown in Q6 as there were significant differences ($p = .028$). In the EG participants would consider wearing the haptic vest at work ($M = 3.50$) than the CG who disagreed ($M = 4.50$). With that being said there were statistically significant differences between the EG and CG in Q7 ($p = .029$). These results suggest that the haptic vest would be worn by participants' in their leisure time in the EG (M= 2.72) than the CG (M= 3.83).

In terms of the HR monitor wristband, the results reveal that for Q1 there were no differences in responses across both groups (EG and CG). This implies that the users' were pleased to wear the Mio Go wristband, which was deemed very comfortable to wear. In the case of Q2 there were also no significant differences in results as both groups agree that the HR device is helpful in terms of the activities it offers. For Q3, Q4 and Q5 there were insignificant results showing that participants' in both the EG and the CG prefer wearing the HR device in public, work and leisure time as opposed to the haptic vest. This could be because the HR device is discreet, small and can be concealed. Overall, this device has received positive feedback from users and would be worn in the future.

Overall, the results confirm the hypothesis as most users who were exposed to the haptic effects and olfaction (EG) would adopt both of the wearable devices into their daily lives but the same cannot be said for the CG who were keener on adopting the HR monitor wristband than the haptic vest. This could be because there were no haptic vest effects present in this group.

5.8 Human Factors Results

In order to understand if age, gender and education influence a user's satisfaction and enjoyment of mulsemedia applications we analysed the impact of each on the individual items of the self-reported QoE questionnaire. We wanted to test the following hypothesis:

- Human factors will influence the users QoE with wearables in a mulsemedia context

To this end, we undertook an Analysis of Variance (ANOVA) test with age, gender and education as independent variables and the user QoE responses as dependent variables. The descriptive statistics are displayed in (Table 5.6) and the results of this analysis are shown in (Table 5.7). The ANOVA revealed a highly significant main effect of age (p= .000), gender (p= .020) and education (p= .002) for Q1. Apart from the age group (31-35), most of the age groups enjoyed watching the videos whilst wearing the haptic vest, especially 18-21 and 26-30 years old (M= 2.28; M= 1.58). Moreover, the male participants (M= 2.49) enjoyed wearing the haptic vest slightly more than the females (M= 2.73). The education category shows that the PhD students (M= 2.30) agreed with the Q1 statement more than the undergraduate and postgraduate students. Across the board the participant's responses were positive, showing that the haptic vest was well received. In respect of Q2, there were no significant results for gender and education apart from age (p = .000). Most age groups (18-21, 22-25 and 41+) found the haptic effects relevant to the video clips they viewed, especially the younger generation.

With regards to the questions about the vibration of the vest, the ANOVA revealed statistically significant results of age and education in Q3 (p= .003; p= .001) and in Q4 (p= .001; p= .001). For both Q3 and Q4 the younger generation aged (22-25 and 26-30) found the haptic vest rather distracting as well as annoying. The postgraduate students' responses were neutral in Q3 (M= 3.00) however, in Q4 the students agreed (M= 2.96) that the haptic vest was annoying. For Q5, there were no differences amongst gender and education only age revealed statistically significant results (p= .000). Two age groups (18-21 and 41+) have similar mean values (M= 2.68; M= 2.79) as they considered that the haptic vest employed enhanced their sense of reality whilst watching the video clips. The results in Q6 are significantly determined by age (p= .001). This implies that majority of the age groups (18-21, 22-25, 26-30 and 41+) felt that the haptic vest effects enhanced their viewing experience. Lastly, in Q7 the results show that age (p =.000) has statistically significant results. This denotes that almost all participants enjoyed the multisensorial experience apart from the age groups (31-35 and 36-40) years old. It appears that the younger generation (18-21 years old) had a slightly higher mean (M= 2.10), indicating that overall, they had an optimistic outlook of mulsemedia that influenced their experience. Overall, these results have shown that the human factors influenced users QoE therefore this confirms our hypothesis.

Table 5.5: Results of the end of experiment questionnaire

Haptic Vest	**Group**	**Mean**	**Std.**	**F**	***T***	***p*-value**
Q1	EG	2.11	1.07	1.905	-1.203	.242
	CG	2.66	.516			
Q2	EG	4.27	.669	.334	.811	.426
	CG	4.00	.894			
Q3	EG	4.00	1.08	1.627	-.347	.732
	CG	4.16	.752			
Q4	EG	2.38	.978	**2.820**	**-2.239**	**.036**
	CG	3.33	.516			
Q5	EG	3.44	1.09	**4.136**	**-2.242**	**.035**
	CG	4.50	.547			
Q6	EG	3.50	.985	**2.750**	**-2.345**	**.028**
	CG	4.50	.547			
Q7	EG	2.72	1.07	**1.319**	**-2.334**	**.029**
	CG	3.83	.752			
HR monitor band	**Group**	**Mean**	**Std.**	**F**	***T***	***p*-value**
Q1	EG	1.66	.594	.063	-.558	.583
	CG	1.83	.752			
Q2	EG	2.11	.582	1.921	-1.270	.217
	CG	2.50	.836			
Q3	EG	2.22	.942	.020	-.978	.339
	CG	2.66	1.03			
Q4	EG	2.22	1.00	.467	-.978	.339
	CG	2.66	.816			
Q5	EG	2.16	1.04	.070	.000	1.000
	CG	2.16	.983			

Table 5.6: Descriptive Statistics Demographics

	Age						Gender		Education		
Question	**18-21**	**22-25**	**26-30**	**31-35**	**36-40**	**41+**	**Male**	**Female**	**UG**	**PG**	**PhD**
Q1	M: 2.2826 Std: 1.06798	M: 3.0588 Std: .96635	M: 2.5556 Std: .85559	M: 3.5833 Std: .77553	M: 1.5833 Std: .66856	M: 2.4167 Std: 1.13890	M: 2.4938 Std: .86781	M: 2.7333 Std: 1.36378	M: 2.5679 Std: 1.02394	M: 2.9667 Std: .99943	M: 2.3000 Std: 1.34293
Q2	M: 2.7292 Std: 1.18033	M: 2.4118 Std: .87026	M: 3.2778 Std: .57451	M: 4.0417 Std: 1.08264	M: 4.2500 Std: .75378	M: 2.5417 Std: 1.10253	M: 2.9634 Std: 1.08235	M: 3.2295 Std: 1.33408	M: 2.9518 Std: 1.03480	M: 3.1000 Std: 1.15520	M: 3.4000 Std: 1.58875
Q3	M: 3.3913 Std: 1.18281	M: 2.5294 Std: .87447	M: 2.6471 Std: .60634	M: 3.5833 Std: 1.41165	M: 3.5000 Std: .52223	M: 3.6250 Std: .71094	M: 3.4051 Std: 1.06842	M: 3.1148 Std: 1.09694	M: 3.1750 Std: 1.04063	M: 3.0000 Std: 1.17444	M: 3.8333 Std: .94989
Q4	M: 3.5208 Std: 1.20265	M: 2.5882 Std: .79521	M: 2.8889 Std: .75840	M: 3.6250 Std: 1.34528	M: 3.5000 Std: .52223	M: 3.4583 Std: 1.10253	M: 3.5732 Std: .98169	M: 3.0164 Std: 1.21781	M: 3.3012 Std: 1.06765	M: 2.9667 Std: 1.12903	M: 3.8000 Std: 1.12648
Q5	M: 2.6875 Std: 1.05500	M: 3.1875 Std: .91059	M: 3.0000 Std: .70711	M: 3.9583 Std: 1.2208	M: 3.6667 Std: .65134	M: 2.7917 Std: 1.06237	M: 3.0375 Std: 1.07260	M: 3.1803 Std: 1.10315	M: 2.9753 Std: .99969	M: 3.2667 Std: 1.01483	M: 3.2667 Std: 1.33735
Q6	M: 2.4043 Std: 1.20974	M: 2.6250 Std: .61914	M: 2.6111 Std: .84984	M: 3.2500 Std: 1.15156	M: 4.0000 Std: 1.04447	M: 2.7917 Std: 1.28466	M: 2.6250 Std: 1.11803	M: 3.0328 Std: 1.23784	M: 2.5062 Std: 1.03831	M: 3.1333 Std: 1.16658	M: 3.2667 Std: 1.36289
Q7	M: 2.1064 Std: 1.02648	M: 2.6250 Std: .50000	M: 2.4444 Std: .78382	M: 3.0417 Std: 1.12208	M: 3.7500 Std: 1.05529	M: 2.5417 Std: 1.21509	M: 2.3875 Std: .98718	M: 2.8361 Std: 1.19973	M: 2.3210 Std: .91961	M: 2.8667 Std: 1.13664	M: 3.0000 Std: 1.33907

Table 5.7: ANOVA results (Demographics)

Questions	Age		Gender		Education	
	F	Sig.	F	Sig.	F	Sig.
Q1	15.622	**.000**	5.559	**.020**	6.699	**.002**
Q2	16.553	**.000**	2.306	.131	2.471	.089
Q3	3.743	**.003**	.071	.790	7.748	**.001**
Q4	4.335	**.001**	2.876	.092	8.010	**.001**
Q5	10.316	**.000**	3.091	.081	.457	.634
Q6	4.221	**.001**	2.406	.123	1.656	.195
Q7	6.618	**.000**	3.344	.070	1.295	.278

5.9 Analysis of HR Data

As we have previously discussed in the literature QoE has two measurements-subjective and objective. As a physiological metric, we employed Mio Go HR monitor wristband to carry out objective measurement. The HR of each participant was collected at the rate of one reading per second and measured in BPM. We collected 120 HR readings for 6 video clips. The HR readings for both group (EG and CG) varied with the means for each video illustrated in (Fig. 5.2) and the variations shown in (Fig. 5.3).

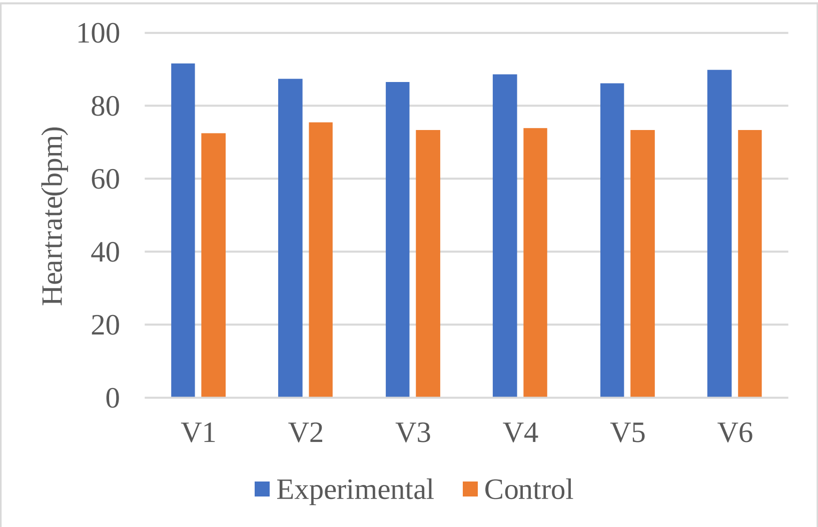


Figure 5.2 Average HR for all the video clips

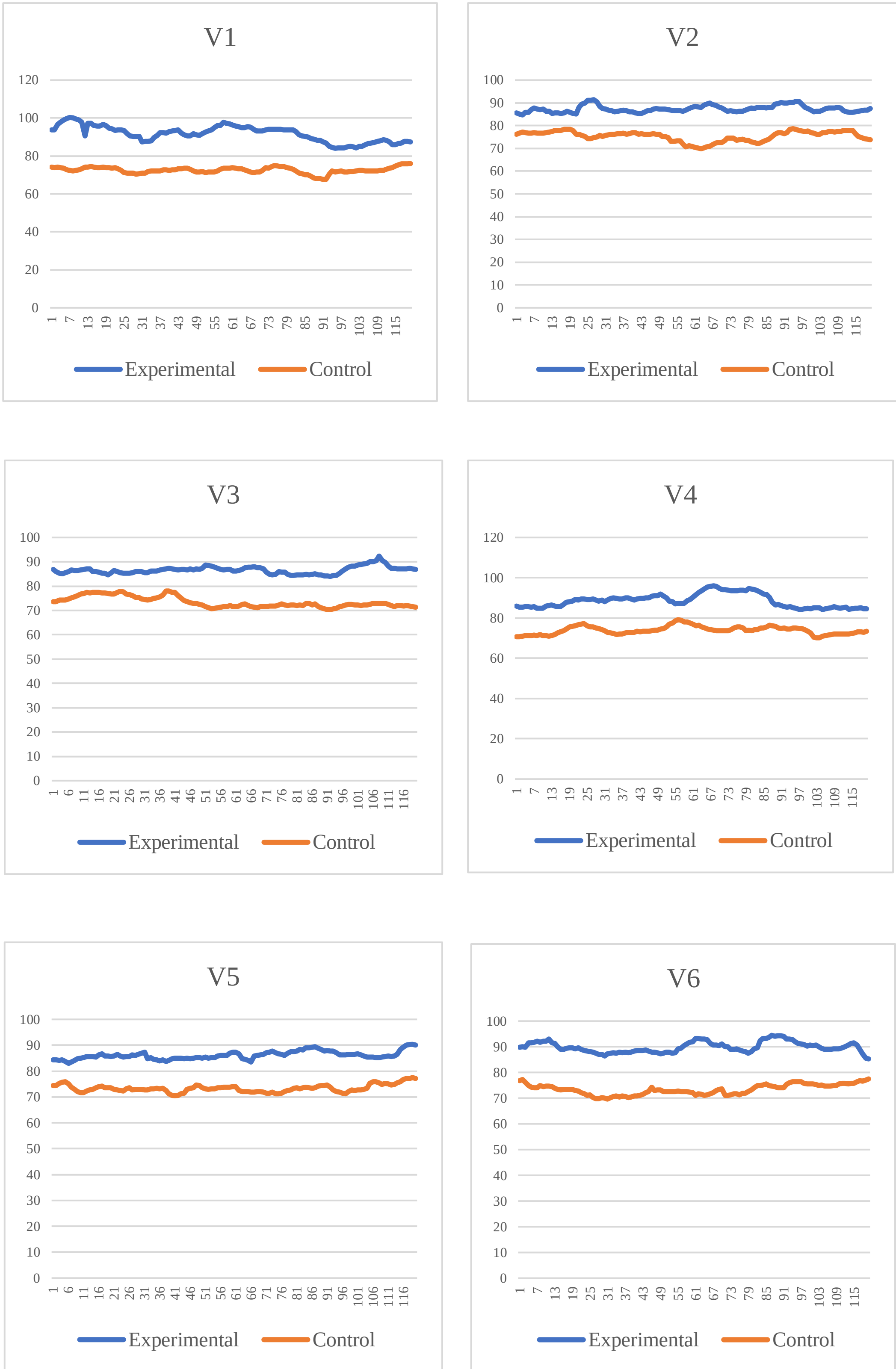


Figure 5.3 HR data (BPM) of the participants for each video

In order to understand whether there are any differences in the HR between the two groups (EG and CG), we tested the following hypothesis:

- The users HR will be not be the same in the EG and CG

We undertook an independent samples t-test to test our hypotheses, the results of which are shown in (Table 5.8). The results demonstrate a statistically significant difference in the HR between the two groups for all the videos. We observed a tendency for a higher HR in the EG for the whole duration of the videos. This indicates that the two groups experienced a different mood in the two setups: (i) the one using crossmodally matching smell, haptic vest and HR monitor wristband (EG) and (ii) the one where only HR monitor wristband was provided as no smell and haptic effects were present in the CG. The most significant differences in HR appear for video clips 1 and 6. This shows that these video clips considerably changed the user's mood especially in the EG scoring a high HR when compared to the CG. This could be due because of the content or the two setups. The results have revealed that the users HR between the two groups was not the same it was different, and this confirms our hypothesis.

Table 5.8: HR Independent sample t-test

Video	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval	
				Lower	Upper
V1	.000	19.125	.415	18.305	19.945
V2	.000	11.850	.245	11.366	12.334
V3	.000	13.042	.245	12.559	13.524
V4	.000	14.642	.365	13.922	15.361
V5	.000	12.692	.192	12.313	13.070
V6	.000	16.375	.268	15.847	16.903

5.10 UEQ Analysis

As mentioned in Chapter 3 the UEQ short version was used in our study because we wanted to learn about the attitudes of users' towards the two wearable computing devices (haptic vest and HR monitor wristband) employed in our study. The UEQ consists of 8 items (Table 5.9) recording two elements, respectively pragmatic and hedonic quality. At the end of the experiment participants from both groups (EG and CG) judged the two wearables. We used the short UEQ data analysis tool in Microsoft Excel developed by (Schrepp, 2017) to measure the reliability of the 8 items. The tool reports the mean, standard deviation, confidence intervals and Cronbach Alpha which are detailed in the following sections.

Table 5.9: Short Version UEQ

1	obstructive	o o o o o o o	supportive	**Pragmatic**
2	complicated	o o o o o o o	easy	
3	inefficient	o o o o o o o	efficient	
4	confusing	o o o o o o o	clear	
5	boring	o o o o o o o	exciting	**Hedonic**
6	not interesting	o o o o o o o	interesting	
7	conventional	o o o o o o o	inventive	
8	usual	o o o o o o o	leading edge	

5.10.1 Cronbach Alpha

Cronbach alpha is the most commonly used measure of reliability and has become widespread in the literature (Cronbach, 1951). Cronbach's alpha provides a measure of internal consistency of a test and generally ranges in value from 0 to 1. Internal consistency assesses the inter-correlations between items that should all measure the same construct (Tavakol and Dennick 2011). A widely accepted value of Cronbach's alpha is generally 0.70 which reflects good reliability (Nunnally and Bernstein, 1994; Bland and Altman, 1997; Graham, 2006). We used Cronbach Alpha because there are multiple Likert-type questions in the UEQ that form a scale and we wanted to determine whether the scale is reliable.

The results revealed that the consistency of the pragmatic quality and hedonic quality scales was reasonably high, as the Cronbach, alpha values exceeded the threshold of 0.70. Accordingly, the corresponding Cronbach alpha values were 0.77 (pragmatic quality) and 0.81 (hedonic quality) for the haptic vest in the EG. The Cronbach alpha values for the CG were 0.73 (pragmatic quality) and 0.72 (hedonic quality). In terms of the HR monitor wristband the results show that the Cronbach alpha for pragmatic quality was 0.78 and for hedonic quality 0.73 for the EG. In the CG the values were 0.77 for pragmatic quality and 0.74 for the hedonic quality. This concludes that the results reported here indicate there is internal consistency associated to the 8 items as the reliability of the questionnaire is sufficiently high and participant's attitudes towards wearables were generally positive.

Schrepp (2017), has designed the tool that rescales the data from seven-stage (7-point Likert scale) to the range -3 to +3 and calculates the scale values for pragmatic and hedonic quality per person. Accordingly, -3 represents the most negative answer (horribly bad), 0 a neutral answer, and +3 the most positive answer (extremely good). Also, the scale means are interpreted with values between -0.8 and 0.8 that signify a neural evaluation of the equivalent scale. The values that represent a negative evaluation are < -0.8 and the values that represent a positive evaluation are >0.8 (Schrepp et al. 2017).

The results in the EG have shown the mean values are above the threshold of >0.8 for both pragmatic (0.94) and hedonic (1.01) quality of the haptic vest. The mean per item have positive values apart from item 1 (M= 0.38) and item 8 (M= 0.72) that had a lower mean see (Fig.5.4). This suggests that some participants found the haptic vest quite obstructive to wear and did not find the device as a leading edge. Also, most of the participants' responses were average and their outlook on the haptic vest leaned slightly more towards hedonic implying that they found the wearable device fun and exciting to wear. However, there were two items (2 and 4) in the pragmatic quality that stood out and have highly positive mean indicating that participants deemed the haptic vest to be clear and easy to use.

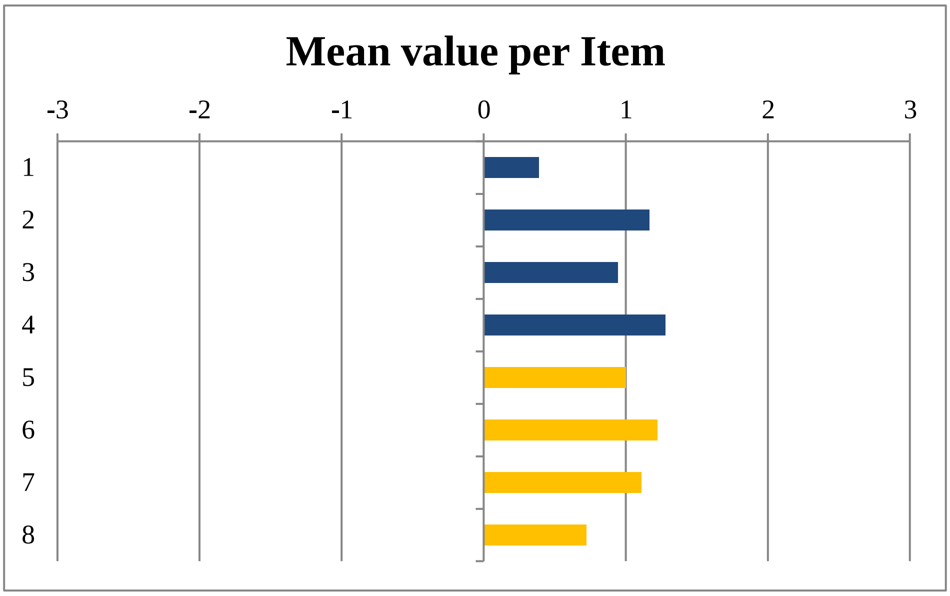


Figure 5.4 Mean Values for the Haptic Vest in the EG
(Blue bar is for pragmatic items and Yellow bar is for hedonic items)

The mean values in the CG displayed (1.00) for pragmatic quality items and (1.12) for the hedonic quality items. The mean values per item were generally positive and participant's responses were similar across the board for both pragmatic and hedonic qualities. However, item 7 in the hedonic quality scored a higher mean as participants found the haptic vest inventive as shown in (Fig. 5.5).

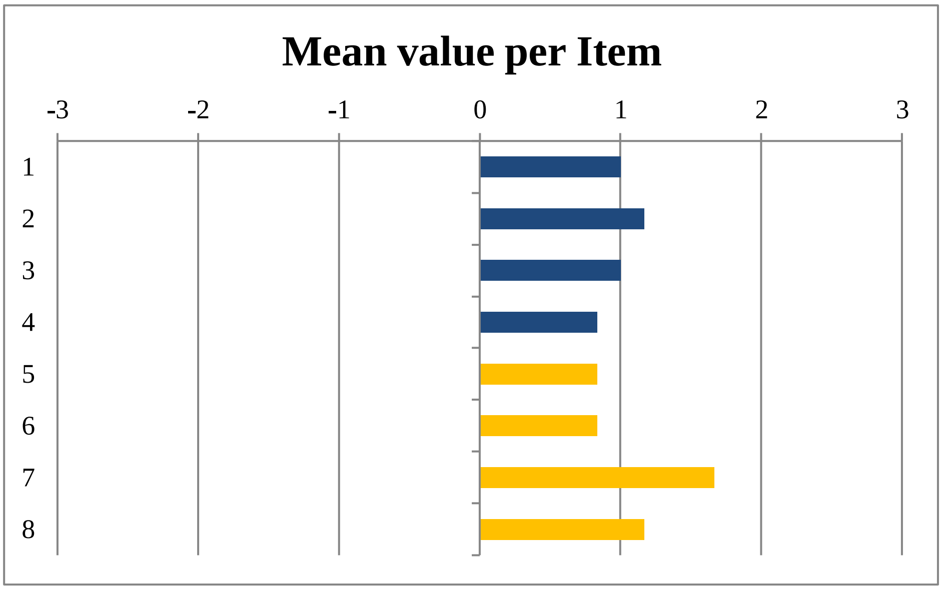


Figure 5.5 Mean Values for the Haptic Vest in the CG
(Blue bar is for pragmatic items and Yellow bar is for hedonic items)

In terms of the HR monitor wristband the results unveiled mean values of (1.54) for pragmatic and (1.47) for hedonic quality in the EG. The mean per item were more positive than the haptic vest as shown in (Fig.5.6). Items 1, 2, 3, 6 and 8 have high positive mean this shows that the participants' found the device supportive, easy, efficient, interesting and leading edge. Overall, more items had a greater mean in respect of the pragmatic quality as participants found the HR monitor wristband very useful to wear in terms of its functionalities. The mean scores between pragmatic and hedonic quality were very close and participants found the device appealing.

The mean values were also above the threshold in the CG for both pragmatic (1.33) and hedonic quality (1.62). The mean values per item were all positive, participants impressions towards HR monitor wristband leaned more on the hedonic quality items. Items 7 and 8 had a higher mean with the same value (M= 1.83) as participants found the wearable device inventive and leading edge. However, from the pragmatic quality item 1 had a very high mean (M= 2.00) suggesting that participants found the device rather supportive see (Fig.5.7). Furthermore, the confidence intervals of our values are provided in (Tables 5.10, 5.11, 5.12 and 5.13).

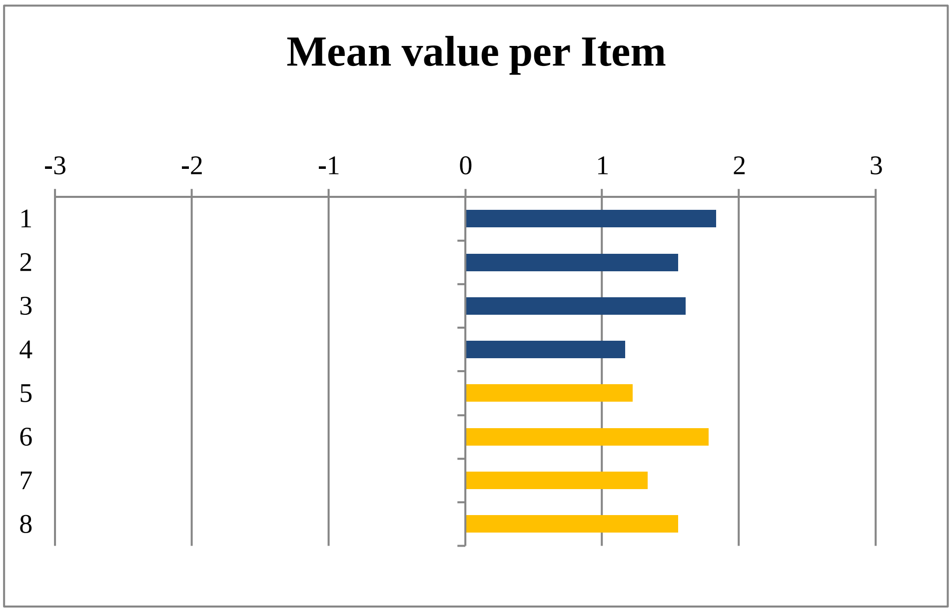


Figure 5.6 Mean Values for the HR monitor Wristband in the EG (Blue bar is for pragmatic items and Yellow bar is for hedonic items)

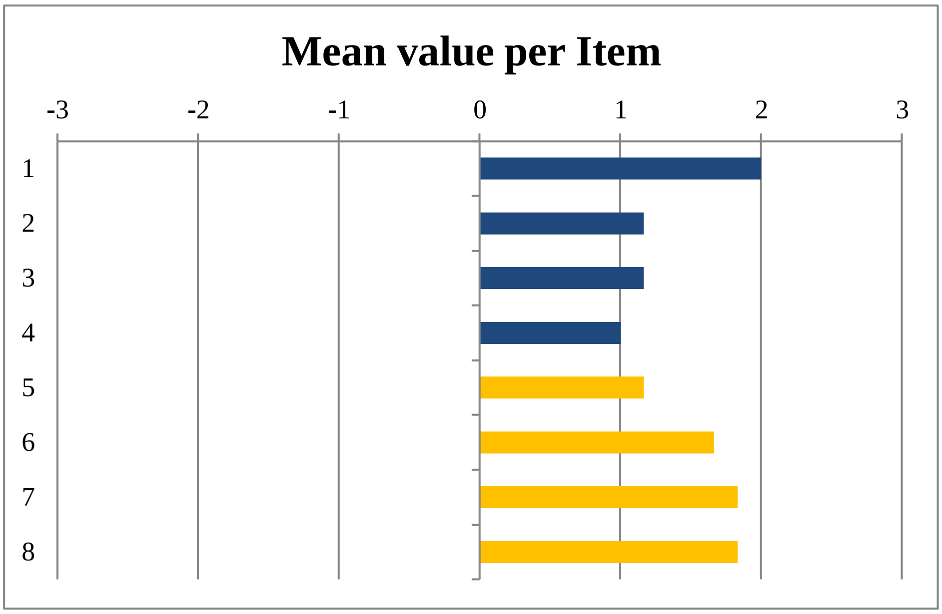


Figure 5.7 Mean Values for the HR monitor Wristband in the CG (Blue bar is for pragmatic items and Yellow bar is for hedonic items)

Table 5.10: Confidence Interval Haptic Vest EG

Confidence interval (p=0.05) per item						
Item	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence interval**	
1	0.389	1.685	18	0.779	-0.390	1.167
2	1.167	1.724	18	0.796	0.370	1.963
3	0.944	1.626	18	0.751	0.193	1.696
4	1.278	1.227	18	0.567	0.711	1.845
5	1.000	1.455	18	0.672	0.328	1.672
6	1.222	1.665	18	0.769	0.453	1.991
7	1.111	1.641	18	0.758	0.353	1.869
8	0.722	1.809	18	0.836	-0.113	1.558
Confidence intervals (p=0.05) per scale						
Scale	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence Interval**	
Pragmatic	0.944	1.226	18	0.567	0.378	1.511
Hedonic	1.014	1.310	18	0.605	0.409	1.619
Overall	0.979	1.028	18	0.475	0.504	1.454

Table 5.11: Confidence Interval HR monitor wristband EG

Confidence interval (p=0.05) per item						
Item	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence interval**	
1	1.833	1.200	18	0.555	1.279	2.388
2	1.556	1.199	18	0.554	1.002	2.110
3	1.611	1.539	18	0.711	0.900	2.322
4	1.167	1.757	18	0.812	0.355	1.979
5	1.222	1.166	18	0.539	0.684	1.761
6	1.778	1.665	18	0.769	1.009	2.547
7	1.333	1.372	18	0.634	0.700	1.967
8	1.556	1.504	18	0.695	0.861	2.250
Confidence intervals (p=0.05) per scale						
Scale	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence Interval**	
Pragmatic	1.542	1.119	18	0.517	1.025	2.059
Hedonic	1.472	1.064	18	0.491	0.981	1.964
Overall	1.507	0.631	18	0.291	1.216	1.798

Table 5.12: Confidence Interval Haptic Vest CG

Confidence interval (p=0.05) per item						
Item	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence interval**	
1	1.000	2.530	6	2.024	-1.024	3.024
2	1.167	1.941	6	1.553	-0.386	2.720
3	1.000	2.000	6	1.600	-0.600	2.600
4	0.833	1.472	6	1.178	-0.344	2.011
5	0.833	2.041	6	1.633	-0.800	2.467
6	0.833	1.722	6	1.378	-0.545	2.212
7	1.667	1.966	6	1.573	0.093	3.240
8	1.167	2.229	6	1.783	-0.617	2.950
Confidence intervals (p=0.05) per scale						
Scale	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence Interval**	
Pragmatic	1.000	1.517	6	1.213	-0.213	2.213
Hedonic	1.125	1.506	6	1.205	-0.080	2.330
Overall	1.063	0.907	6	0.726	0.336	1.789

Table 5.13: Confidence Interval HR monitor wristband CG

Confidence interval (p=0.05) per item						
Item	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence interval**	
1	2.000	2.000	6	1.600	0.400	3.600
2	1.167	1.472	6	1.178	-0.011	2.344
3	1.167	2.483	6	1.987	-0.820	3.154
4	1.000	2.280	6	1.825	-0.825	2.825
5	1.167	2.041	6	1.633	-0.467	2.800
6	1.667	1.366	6	1.093	0.573	2.760
7	1.833	1.169	6	0.935	0.898	2.769
8	1.833	1.169	6	0.935	0.898	2.769
Confidence intervals (p=0.05) per scale						
Scale	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence Interval**	
Pragmatic	1.333	1.586	6	1.269	0.064	2.603
Hedonic	1.625	1.115	6	0.892	0.733	2.517
Overall	1.479	0.691	6	0.553	0.926	2.032

5.11 Discussion

From the self-reported questionnaire, the findings from the independent sample t-test conveyed that there was a significant difference in the user responses between both the EG and CG. Participants who wore the haptic vest with effects (EG) found the wearable device effective in its utility, as employing mulsemedia did enhance users' QoE. However, participants in the CG were not enthused when viewing the video clips as they did not get much out of the device (haptic vest) because the effects were not present in this group. As regards to the end of experiment paper questionnaires, the responses to the SUS questions revealed that the users' responses in the EG were neutral towards the haptic vest as compared to the CG where participants had a rather negative attitude. On the bright side, both groups were satisfied in wearing the HR monitor wristband and would incorporate the device into their daily lives. The implications of these findings suggest that the participants in both (EG and CG) were keener in adopting the HR monitor wristband than haptic vest into their daily lives and it could be because of the design.

As previous literature by (Moen, 2007; Bryson, 2007; Anderson and Lee, 2008; Amft and Lukowicz, 2009; Poslad, 2009 and Paradiso et al. 2010) have shown that design issues create a barrier for user adoption. Regarding the HR monitor wristband this type of device is well-known amongst people as they are well acquainted with it as opposed to the haptic vest. HR monitor wristbands are very popular in the health and fitness market (Mashable, 2019). However, not many people are aware of a haptic vest as it is less known so this could be another reason why users may have been hesitant in adopting this device.

The human factor results showed that all three demographics (age, gender and education) have an influence in users' QoE with wearable devices. However, age and education were the two influencing factors that impacted the users' responses the most. These findings confirm the work of (Murray et al. 2013b, Scott et al. 2015; Zhu et al. 2015 and Zhu et al. 2018) who found age, gender and personal interests influences users QoE.

Lastly, the UEQ part of the questionnaire has revealed that the EG and the CG participants responses leaned slightly more towards the hedonic quality for most of the items regarding the haptic vest. For the HR monitor wristband, the EG leaned more on the pragmatic qualities whereas the CG scored higher in the hedonic qualities. These results imply that participant's impressions towards the wearables were mostly linked to the hedonic quality items. The participants found the wearable devices fun, original, interesting and engaging.

5.12 Conclusion

The results have conveyed that there were mixed views towards the two wearables employed in this study. However, majority of participants prefer the HR monitor wristband in terms of its practicality as opposed to the haptic vest. In summary, it appears from the results that the users from the EG enjoyed wearing the haptic vest and that it enhanced their overall experience as compared to the CG. This could be due to the use of olfaction as well as the content itself.

Chapter 6: Guidelines in Evaluating QoE with Wearables

6.1 Overview

In this chapter, we address the fifth objective of our research and focus on setting guidelines in evaluating user QoE with wearables. Explicitly, we explore previous wearable guidelines that have been proposed in the literature. This chapter is structured as follows: Section 6.2 discusses previous studies that have developed or proposed guidelines. Section 6.3 gives an overview of the outcome of the experiments in Chapters 4 and 5. Section 6.4 introduces the QoE guidelines for wearables. Section 6.5 discusses the guidelines presented. Lastly, conclusions are drawn in Section 6.6.

6.2 Background

There are guidelines that have been presented for wearables in the literature mostly related to design aspects. Few guidelines exist to assist developers and designers in creating accessible wearables. Of these, worthy of mention are those of Wentzel et al. (2016) and Wentzel and Geest (2016), who created a set of design guidelines for accessible wearables that cater to the needs of people with a disability. They evaluated the guidelines with developers, researchers and visually impaired people. Burak and Özcan (2018), extracted generalisable design guidelines from their research about how to design wearables and movement-based gameplay for tabletop role playing experience. From their results, they evaluated design implications from players related to game design and accordingly designed a new gaming system (WEARPG) that incorporates arm-worn devices and movement-based gameplay in tabletop role playing experience. By testing their new system amongst users, new design guidelines were identified enabling the authors to improve the system before developing a prototype. Accordingly, they designed and implemented an arm-worn device and a tangible device. The use of wearables and movement-based gameplay increased player's immersion experiences. Much earlier, Gemperle et al. (1998), examined dynamic wearability and proposed design guidelines insisting that unobtrusive placement is an important consideration as well as keeping aesthetics in mind. Overall, though, not many guidelines have been presented in relation to wearables. Moreover, to the best of our knowledge there is no single study that has put forward a set of guidelines in evaluating QoE with wearables in multimedia and mulsemedia contexts. This is especially even more surprising, given the importance of QoE to the user multimedia experience.

6.3 Summary of Experiments

This section presents a summary of the results from two QoE experiments we performed that evaluate two wearable devices (KOR-FX gaming vest and Mio Go HR monitor wristband). The QoE guidelines for wearable devices are based in part from the results obtained from these studies. The studies were motivated by the need to address the existing gap in knowledge and were undertaken while the participants employed the two wearable devices. The first study evaluated user QoE with wearables devices in the traditional multimedia context. Participants were instructed to wear two wearable devices and view 7 different video clips that were based on natural scenes. After viewing each video clip the participants answered a series of questions in regards to the haptic vest to capture their views and opinions. A further set of questions based on both devices was answered at the end of the experiment by participants. Also, during the experiment the HR was collected per participant with the use of the HR monitor wristband.

The second study extended the previous study by evaluating the user QoE of wearable devices in a non-traditional mulsemedia context. Olfaction was incorporated and crossmodally matched accordingly to the literature. The experiment was in a controlled setting where there were two groups (EG and CG).

The EG was exposed to 6 smells crossmodally matched to the 6 video clips and wore both devices. However, the CG had no smell, wore a haptic vest without effects present and only the HR was measured via wristband. Similar to the first study, both subjective and objective measures were carried out. Subjective measures involved SUS questionnaires and an additional UEQ questionnaire was added in the mix. The objective measure was the HR that monitored a user's pulse rate throughout all the videos.

6.3.1 Outcome of the Experiments

As shown in Chapter 4, the results of the study unveiled that users' QoE was indeed enhanced but only to a certain degree. The wearable devices made a significant impact on a users' experience, especially the HR monitor wristband. The haptic vest was not aesthetically pleasing to most participants as they reported that they would not wear it in public or work. However, on the bright side some of the particpants would wear the haptic vest in their leisure time. We have found that the design and style of the haptic vest is crucially important as it did not appeal to everyone. Whilst the haptic vest vibrations made a great difference for certain video clips the same cannot be said for the rest of them, and this could be due to content or the audio. The content of the videos needs to be looked at to suit the needs of the users'. Audio could have either encouraged or disencouraged a users experience with the wearables. It could be that the original sound was not amusing or the volume was too high/low leading to the haptic effects not satisfying users.

Also, we found that human factors are important in this context, having influenced a users' QoE with wearables. In addition, it is important to include objective measures such as a physiological metric' accordingly, we have found that the HR varied amongst the video clips. The HR for the majority of the video clips was quite high suggesting that the participants either enjoyed or were stressed in watching these clips. In line with these results we will be proposing guidelines as well as recommendations which are discussed in section 6.4.

As depicted in Chapter 5, there are many aspects that we found are crucially important. Incorporating mulsemedia provided better results as compared to our first study that followed a traditional approach with multimedia. Most of the video clips viewed were enjoyed by participants in both groups (EG and CG). This could be due to the olfaction, content or audio that influenced a users’ experience in a positive way. There were differences between the EG and CG; accordingly, the EG, whose participants experienced haptic and olfactory effects responded positively, whilst this was not the case with pariticipants from the CG. In light of this, we learned that only few participants would consider wearing the haptic vest in public, work and leisure time. Similar to our first study, participants in both groups (EG and CG) would prefer wearing the HR monitor wristband and incorporate the device into their daily lives as compared to the haptic vest. This could be due to the HR monitor wristband being discreet and not too obvious, whereas the haptic vest is rather cumbersome and the design of it does not appeal to everyone. Regarding the human factors mostly age and education influenced users QoE in the mulsemedia context.

From the UEQ questionnaire we learned that both hedonic and pragmatic qualities play an important role and need to be considered in any guidelines when evaluating wearables. Also, both objective and subjective measures provided insights to users attitudes and behaviour towards wearables, therefore these measures will be part of our guidelines and recommendations. Moreover, there were variations in the HR in both groups showing that the EG had a higher HR than the CG this could be because the haptic effects may have excited or annoyed the participants when viewing the video clips. The CG had a lower HR as there were no haptic or olfactory effects; therefore this shows that the use of mulsemedia effects increases participants HR.

Overall, we have learned that QoE in the second study was better than in the first. Multimedia itself was not enough to immerse users whereas mulsemedia made a considerable difference in the users’ experience whilst wearing wearables.

6.4 Guidelines

This thesis presents a set of guidelines for evaluating user QoE of wearable devices in a multimedia and mulsemedia context. The work presented in this chapter is grounded on two experimental QoE studies designed to understand users' attitudes and behaviour towards wearable devices. The set of guidelines are meant to be used to inform developers and researchers in evaluating user QoE for wearable devices. From the quantitative findings of these studies (Chapters 4 and 5), we have derived a set of guidelines that provide a foundation upon which to provide insight and direction to developers when developing wearable devices suitable for use and capable of satisfying users' needs see (Table 6.1).

Table 6.1 Guidelines

The guidelines are as follows:	
Guideline 1	Ensure the device can be affixed sturdily on the body.
Guideline 2	Facilitate adjustable seating considering height, armrest and backrest to ensure user comfort.
Guideline 3	Ensure a user is positioned correctly when facing the computer screen.
Guideline 4	Perform experiments in a quiet environment with minimal distraction.
Guideline 5	Display cross-modally mapped multimedia content
Guideline 6	Incorporate human factors (age, gender and education).
Guideline 7	Include insights of hedonic and pragmatic qualities of wearables.
Guideline 8	Design subjective usability questionnaires aligned with the device type.
Guideline 9	Utilise objective QoE measures (e.g. HR).
Guideline 10	Stimulate unobtrusive/ subtle wearable device and use.

Guideline 1: Ensure the device can be affixed sturdily on the body

If the device is to be affixed to the body, it is important that it is secured on properly making a user feel comfortable. When attaching the devices on a user's body one must leave room for movement. Users' should be able to move around contentedly without feeling uneasy therefore the fitting should be not too tight/loose and a confirmation from the user is crucially important. In respect of our studies we assisted the participants in putting on the haptic vest and strapped the HR monitor wristband either on their left or right wrist based on their preference. This may have contributed in most participants reporting that they found the two wearable devices comfortable and enjoyed wearing them. From a design point of view Rutter (2019), has deliberated that the design of a wearable device is good when it fits perfectly with the user's body. In our studies both wearables were fitted properly on the user's body to ensure comfort as well as users' getting the upmost experience as if the fitting is loose or not attached suitably this could lead to a negative user QoE.

Guideline 2: Facilitate adjustable seating considering height, armrest and backrest to ensure user comfort

Adjusting the chair in terms of its height, to be not too high/low is important. We encourage to correct a user's sitting posture to avoid them encountering any physical pains especially if a user is to be seated for over 30 minutes. We recommend using a chair that has the ability of adjusting the seat height, armrest and back rest, as this will provide a comfortable and relaxing sitting position. As mentioned by Ayoub (1973) and Allie and Kokat (2005) the right chair height is when a user's feet are flat on the floor. It is vital to be mindful of the importance of good posture as making sure users sit up straight can boost their self-confidence and mood (ScienceDaily, 2009). In both of our studies, we correspondingly adjusted the chair's height, arm rest and backrest until the users were satisfied. A study by Murray et al. (2017) highlights that comfort is crucial when carrying out an experiment on olfaction-based mulsemedia QoE. The authors have found that getting the height as well as a user's posture intact leads to unbiased results.

Guideline 3: Ensure a user is positioned correctly when facing the computer screen

One must ensure that a user is positioned correctly when facing the computer screen, bearing in mind the distance should be not too close or far from the desk. In the case of our studies, we checked and adjusted accordingly the monitor screen as well keeping a good distance between a user and the desktop computer. As suggested by Chandra et al. (2009) and Woo et al. (2015), the screen monitor should be positioned in the centre in front of user's eyes to avoid neck and shoulder pain. Also, the screen's height should meet the level of the user's eyes for instance, a short person cannot have his/her screen in the same position as a tall person. Moreover, the monitor viewing distance should be arm's length away when a user is sitting in their chair. To minimize eyestrain a user must not be positioned too close or too far from the screen. Whilst this guideline is well known for desktop-based computers, it is reassuring to know that it also applies to when users are looking at the screen whilst having wearables on them. Specifically, in our experiments users were exposed to multimedia video clips whilst wearing two wearable devices; therefore, it was important that users were positioned correctly to ensure their viewing experience was not affected.

Guideline 4: Perform experiments in a quiet environment with minimal distraction

Experiments should take place in a quiet room where there are no distractions that keep users' from maintaining focus and productivity. We conducted our experiments in a noiseless and spacious room, where the walls were white. As recommended by Murray et al. (2017), and ISO standard (2007), when performing olfactory evaluations, the walls in the rooms should be matt-off-white to minimize the effects of synaesthesia.

Guideline 5: Display cross-modally mapped multimedia content

Multimedia videos should accentuate the core content to enhance users' QoE. Our videos were crossmodally matched to certain, objects colours and smells. However, some videos were better perceived than others. In Chapter 4 video clips 3, 4 and 6 (red, dark and angular) are the ones that participants enjoyed most whilst wearing the haptic vest see (Table 4.1: Q1). Specifically, these videos and the addition of video clip 7 (round) influenced many users responses in a positive way. Amongst all the videos, the one that users' found pleasing was video clip 4 as it enhanced their viewing experience see (Table 4.1: Q7). The results conveyed in chapter 5 were different as participants in both EG and CG enjoyed watching all 6 video clips in response to Q1 as shown in (Table 5.4). This could be because olfaction was employed, or that haptic effects may have attracted the users' attention when viewing the video clips. Specifically, 4 of the video clips (blue, dark, angular and round) made a great impact with participants in the EG who reported that the haptic vest enhanced sense of reality as well as their viewing experience (Table 5.4: Q5 and Q6).

Guideline 6: Incorporate human factors (age, gender and education)

Given the impact that human factors have on QoE with wearable devices, it is essential to incorporate various dimensions of human factors (e.g. age, gender, education) into any QoE evaluation for wearables. As highlighted in the Qualinet paper, one of the influencing factors of QoE is human that relate to a user (Brunnström et al. 2013). As defined by Kohn et al. (1999): *"Human factors examine the relationship between human beings and systems with which they interact"*. Based on our initial findings human factors play an important role as age was predominantly the influencing factor in our first study (Chapter 4). In our second study (Chapter 5) age and education had a significant impact on the users' QoE. In the context of this guideline, Scott et al. (2015; 2016) have previously explored the influence of human factors on perception of multimedia quality, perceived video quality and enjoyment. From their results they found that human factors such as personality and cultural traits play a key role and influence users' responses especially in the way enjoyment and perceived quality are rated. Additionally, Zhu et al. (2015) explored user factors in video QoE. They found that gender and cultural background have a significant impact on users QoE as females were more involved in the viewing experience of the videos than males. The cultural background results were shown to have impacted QoE ratings as Asian participants rated their QoE much higher than Western participants.

Although we only explored a subset of human factors in our work, it is perfectly plausible that other factors such as personality and culture should also be considered in evaluating QoE with wearable devices, and it is left to future research to confirm this hypothesis.

Guideline 7: Include insights of hedonic and pragmatic qualities of wearables

In our work, we explored considerations of hedonic and pragmatic qualities of wearables using a UEQ questionnaire designed by Schrepp et al. (2017). The UEQ questionnaire is based on self-reported measures to assess the user's experience when using a technical product regarding hedonic and pragmatic product qualities. We incorporated the UEQ questionnaire for our second study. Participants interacted with two different wearable devices and the responses from the EG to the haptic vest leaned more towards the hedonic qualities as they found the device fun and exciting to wear. However, there were some pragmatic qualities found in the responses as the haptic vest was perceived to be clear and easy to use. In the CG participants responses were similar between hedonic and pragmatic quality items. However, item 7 received a high score as participants found the haptic vest inventive.

In terms of the HR monitor wristband both hedonic and pragmatic qualities of the device were well received by the participants in both groups (EG and CG). However, the EG leaned slightly more towards pragmatic quality items whereas the CG leaned towards the hedonic quality items. Resulting from their work on perceived qualities of smart wearables Karahanoğlu and Erbuğ (2011) have found that hedonic qualities are essential as well as pragmatic qualities. Merčun and Žumer (2017), have commented that both hedonic and pragmatic qualities combined would lead to either positive or negative emotions and guide the acceptance of the product. In our work, we have found that these recommendations are also applicable when it comes to enhancing the QoE associated with the two wearable devices employed in our study.

Guideline 8: Design subjective usability questionnaires aligned with the device type

Subjective measures are usually carried out in the format of questionnaires; it is important therefore that the questions are designed carefully and are aligned with the device type. Typically, keep the questions clear and concise, so that they can be answered easily by the user. Using simple language is recommended as it will help users understand the questions and inform them the goals of our experiments. Having questionnaires aligned with the particular device type is one of the things we did in our studies as shown in Chapter 3. Also, having clear, unambiguous questions is one of the principles of good questionnaire design (Burgess, 2001).

Guideline 9: Utilise objective measures (such as HR)

Utilising objectives measures when evaluating QoE with wearables is equally important as to using subjective measures. Wearable sensors that are worn in contact with a user's body measure physiological responses such as the HR, blood pressure, body temperature and many more (Dias and Cunha 2018). In our work, we used a Mio Go HR monitor wristband device to carry out objective measurement. We connected the wristband to a smartphone via Bluetooth where continuous physiological data of a participant was collected and transferred into a mobile application. In our first study we wanted to see how fast or slow a participant's heart beats against the video clips whilst wearing a haptic vest. In our second study we wanted to find out if there are any differences in the HR between two groups (EG and CG). The participants HR varied, and HR monitor wristband was shown to be useful in providing insights, which otherwise would have proven hard to uncover. Accordingly, we have learned that certain video clips increased user HR and had an impact on QoE. Moreover, the recommendation of employing HR monitor is in line with previous research, as Vermeulen et al. (2016) have stated that HR sensors are non-obtrusive in comparison to other physiological sensors such as those measuring GSR. The HR sensors are subtly embedded into devices such as fitness trackers or smartwatches that people are already wearing.

Guideline 10: Stimulate unobtrusive/ subtle wearable device and use

Stimulate unobtrusive/ subtle wearable device and encourage use in a public environment. As detailed in Chapter 3 the end of experiment questionnaires (Table 3.3: Q5, Q6, Q7 and Table 3.4: Q3, Q4, Q5) regarding whether participants would consider in wearing the two devices in public varied. From both of our studies it appears that most participants preferred wearing the HR monitor wristband and would incorporate it into their daily lives (work, public and leisure time). However, in the first study (Chapter 4) many of the participants disagreed in respect of adopting the haptic vest in the public environment, although a few of them would be happy to wear it in their leisure time. Similar results were found in our second study (Chapter 5), however the user's attitudes were generally neutral. This emphasises that some users may wear the haptic vest in the public. Users may be reluctant to wear a haptic vest due to its design; moreover, the appearance of the haptic vest is not discreet, as opposed to the HR monitor wristband. The haptic vest does not necessarily need to be worn over the user's garments - it can be worn underneath their top or shirt that way it would be hidden. Again, this recommendation is in line with previous research such as that of Rekimoto (2001), who suggests that, in order for wearable devices to be adopted for everyday use, they should be unobtrusive and natural as possible. Should this be the case, our work suggests that user QoE can be enhanced.

6.5 Discussion

This chapter has presented a set of guidelines as emanated from the experimental studies. The studies were carried out to address the existing gap in knowledge, and, on their basis, we have identified the attributes that will enhance users' QoE. Consequently, we have formed the attributes identified from our findings into guidelines. Developers, researchers and designers may apply the guidelines that are applicable to the context of use to their studies, as not all of them will suit the user's requirements. Moreover, whilst some of the guidelines are also applicable to traditional, desktop computing scenarios, our experiments have highlighted their pertinence to wearable computing QoE. Lastly, it is also important to remark that, although we have presented a set of empirically derived guidelines, they are yet to be validated and generalised.

6.6 Conclusion

In conclusion, the guidelines in evaluating user QoE with wearables have been presented and have provided a foundation upon which future QoE experiments with wearables can be based. The guidelines are drawn from the quantitative evidence of two studies traditional (multimedia) and non-traditional (mulsemedia). These guidelines are presented with the hope that they will be utilised to aid researchers and developers to better examine QoE for existing and future innovations linked to wearable devices. We shall now move onto the next chapter that will conclude this PhD thesis.

Chapter 7: Conclusion

7.1 Overview

The last chapter of this thesis concludes the research findings in relation to the aim and objectives defined in Chapter 2 and outlines the key contributions as well as discussing the future work. The chapter begins with Section 7.2 discussing the research domain. Section 7.3 details the contributions whilst Section 7.4 summarises the research findings. Section 7.5 discusses the limitations. Lastly future work is discussed in Section 7.6.

7.2 Research Domain

Consumer wearable devices are on the rise and have gained a substantial amount of popularity in the recent years especially in the healthcare, fitness and medicine domains. Wearables are embedded with sensors that have the potential to facilitate health behaviour and change a user's lifestyle as these devices are able to keep track of one's HR, calories burned, sleep and so forth. These capabilities have started to become part of a user's daily routines. Also, wearables provide entertainment in the form of VR and AR headsets giving users immersive experiences whilst playing games. Other areas, such as jewellery and fashion have embedded software into the garments, rings, bracelets, earrings and necklaces as discussed in Chapter 2. As highlighted in Chapter 1 that although wearables are set to grow in the coming years and provide many functionalities to end user's there have been issues raised regarding (design, privacy and security) that have been mostly studied. However, measuring QoE in terms of user's satisfaction/level of enjoyment or annoyance with wearables has been ignored especially in multimedia and mulsemedia contexts.

In the light of these findings, our research defined the following research aim: To evaluate QoE of wearable computing devices in multimedia and mulsemedia contexts.

- **Objective 1: Design suitable questionnaires in capturing users' QoE when interacting with wearables.** We incorporated the SUS and UEQ when designing the test questions. We introduced two types of SUS questionnaires: one targeting the haptic vest whilst users viewed the video clips on the screen and the second one was presented after the experiment based on both the haptic vest and the HR monitor wristband. The UEQ was incorporated in the second study and presented at the end of experiment. We translated the data collated from the questionnaires using both SPSS and Excel.

- **Objective 2: Evaluation of QoE with wearables in the multimedia context.** In order to examine the initial user interaction with two wearable devices, we followed a positivist methodology. We collected quantitative data using subjective measures (questionnaires) and objective measures a physiological metric (HR) to evaluate QoE.

- **Objective 3: Examine the impact of mulsemedia on user QoE with wearables.** Here, we extended upon the previous study and examined the perceptual impact of mulsemedia on wearable devices. We chose to combine different visual dimensions (brightness, colour and shape) with crossmodal matched olfaction with auto generated (from audio) vibrotactile feedback haptic vest.

- **Objective 4: Exploration of human factors to determine meaningful user requirements for effective interactions, which can then be used as recommendations for multimedia and mulsemedia applications and wearables.** Accordingly, we have investigated the impact of age, gender and education on users' perception of both multimedia and cross-modal mulsemedia content with wearables.

- **Objective 5: Propose a set of guidelines, which can be applied to either new or existing wearables, for evaluating user QoE.** Our ultimate goal was to combine the findings from both of our studies (Chapters 4 and 5) into a set of comprehensive guidelines. Adopting the guidelines presented will be a first important step in evaluating user QoE with wearables in the contexts of multimedia and mulsemedia.

7.3 Research Contribution

The main contribution of our work is that we have explored and discovered user attitudes and perceptions associated with wearables. Before we carried out this research, we found that in the literature there was not a single study that evaluated user QoE with wearables in multimedia and mulsemedia contexts. This existing gap in knowledge motivated the need to explore wearables in light of capturing users' attitudes and behaviour with such devices. Wearables have undoubtedly been trending in the consumer market, but user acceptance and user's level of enjoyment were unexplored areas. Accordingly, we worked towards the goal of finding out users' views and opinions in relation to two wearable devices (haptic vest and HR monitor wristband). In support of our main contribution, the following sub-contributions were made:

7.3.1 Contribution 1

We explored user QoE with two wearable devices in a multimedia context. By applying the QoE concept we got insights to the user's experience with wearable devices. Generally, the two wearables were perceived positively as many users reported they had a satisfying overall experience. We found that amongst the two wearables that the HR monitor wristband is the device that participants would incorporate into their daily lives rather than the haptic vest. This could be because the HR monitor wristband is more discreet, sleek, and less noticeable when compared to the haptic vest. The users' interests in most of the video clips varied as some were more enjoyed than others this could be because of the content. Also, the HR varied throughout all the video clips contributed in the HR to either go up or go down all depends on a user's mood something that can be explored in the future. Overall, the results displayed that the use of wearables whilst viewing the video clips did increase user QoE to a certain extent.

7.3.2 Contribution 2

In the previous literature we have found that mulsemedia has been emphasized in enhancing user QoE (Ghinea and Ademoye, 2011; Ghinea and Ademoye, 2012a, 2012b; Jalal and Murroni, 2017; Jalal et al. 2018; Monks et al. 2017; Murray et al. 2017; Rainer et al. 2012; Waltl et al. 2010; Yuan et al. 2014, 2015). After reviewing the literature on mulsemedia we noticed that it has not been associated with wearables.

Even though the focus of this study is on wearables we decided to explore user QoE with wearables in mulsemedia context by incorporating different smells crossmodally matched to the 6 video clips to enhance user QoE. We found that mulsemedia considerably enhanced user QoE with wearables in the EG who wore the haptic vest with effects. Also, the participants' views in wearing the haptic vest in their daily lives were neutral in the EG and quite negative in the CG. However, the HR monitor wristband was perceived positively, and both groups would incorporate the device into their daily lives.

Moreover, the UEQ revealed that participants in the EG leaned more towards the hedonic qualities for the haptic vest whereas the CG the results were somewhat equally the same for both hedonic and pragmatic qualities. In terms of the HR monitor wristband the participants responses likened items of pragmatic quality in the EG. However, in the CG participants impressions towards this device favoured the hedonic quality items. Furthermore, the HR was much higher in the EG than CG this could because of the haptic effects, olfaction, audio or content.

7.3.3 Contribution 3

Regarding the human factors we have found that demographics such as age and gender have been mostly studied. As work by Arvanitis et al. (2011) reported that gender could be a great influence on users' attitudes. Their results showed that the perceived usefulness and levels of satisfaction towards mobile AR systems for science education were low amongst females than males. Similarly, Schaar and Ziefle (2011), argued that women tend to have lower technical experience and are more reluctant to adopt smart wearable shirts then men. Similar results have been found in the works of Canhoto and Arp (2016) and Rauschnabel and Ro (2016) where age and gender were identified as the influencing factors on users. In regards, to our studies we decided to apply the most common demographics (age, gender and education) as we found in the Qualinet white paper that human factors are one of the influencing factors in QoE (Brunnström et al. 2013). From our results we found that primarily age had the most impact on users QoE in the first study. In our second study all three categories were of significance however, age as well as education were the factors that influenced users' QoE the most in our second study.

7.3.4 Contribution 4

We have only come across a few studies on wearables' guidelines namely Gemperle et al. (1998); Wentzel et al (2016); Wentzel and Geest (2016) and Burak and Özcan (2018) who have presented design and accessible guidelines for wearables. However, not much work has been published in instructing developers and designers to design wearables as such that appeal to users. User experience as well as their views are key when designing and developing wearable technologies. To this end, we presented a set of guidelines from a culmination of two QoE studies. Although the guidelines are evidence based and they are yet to be validated, nonetheless, they will enable developers and designers to gain insights of user's views and opinions that will help them enhance user QoE for future wearable technologies.

7.4 Research Findings

Our research findings can be effectively divided into five sections. These sections correspond to the five main objectives of our work: questionnaires, QoE of wearables in multimedia, mulsemedia and QoE of wearables, human factors and guidelines.

7.4.1 Questionnaires

As highlighted in Chapter 2, subjective measures are crucially important in QoE as these measures focus on users' perceived quality, satisfaction as well as their overall experience and interaction with an application or service. We utilized SUS in our first study due to its popularity and validity with a roughly equal split of positive and negative statements. For our second study we further added the UEQ, which was split into two categories, specifically pragmatic and hedonic quality. The use of these questionnaires enabled us to collect valuable and interesting feedback from users.

7.4.2 QoE of wearables in multimedia

Previous literature has explored QoE in the telecommunications and multimedia sectors. Most of the studies have looked at QoS aligned with QoE as network operators and service providers want to improve and present a good service to its end-users. However, there has been virtually no research that has explored QoE of wearables with multimedia content seeing that QoE is inextricably linked to multimedia computing, therefore we conducted research with two wearable devices and incorporated multimedia video content to examine user QoE.

The findings of our first study (Chapter 4) have highlighted the following: the first is that the haptic vest can have a significant effect on users' QoE, particularly with certain video clips. Participants reported that they enjoyed viewing some video clips and felt the haptic effects enhanced their viewing experience to a certain extent. However, some video clips were not perceived positively. As mentioned before this could be due to the content, audio or the haptic effects not aligning well with a user. Overall, the responses for the on-screen questionnaire for the haptic vest were pretty average. The end of experiment questionnaire for both devices (haptic vest and HR monitor wristband) revealed that the participants are keener in adopting the HR monitor wristband as opposed to the haptic vest. The participants' attitudes were slightly negative towards the haptic vest.

As a final remark, our findings have also shown that the HR varied across the video clips as participants HR was higher in some of them. This indicates that the participants were either excited or stressed, which in itself is also a worthy opportunity for future exploits.

7.4.3 Mulsemedia and QoE of wearables

QoE is considered to be a very important aspect of mulsemedia (Yuan et al. 2014). As discussed in Chapters 2 and 5 there are many studies (Covaci et al. 2018; Nakamoto et al. 2008; Zou et al. 2017; Hancock et al. 2013 and Gustavo, 2018) that have explored user QoE of mulsemedia applications. Moreover, enhancing user QoE with olfactory media has been proven effective in (Ghinea and Ademoye, 2011; Ghinea and Ademoye, 2012a, 2012b; Jalal and Murroni, 2017; Murray et al. 2014; Murray et al. 2013; Tortell et al. 2007; Yuan et al. 2014; Yuan et al. 2015; Zhang et al. 2016). The literature has emphasized that mulsemedia increases user QoE, therefore we decided to employ it in our studies and explore the user experience of wearables in such a context which has been unexplored.

Our second study (Chapter 5) tailors crossmodally matched mulsemedia content and explored wearables' QoE. Our results from this study showed that the wearable devices as well as the integration of olfaction made a considerably positive impact whilst users viewed the video clips. A significant difference was measured with and without the haptic effects and olfaction between two groups (EG and CG). Differences were found as the EG appeared to have likened the use of the haptic effects that heightened their experience as compared to the CG. We believe that the reason for the difference in user QoE is due to the level of immersion, as the haptic vest vibration effects significantly impact user level of enjoyment greatly as seen with the EG. The user QoE was found to be significantly low in the CG as they did not feel any haptic effects and did not engage well with most of the video clips as some of their responses were either neutral or leaned more towards the disagree statement. The end of experiment questionnaires were based on (SUS and UEQ). The responses to the SUS questions highlighted that the users' in both groups would employ the HR monitor wristband more than the haptic vest in their daily lives. Regarding the UEQ the user's in the EG and CG leaned more towards the hedonic qualities of the haptic vest. However, the responses from the EG for the HR monitor wristband leaned slightly more towards the pragmatic qualities whereas the CG favoured the hedonic qualities of this device.

This conclusion has possible implications on the future of wearable devices, as we believe that any device that is perceived to enhance user QoE has a chance of being accepted by a user. Although the functionalities of wearables may be useful, nonetheless the design of such devices plays a key role. Accordingly, our results showed that the haptic vest did heighten user's level of enjoyment but the responses to whether the participants would wear it in their daily lives were neutral. Similar results were found in our first study users' may feel self-conscious in wearing particular wearable devices in public places. This again is an area that can be explored in the future.

7.4.4 Human Factors

The literature so far has looked at human factors in multimedia as many studies (Scott et al. 2015; Zhu et al. 2015 and Zhu et al. 2018) have found that that human factors influence user QoE. However, not much research has been done exploring the impact of human factors in mulsemedia. Indeed, only one study (Murray et al. 2013) has examined human factors with mulsemedia, and not in respect of wearables. To the best of our knowledge human factors have not been considered before for QoE with wearables in both multimedia and mulsemedia contexts. We explored a subset of human factors such as age, gender and education. From both of our studies we found that these demographics have a significant impact on users' QoE. The first study revealed that amongst the three human factors age was a major influencing factor however, in our second all three categories played a part in influencing the QoE mostly age and education.

In conclusion, the initial findings from both of our studies have shown that human factors are important to consider when evaluating QoE with wearables as one can gain substantial insights.

7.4.5 Guidelines

We have comprised a set of guidelines extracted from our quantitative studies as detailed in Chapter 6. These guidelines are evidence-based from the research conducted as part of this thesis and are there to assist developers and researchers when developing wearable devices suitable for use and capable of satisfying users' needs. Furthermore, the guidelines are designed to examine QoE better for existing and future innovations linked to wearable devices.

7.5 Limitations

There are a couple of limitations to be addressed, initially this is the first study to investigate wearables user QoE within the context of (multimedia and mulsemedia) however we only used two wearable devices in our studies. Secondly, the sample size of 48 across both of our studies is fairly small but was adequate for this research. Thirdly, whilst the multimedia content (7 video clips) that we employed for our studies were chosen for the specific experimental purposes of our studies, they are not representative of general multimedia content and that future work could explore wearables QoE with more representative multimedia content, in which genres such as movies, sport, music, documentaries, etc. are also represented. Lastly, we combined the views of user's experiences with two wearable devices from both studies and presented a set of guidelines. The guidelines will aid developers and researchers in evaluating user QoE for wearable devices. Both developers and researchers can apply the guidelines to evaluate existing wearable devices and can expand upon them accordingly. Whilst the guidelines are evidence based, yet they need to be validated and generalised with researchers as well as developers who have previous experience in developing wearable devices. Also, the draft guidelines require validation from experts who have immense knowledge with the QoE concept. Validation would prove that the guidelines are acceptable and can be used in many contexts. Without validation we cannot guarantee of how sound our guidelines are and that is a limitation to our study.

7.6 Future Work

Our work has shown that users' views towards the two wearables employed in our studies were generally positive and the QoE was enhanced to a certain extent. However, we have learned that multimedia content in QoE is important as it influenced many user's responses in the studies described in the thesis. To this end, the content needs to be further investigated to cater the needs of users, as some of the videos were better perceived than others. Although the two wearables were near enough perceived positively, nonetheless the responses from participants to the adoption and acceptance of these devices was mixed. The haptic vest was perceived less attractive than the HR monitor wristband. Design of the haptic vest is something that requires attention as it needs to be aesthetically pleasing to be adopted in user's daily lives. As a result, if commercially available wearables are not evaluated in terms of QoE and the developers ignore the user-perspective and experiences, then there is a risk that these devices will not get adopted. Indeed, a good example is represented by the haptic vest and HR monitor wristband, as our work has shown that, irrespective of their hype and futuristic design, they will not be accepted by users if the associated user QoE is not a positive one.

As mentioned by Kalantari (2017), the adoption of wearable devices has been relatively slow when compared to smartphones. The adoption of wearable technology for multimedia consumption is a direction for future research, as more wearables are becoming available and the need to see whether these devices will be adopted is an area that requires further investigation. Also, the design of wearable devices to enable a better interaction of users with wearable-displayed multimedia content is another avenue for future exploration. It has been emphasized in the work of Chan et al. (2013) and Lucero et al. (2013) that discrete, private and subtle interaction is important as users are able to act as naturally as possible in a public setting. In addition, we need to explore more wearables QoE such as AR glasses, VR headsets, smartwatches, jewellery and so forth as we only looked at two wearable devices. Moreover, we realised that the guidelines are based on two exploratory studies and that more complementary studies need to be done in order to further confirm and validate these guidelines and as such the list of guidelines are not definitive. Indeed, the guidelines can be modified or extended in the future, as our understanding of wearables' QoE extends and deepens.

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Appendix A

System Usability Scale (SUS)

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

(Gutiérrez-Carreón et al. 2015)

Conclusion