Measuring what Matters in Immersive Environments

By emteq labs

emotion: quantified

emteq labs

Contents

Page 3. **Executive Summary**

Page 5. **Measuring what Matters**

How Emotions are Measured

Facial Coding

Facial Expressions as Emotions

The Dimensional Model

Skin Conductance

Heart Rate and HRV

Eye Tracking

EEG

Page 11. **The Benefits of VR for Emotion Analytics**

Page 12. **The Science of Emotion Tracking in VR**

An Introduction to emteq labs

How Does it Work?

Benefits

Applications

Page 17. **Case Study: The world's largest biometric data collation**

Executive Summary

Not all individuals experience emotions in the same way, yet traditional methods of measuring emotion either lack objectivity, ignore the context or are subject to subjectivity which affects the validity of the results.

emteq lab's latest Virtual Reality (VR) technology builds on over 40 years of research into the relationship between facial expression and emotion, measuring arousal (level of activation or excitement), valence (whether a reaction is positive, negative or neutral) and action. Their proprietary technology uses multimodal, biometric sensors within a virtual reality headset. By pairing this technology with VR immersive environments, emotional responses are measured in conditions that simulate real-world situations. The sensors within the headset monitor responses in heart rate and heart rate variability, facial electromyography (fEMG), skin conductance, eye movements, and bodily motion to provide the most ecologically valid platform to quantify emotion more accurately and objectively.

To demonstrate of the accuracy and validity of the technology, emteq labs and researchers from Bournemouth University conducted the world's largest multi-modal, biometric data collection in VR, at the Science Museum, in London, in 2019. 'Who am I?' was the first study of its kind, using VR to create controlled scenarios, stimulating physiological emotional responses, all monitored through the emteqPRO headset and platform.

A solution that can track and objectively grade emotion, specifically the symptoms of anxiety over time, could significantly aide the evaluation and development of new therapies and training environments. For patients, such technology could allow biometrically graded exposure response therapy, enabling patients to manage their emotions and control undesirable behaviours. Content creators may use this platform to revolutionise the delivery of solutions that objectively improve outcomes.

> Developing new treatments and training solutions requires an understanding of the range of 'normal' responses to interventions. This is particularly important for healthcare issues such as treating anxiety and depression. In the past, members of the public contributed to the human genome project, which in turn has enabled many new treatments to be developed. We hope that we will begin the process of understanding the range of behavioural responses that will act as a baseline for future research and the development of individualised treatments of mental health conditions.

Dr Charles Nduka, Chief Science Officer and co-founder of emteq labs

How Emotions are Measured

Successful storytellers, creators, teachers and trainers understand the role emotion plays in driving engagement and influencing behaviours. The majority of commercial applications for emotion evaluation have been for testing audience responses.

EEG brain activity

Eye tracking

Heart rate

Skin response

Bodily movement

Facial expression

Why not just asked people what they feel?

A number of methodologies have been used in the past to understand a person's intentions and motivations. Questionnaires are well-established means of trying to gain insights into personality traits, preferences and likes, however, we also know that what people say and what they feel does not always correlate and hence the importance of objective measures.

Implicit testing has been used effectively to uncover hidden or subconscious feelings and biases but these tests are generally obtrusive and interruptive. A number of objective technologies have been successfully used to pervasively measure behaviour including:

- Facial coding
- Skin conductance (aka galvanic skin response)
- Heart rate
- Heart rate variability (HRV)
- Eye tracking
- Brain wave measurement (EEG)

The accuracy, scalability and practicality of these technologies vary tremendously.

Facial Coding: Do we really all express in the same way?

The use of images to evaluate facial expressions was kick-started by the pioneering work of Paul Ekman. He developed a coding system that translated facial muscle movements into “action units” that correspond with certain changes in expression.

This facial action coding system (FACS) was initially manually assessed by trained coders, which was a laborious process. As computer vision technologies developed in the 1990s and machine learning advanced, researchers were able to train these systems using expert coders to provide the “ground truth” label for each image. Underpinning this technology was the assumption that:

- There are only a small subset of emotional expressions (happy, sad, fear, anger, disgust, surprise, contempt);
- All people express in the same way to the same stimulus;
- Expressions can be inferred regardless of context.

Whilst these assumptions may seem to be correct under specific circumstances under laboratory conditions, more recent work has shown that these assumptions do not always hold true in the real world.

Categorical (classical) model

The Categorical (classical) model assumes discreet categories, ignorant of context.

Facial Expressions as Emotions

In 2019, world-renowned emotions pioneer Professor Lisa Feldman Barrett rocked the research community with her publication of a 68-page review of methods used to infer emotions from facial images. The findings of her research conclusively demonstrated that current models for inferring emotions from facial coding and classifying them into six categories needs to be carefully considered.

> There are three common procedures for measuring facial movements in a scientific experiment. The most sensitive, objective measure of the facial movements, called facial electromyography (fEMG) detects the electrical activity from actual muscular contractions... This is a perceiver-independent way of assessing facial movements that detects muscle contractions that are not necessarily visible to the naked eye.

Professor Lisa Feldman Barrett, Professor of Psychology at Northeastern University.

The main issue with the validity of scientific facial coding is the **lack of context** provided by just viewing the face.
For example, furrowing the brow may be indicative of anger, which would typically lead the individual to increase engagement to remove the source of irritation. By contrast, the same expression may be seen in frustration, which would typically result in the opposite behaviour, with the individual moving away from the source of irritation. The comprehensive analysis of prior facial coding research by Professor Lisa Feldman Barrett and colleagues found that scientific models, underpinning facial coding methods, are seriously flawed.[1]

Current researchers use emteq labs technology to assess emotional responses using the **Dimensional model** of emotions.

[1] **Emotional Responses Reconsidered: Challenges to Inferring Emotion from Human Facial Movements. Professor Lisa Feldman Barratt et al.**

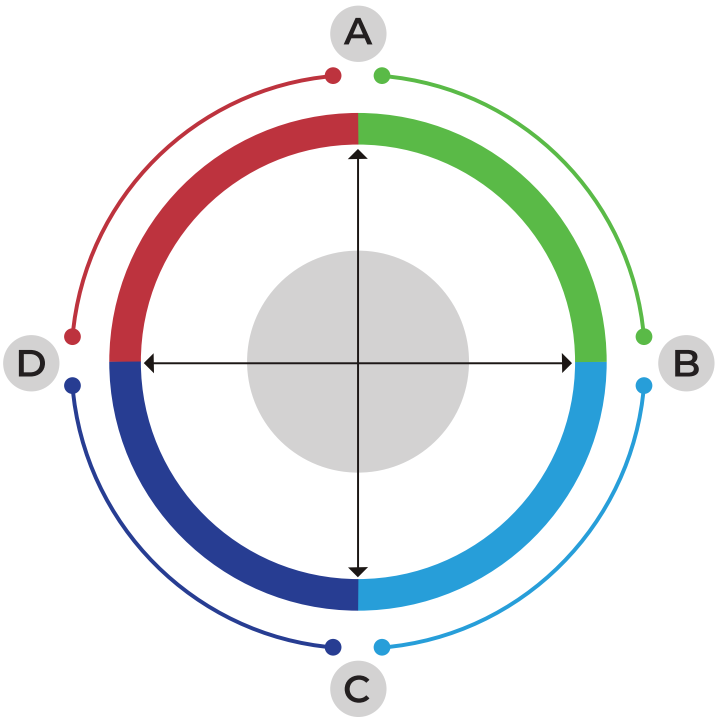
The Dimensional Model

Psychologists and researchers seeking to understand human responses to stimulii are principally interested in measuring whether those viewing media content are experiencing positive or negative emotions, known as **valence**.

They also want to understand whether there is evidence of engagement or excitement as determined from measures of physiological activation, termed **arousal**.

Valence and arousal are often plotted on a two-dimensional graph called the **Dimensional model**. The activation axis, plotted vertically, ranges from deactivation (low arousal) to activation (high arousal). The valence axis, plotted horizontally, ranges from negative to positive.

Dimensional model



- **A** High Arousal (exciting, agitating)
- **B** High Valence (positive)
- **C** Low Arousal (soothing, calming)
- **D** Low Valence (negative)

Skin Conductance

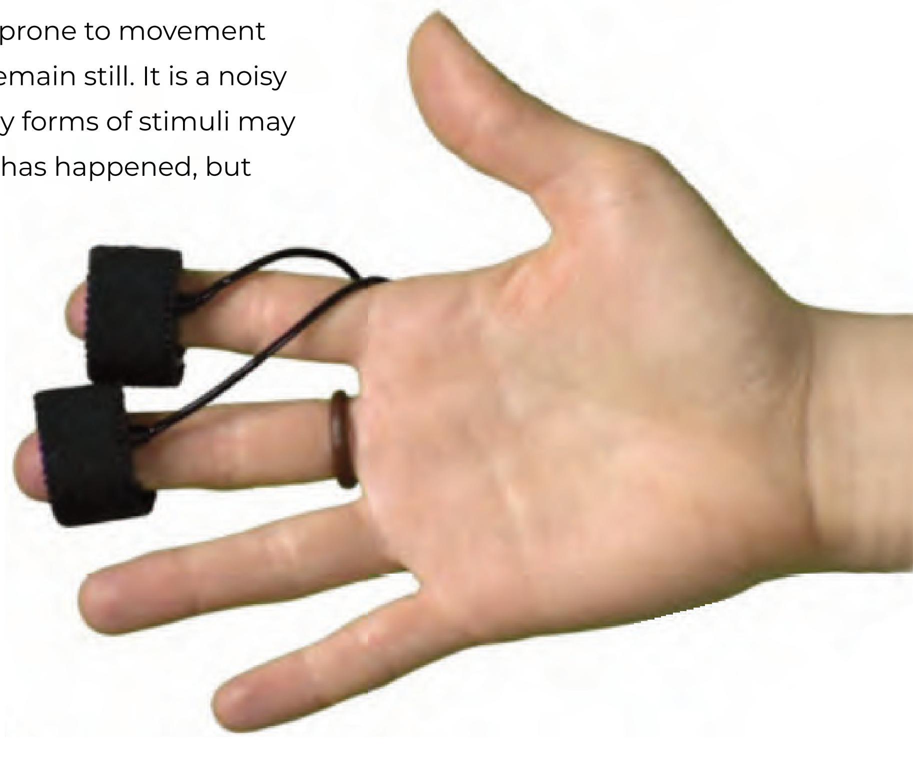
We can detect when a person is stressed by changes in the skin which are manifested by alterations in blood flow and sweating. These are mediated by the nervous system. The central nervous system (CNS) comprises the brain and spinal cord. The peripheral nervous system (PNS) connects the CNS to the body and consists of two parts; the autonomic nervous system (ANS) and the somatic nervous system (SoNS). The SoNS mediates voluntary control of body movements.

The ANS regulates fundamental physiological states that are typically involuntary, such as heart rate, digestion and perspiration.

The ANS includes two components, the sympathetic nervous system (SNS), parasympathetic nervous system (PNS) that work in an opposing manner maintain the internal equilibrium of the body. The PNS activity changes slowly such as in response to food "rest and digest" whereas the SNS activates rapidly to elicit the "fight or flight" response. The main effects of SNS activation are due to the release of adrenaline and manifest as an increase in heart rate, sweating, pupil dilation. As sweat is a salt solution and therefore can conduct electricity, changes in the activity of the SNS can be inferred from the fluctuations in conductivity of the skin of the limbs. Most typically this is measured with sensors attached to the fingers, although it can be measured from the wrist or foot.

It is important to note that measurements of sweating only reflect the activity of the SNS and not the PNS which is a major drawback of this method.

Also, skin conductance (sometimes called galvanic skin response (GSR) or electrodermal response (EDR)) is prone to movement artifacts, so the measured limb needs to remain still. It is a noisy signal that fluctuates constantly, and many forms of stimuli may cause a change; it tells us that something has happened, but not what or why.



Changes in sweat production are best measured from the fingers rather than the wrist

Heart Rate and HRV

The heart is controlled by both the PNS and SNS, therefore heart rate provides a better indicator of the level of physiological activation or arousal than skin conductance. The heart rate is most accurately measured using electrocardiography (ECG), however this is cumbersome, requiring access to the chest.

Photoplethysmography (PPG) is a non-invasive way to assess blood flow through small calibre vessels near the skin and thus measure heart rate (in fact, pulse blood volume). This method is used in professional medical grade heart rate monitors, as well as consumer devices such as the Apple Watch. Changes in heart rate can be detected by calculating the timing differences between successive beats (beat-to-beat interval, IBI) combined with algorithms to control for artifacts resulting from movement which affects signal quality. With increased attention, or high positive or negative valence, there is a rapid transient reduction in heart rate, however absolute changes are difficult to correlate with emotional responses - both positive (excitement) and negative emotional stimuli (fear) can increase heart rate.

A further important measurement is heart rate variability (HRV). With each breath there is normally a fluctuation in heart rate. Healthy hearts have fluctuations in the IBI, whereas less healthy individuals have reduced variability. Also, anxiety and depression cause low HRV. Research using film clips demonstrated that those with higher HRV showed greater emotional responses to characters with feeling such as empathy. These findings indicate that HRV allows researchers to “scale” emotional responses of participants.

PPG sensors to measure heart rate are widely used but only provided limited information by themselves.

Image: Apple Watch

Eye Tracking

Whilst attention may be directed towards sound, smell or touch, our eyes are unique in allowing potentially threatening objects to be safely examined from a long distance. An unexpected stimulus results in the individual's attention being directed to it. Eye-tracking allows one to infer and quantify interest through measures of the time taken for the point of interest to be noticed, how long the gaze settles there, how often the individual looks back at the object, and the sequence in which objects are observed.

Eye tracking requires one or more cameras that track the position of the pupils, whilst simultaneously recording what the persons sees. This can be done with a computer, an attached or built-in camera, or via specialised glasses incorporating an outward-facing camera. Until recently, eye-tracking was confined to research studies due to the privacy invading potential of having a camera always on. However, eye tracking is rapidly moving from being a purely a research tool, to a method to improve user experiences in VR.

The use of eye-tracking allows images to be dynamically displayed at a higher resolution coinciding with wherever the user looks. The combination of understanding what a person is experiencing and their interest in it, are a powerful combination. This explains why Facebook has invested so heavily in Virtual Reality (VR) via their purchase of Oculus.

Eye tracking can tell us "what" but not "why".

Image: Tobii 2 eye tracking glasses

Electroencephalography (EEG)

Measuring brain activity using EEG is traditionally a laboratory tool. It involves applying electrodes to the scalp and reading the tiny electrical signals from the skin above the relevant areas of the brain. The electrodes are commonly held in place with a hat or cap, so that good contact is maintained with the scalp skin.

It is a difficult technique to use as there is a direct relationship between the inconvenience of the measurements and the accuracy of the signals. The more electrodes, the greater the spatial resolution.

As the electrical signals are very small and may be overwhelmed by signals due to eye or facial movements, the method is prone to motion artifact or loss of signals. However, more recently there are some systems designed for use outside of the laboratory, using a smaller number of sensors and a corresponding loss of sensitivity. The principle use of EEG is to evaluate concentration based on asymmetry in the signals emanating from the front of the brain.

EEG requires multiple sensors for accurate readings.

Camera vs Contact Sensing

Camera-based facial analytics systems have several limitations, not least privacy concerns, difficulty with measurement in poor lighting conditions and the inability to provide data when the face is not directed towards the camera.

Previous research by Professor Jeffry Cohn at Carnegie Mellon University has shown that directly measuring facial muscle activation via fEMG provides higher sensitivity, faster sample rates and is independent of head posture or lighting conditions. In fact, the original computer vision systems used fEMG to provide the gold standard data to indicate muscle activation.

Historically, this research was a technique confined to the laboratory, due to the complexity of having trailing cables, limited by standard sensors requiring the need for adhesive electrodes, skin preparation and the use of messy conductive gel.

Early work on facial feature tracking and coding featured fEMG to detect the onset of an expression.

Unlike standard surface EMG electrodes which require skin preparation, conductive gel and sticky pads, the emteq labs platform offers a totally dry, integrated sensor system provided either as a fully wireless VR headset (emteqGo) or as an add-in to the HTC Vive Pro, allowing researchers to simply don the headset and start experimenting. emteq lab uses the emteq labs platform ecologically valid measurement of valence response.

Benefits of VR for Emotion Analytics

Evaluating behaviour in VR provides many advantages over typical research set-ups, engendering more confidence in results. For example, it is well known that a range of contextual factors influence an individual's emotional responses which include:

- Prior experiences (priming effects)
- Distractions
- The presence of others
- The appearance and behaviour or others
- Being looked at by others
- The emotional responses of others (social contagion)
- The responses of others to our behaviour

This list is not exhaustive, but it's clear that not controlling the testing environment for these may skew the findings of a study.

emteq labs platform has unique advantages over other solutions:

- User-personalised data
- Confidence that the view is engaged
- Better simulation of social experience
- Ability to alter viewing experience, number of people, their characteristics and behaviour

The Science of Emotional Tracking in VR

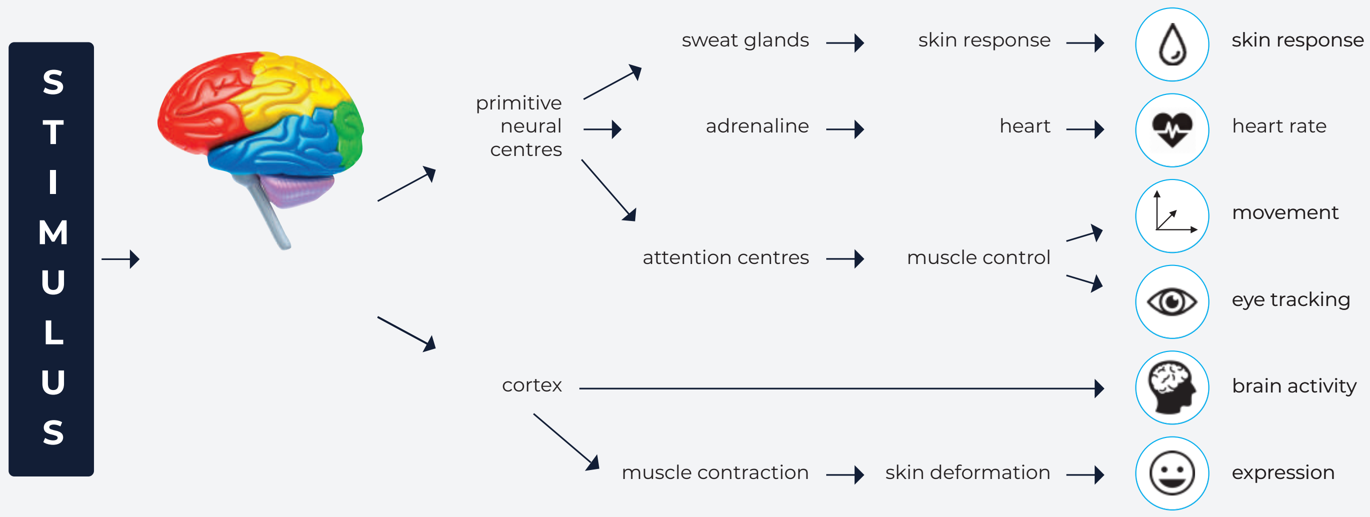
Positive valence is immediately recognisable in a smile, whereas negative valence is indicated by a frown of anger, confusion, or frustration. A series of studies in the 1980's demonstrated the relationship between activation of the corrugator supercilli muscles above the eye, increasing proportionally with a decrease in valence. Conversely, activation of the zygomaticus major, the muscle which draws the angle of the mouth, increases with an increase in valence.

EMG is more sensitive than computer vision for detecting tiny muscle activation. Even in the absence of overt facial expression, emotional states are accompanied by specific changes in fEMG activity. In fact, fEMG is sensitive enough to capture muscle movements that are undetectable to the naked eye.

Outputs from emteq labs' platform include the measurement of:

- Emotional valence
- Attention
- Gaze patterns
- Physical movement
- Excitement based on physiological measures- Heart Rate and Heart Rate Variability (HRV)

Real-time emotion data can be streamed and stored through emteq labs open API and data may be monitored via its connected dashboard app. This allows identification of the exact moment the user responded to the virtual experience, which can then be mapped to what the user saw and heard. Researchers in their fields of mental health, psychology, advertising and market research can for the first time measure moment-by-moment emotional responses and user engagement.



Following an emotional stimulus, there is a cascade of events involving multiple systems which is why multi-modal sensing provide better insights.

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Virtual Reality offers an enormous opportunity for psychologists to study behaviour in realistic environments. The emteq labs system offers an integrated solution for those wishing to integrate ambulatory psychophysiology into their experimental work. By embedding facial electromyography into the head-mounted display, the system allowed us to collect data wirelessly that could be synchronised with stimuli in the virtual world.

Prof. Stephen Fairclough
Professor of Psychophysiology
in the School of Natural Sciences and Psychology,
Liverpool John Moores University.

An Introduction to emteq labs

Our technology is based on a foundation of research conducted over 40 years on the relationship between facial expression and emotions. This work led to insights into our understanding of areas of psychology, human computer interaction, cognitive performance, and mental health.

emteqPRO is a biosensing platform for VR, combining an insert to the HTC Vive headset which incorporates an array of proprietary sensors with artificial intelligence to enable emotion and performance analysis of the wearer. The combination of multi-modal sensing, together with context tagging and user profiling, provides unparalleled insights for academic and market research.

emteqGO is an integrated headset, offering the same array of sensors, within a Pico headset. This offers the benefit of enabling remote data capture across a wider demographic than typical research panels.

Benefits

Our **emteqPRO** and **emteqGO** systems are the only commercially available platforms that enable multi-modal sensing using fEMG, plus contextual recording of the measured responses. The emteq labs solution is based on validated science and provide:

- Larger breadth and depth of data
- A deeper understanding of the participants through psychographics
- Complete viewer immersion
- Experience of more realistic environments
- Ability to change the context, perspective and view of the user

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We used emteq's EMG system to create an adaptive game for cognitive training in virtual reality. We were able to automatically measure real-time user facial behaviour in virtual reality settings and undertake cross-disciplinary experiments with neuroscientists.

Dr Hatice Gunes
Assoc Professor/Reader in Affective Intelligence & Robotics
Department of Computer Science & Technology, University of Cambridge.

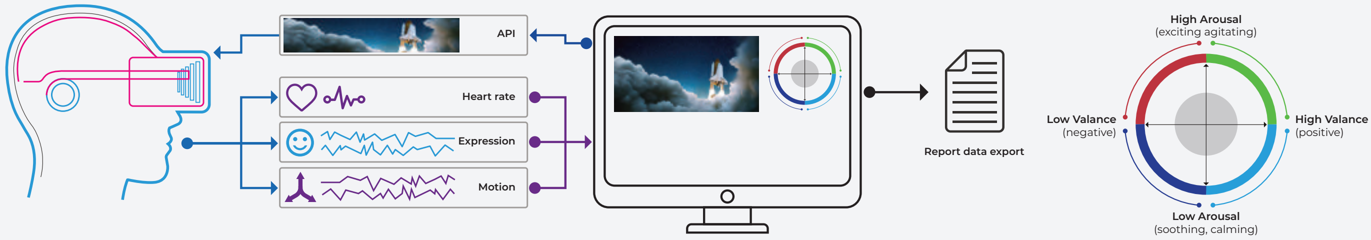
How does it work?

Our fEMG sensors are built into the facial interface of the VR headset (for Vive Pro, our emteqPRO system replaces the manufacturer provided facial interface). It requires no gels, wires or other connectors. In addition to the multiple fEMG sensors, we have incorporated PPG sensors within the facial interface to record pulse data.

Features

- Dry EMG sensors array embedded into the headset insert
- No inter-sensory latency
- EMG sampling rate of 1000 samples/sec'
- 24-bit EMG signal resolution
- Photoplethysmograph (PPG) pulse rate
- Heart Rate Variability (HRV)
- Integrated 9DOF accelerometer/gyroscope
- Movement and posture analysis at 50Hz
- Gaze tracking (eye tracking available via HTC Vive Pro Eye integration)
- Live data streaming to Unity via open API
- Automated annotation of context
- Real-time signal quality monitoring
- Export to file for ingest by 3rd party tools (e.g. Matlab)
- SDK for Unity3D engine
- emteq labs dashboard app for data collection and system monitoring. Requires Windows 10.

Applications



Facial EMG, heart rate and movement data from the headset is wirelessly transmitted to the Analytics Dashboard.

emteq labs technology will revolutionise a wide variety of sectors:

Research in psychiatric and psychological fields such as autism, depression and human-computer interactions, as well as those interested in understanding the basis of our emotional responses to the world.

Gaming & Entertainment to understand which elements create an emotional connection with the audience and/or adjusting game-play according to the response.

Advertising & Marketing to deliver ROI by honing the most engaging ROI by honing the most engaging content prior to release.

Retail for optimising and quantifying retail experiences by tracking shopper behaviours in simulated or real spaces.

Education for evaluating, optimising and personalising courses based on confusion concentration and engagement.

Case Study

Behavioural research from the lab to the real world using virtual reality.

In May 2019, emteq labs partnered with the University of Bournemouth to deliver the world's largest biometric data collation study. The first of its kind, this public display project at the Science Museum in London was part of a two-month long exhibition called "Who Am I?", aimed at inquisitive self-discovery through intriguing objects, provocative artworks and hands-on exhibits.

Across the world, there is a mental health crisis affecting up to 1 in 4 people. The researchers were keen to investigate tools for understanding how people respond to emotional stimuli stimulii, in order to evaluate the potential. In this study, they evaluated the potential of using virtual reality to create controlled scenarios that would enable physiological emotional responses to be monitored and therefore provide a credible solution for the treatment of Mental Health disorders.

The study had two main goals:

- To find out if it is possible to create VR experiences that can reliably elicit valence and arousal
- To identify whether changes in valence and arousal can be detected using behavioural and physiological analysis via the VR technology

To answer these questions, the scientific research team created four different stations in the museum: three active ones and one passive, where visitors could learn about VR and emotions. In the three active scenarios, participants wore emteqPRO headsets and could explore and interact with the environment, sounds and objects. Environments were designed and controlled to deliver a different stimulii: negative, neutral and positive.

> Virtual reality offers an opportunity to have a virtual laboratory to study human behaviours. There is promising evidence that VR could be very useful to study the interaction between emotion and cognition. This could help to treat several mental health disorders with emotional regulation deficits such as anxiety related disorders. This research will begin that process of discovery.

Dr Ellen Seiss,
Deputy Head of Research in the Department of Psychology, Bournemouth University.

The research explored the capabilities of VR to uncover the skills, capabilities and competencies of users as they explored virtual scenes.

Having given informed consent and completed a battery of psychographic assessments (such as personality inventories and strait-trait anxiety scales) volunteers entered a specially designed VR experience. Importantly, no assumptions we made about universal responses and each participant was their own control.

The team installed four standing, and one room-scale Virtual Reality (VR) experience, with content ranging from negative to positive scenarios.

The project gathered data from over 780 individuals, across more than 3,000 recording sessions, creating in excess of 31,000 data streams, **making it the world's largest ever, multi-modal collection of emotional, non-verbal signals**, from a demographically rich audience.

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Conventional systems for measuring changes in how a person responds to an emotional stimulus such as monitoring heart rate and facial expressions are difficult to do in real world unconstrained environments. One would need a camera to record the subject's point of view, as well as multiple cameras to ensure an uninterrupted view of the subject's face. A device to monitor the user's heart rate would also be needed, with all data channels synchronised for later analysis. This is a complex task that would take a long time for each participant to be rigged up with the equipment. We therefore partnered with emteq labs who have created an all-in-one solution that incorporates physiological measurements via specialised sensors in the VR device. This method avoids trailing cables and the inconvenience of attaching chest straps or cables to the subject and is much faster. As researchers we have complete control of what the subject sees and hears, together with automatic tagging of their behaviours and interactions.

Ifigenia Mavridou,
PhD research student, Bournemouth University.

"

This was a fantastic opportunity to obtain a large amount of anonymous data from healthy volunteers who were visiting the exhibition."

Dr Emili Balaguer-Ballester,
Associate Professor of Computational Neuroscience, Bournemouth University.

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In order to provide a background for the data we were collecting, we devised our experience in two stages. In the first stage the participants were providing anonymised information about their personality traits and their reactions to emotions through a questionnaire. In the second stage they were put through a VR experience to see how they reacted to different simulations. We wanted not only to collect the different data that characterised their experience in VR – facial expressions, movement, posture, hear rate – but also to correlate that with their personality, emotional and expressivity traits.

There was a real sense of drawing people in the uncharted, but exciting territories of self-discovery which was the goal of the exhibition and our own desire from a research point of view.

Ifigenia Mavridou, PhD research student, Bournemouth University.

> It was great to be part of a scientific experiment that may contribute to helping scientists to understand mental health conditions. It was intriguing, interesting and fun to participate in.

Participant quote

Results

As well as providing a unique opportunity for the museum and its visitors to collaborate with cutting-edge research, the results of the study conclusively demonstrated that Machine Learning (ML) models could accurately predict physiological data.

The outputs of the research are now available for use in the development of future algorithms. The findings undoubtedly support the ambitions of the team in the continued development of insight into emotional research for future projects, as well as behaviour for the benefit of interpreting and improving the human condition.

Peer reviewed research

Mavridou, I., Perry, M., Seiss, E., Kostoulas, T et al.

Emerging Affect Detection Methodologies in VR and future directions. In: VRIC 2019: 21st Virtual Reality International Conference (pp.35), 20-22 March 2019, Laval, France. ISBN 978-2-9566251-2-4.

Mavridou, I., Seiss, E., Kostoulas, T., Hamedi, M, Nduka, C.

Introducing the EmteqVR Interface for Affect Detection in Virtual Reality. 8th International Conference on Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW), 2019, pp. 83-84. DOI: 10.1109/ACIIW.2019.8925297

Lou, J., Wang, Y., Nduka, C., Hamedi, M., Mavridou, I., Wang, F. Y., & Yu, H.

Realistic facial expression reconstruction for VR HMD users. IEEE Transactions on Multimedia. DOI: 10.1109/TMM.2019.2933338, 8 August 2019.

Mavridou, I., Seiss, E., Kostoulas, T., Nduka, C., & Balaguer-Ballester, E.

Towards an effective arousal detection system for virtual reality. In Proceedings of the Workshop on Human-Habitat for Health. International Conference on Multimodal interaction (ICMI) 2018 (pp. 1-6). DOI: 10.1145/3279963.3279969

Mavridou, I., Seiss, E., Hamedi, M., Balaguer-Ballester, E. and Nduka, C.

Towards valence detection from EMG for Virtual Reality applications. In: 12th International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2018), 4 - 6 September 2018, Nottingham, UK. ISBN 978-0-7049-1548-0

Mavridou, I., Seiss, E., Kostoulas, T., Balaguer-Ballester, E., & Nduka, C.

A System Architecture for Emotion Detection in Virtual Reality. 2018. International Conference EUROVR, London, UK.

Mavridou, I., Hamedi, M., Fatoorechi, M., Archer, J., Cleal, A., et al.

Using facial gestures to drive narrative in VR. 2017. In Proceedings of the 5th Symposium on Spatial User Interaction (SUI) 2017 (pp. 152). DOI: 10.1145/3131277.3134366

Mavridou, I., McGhee, J. T., Hamedi, M., Fatoorechi, M., Cleal, A. et al.

FACETEQ interface demo for emotion expression in VR. In 2017 IEEE Virtual Reality (VR) (pp. 441-442). IEEE. DOI: 10.1109/VR.2017.789236


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