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Emotional Intelligence via Wearables

A method for detecting frustration

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***Abstract*—The research discussed in this paper is part of a pilot study in the use of wearable devices incorporating electroencephalogram (EEG) and heartrate sensors to sense for the emotional responses closely correlated to frustration when performing certain tasks. For this study the methodology used a combination of puzzle, arcade style game and a meditation apps to emulate a task based environment and detect frustration and satisfaction emotions. Preliminary results indicate that degree of task completion has an effect on emotions and can be detected by EEG and heartrate changes.**

***Keywords*—emotional intelligence; wearable devices; EEG; ECG; EQ; heart rate; electroencephalogram**

I. Introduction

Humans have innate Emotional Intelligence (EQ) skills, which are taken for granted. In social situations, we use our senses to collect information from our surroundings, especially how our fellow humans are feeling. The work discussed in this paper is part of a pilot research to investigate the potential use of wearable devices such electroencephalogram (EEG) headsets and consumer heartrate sensors to detect emotions related to frustration when undertaking research from an EQ perspective. Wearable devices that detect emotions can have applications in the field of emotional intelligence (EQ) where self-awareness and that of others emotions is critical for a productive work environment. In the following sections a short literature review is conducted into prior work of emotional detection, with a discussion of the methodology used in this work and the preliminary findings so far.

II. Literature Review of the Emotional Intelligence and Wearables

As humans we all possess in various degrees EQ. The EQ level is related to how quickly "emotional individuals...who experience feeling clearly and who are confident about their abilities to regulate their affect, seem to be able to repair their moods quickly and effectively" [1]. Bradberry [2] breaks down this form of intelligence into personal and social competence. The competence aspect provides the ability to sense our own emotional state and those of other people which can help with our social interactions. In business this aspect of EQ can create cooperative teams and improve productivity.

The EQ field has its roots in psychology and relies heavily on qualitative instruments such as questionnaires and interviews to solicit information about a subject's state of mind. A key drawback of self-report EQ measures such as questionnaires reflect perceived rather actual performance, for example Brackett et al. (2006) cited in [3] found that "around 80% of people believe that they are among the 50% most emotionally intelligent people".

Even with objective observations of subjects the task is never clear cut, psychologists understand as part of their tradition that people have a poker face they present to the world, people want to be accepted therefore they hide inner emotions, and sometimes their ego has a huge effect on subjects reporting on their true emotions [4].

Therefore objective sensing of emotional reactions can provide a more accurate picture about how an individual is performing a certain task.

A. Prior EI Studies Utilising EEG and ECG

Studies into how humans perceive emotions and manage emotions have moved to understanding how human biology relates to emotions. In particular the brain and heart measured using electroencephalogram (EEG) and heart rate electrocardiogram (ECG) sensors to ascertain emotional responses to external stimuli and build a picture of a subjects EQ. A study by Adolphs [5] found that emotions triggered by external stimuli could be visualised using magnetic resonance imaging (MRI) in different parts of the brain such as frontal cortex, amygdala and sensory cortices. The area of emotional processing was researched further by Critchley [6] also using MRI scans of the brain while recoding via ECG corresponding heart rate changes. The study found that "*Activity in a matrix of brain regions predicts the magnitude of cardiac response to visually presented emotional facial expressions. Relative increases in heart rate response were observed to sad and angry facial expressions and relative decreases to happy and disgusted facial expressions, indicating that specific brain regions may support differential processing of sad and angry from happy and disgusted expressions*".

Prior research into brain and heart processes indicate that (1) emotions are reflected in brain and heart activity and (2) it is possible to detect changes in both brain activity and heart rate in subjects for basic emotions.

B. Review of Wearables Technologies

The promise of pervasive and ubiquitous computing [7] in the late 90's was that environments would sense our state and

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needs remotely, wearables are an important component of fulfilling that promise. In the past 5 years there has been an explosion of wearable consumer electronics from the Fitbit, Jawbone, and now the Apple Watch [8]. These devices have been predominately concerned with fitness applications such as number of steps and heart rate. The Apple Watch has taken this paradigm further by packing a sophisticated computer [9] with range of sensors in the size of a watch.

The strong voluntary uptake of devises provides a research opportunity, Gartner [10] research forecasts sales of wearables in 2016 will surpass 275m, a 18% growth from 2015. The ubiquitous nature of wearables will permit for field based research, in a business or university organisation or massive number of individuals equipped with these devices.

Interest in ubiquitous and wearable computing is not recent, Rosalind Picard from MIT in 1995 coined the term Affective Computing and actively researched in the area. Affective Computing was made possible by a variety of computer sensors that could recognise a range of physiological states such facial and speech recognition and to '*yield clues to one's hidden affective state*'. She correctly hypothesized '*a computer you wear, that attends to you during your waking hours, could notice what you eat, what you do, what you look at, and what emotions you express'.* [11]

In consumer wearable electronics the two leading dry electrode EEG headsets are produced by Emotive [12] and the Neurosky [13]. As part of this study the Myndplay headband using the Neurosky chipset [14] was utilised to detect the brain electrical activity via a single EEG headset sensor in position FP1 [15] and divides the incoming signal by frequency ranging from delta to gamma waves. The Apple Watch was selected as the second wearable device to be used for sensing the heart rate of a subject. This devices was worn on the wrist and measured the heart rate continuously via the process of photoplethysmography (PPG) [16], The health and fitness watch app was then used to record heart rate data to develop heart rate variability information and to sense the current emotional state of a subject.

In stark contrast laboratory grade EEG equipment which utilises the 10-20 system can have up to 64 channels and require extensive preparation of test subjects by attaching adhesive gel electrodes [17]. The collection of data requires subjects to be tethered to the electrodes, the electrical signals need to be transmitted to a computer for analogue to digital conversion and for signal processing to split up the various brain states [18]. This can be an issue for field research in Emotional Intelligence whereas in contrast consumer EEG headsets have several benefit over bulky laboratory EEG machines. From a portability perspective wearable headsets are connected to the computer via Bluetooth connectivity (no wires) and automatically on device performs the analogue/digital conversion via its build it in algorithms dispensing with signal analysis [19].

The emergence of wearables presents researchers an opportunity to conduct experiments in the field of EQ with relatively cheap devices instead of using bulky and expensive laboratory equipment.

III. Experiment Method

This experiment has employed triangulation by collecting data from multiple perspectives, methods and sources of information. Quantitative was collected by utilising heart and brain wearable technology to detect their current mood based on a set of activities and qualitative data via interview that captured the emotional state throughout the experiment [20].

A. Participants

- 3 participants were selected from close friends and family.
- Age groups ranging from 26, 24, 44 years old.

B. Experiment Apparatus

1. Questionnaire Interview per experiment to record emotional state.
2. Apple Watch Sport Edition to record heart rate.
3. Heart Graph app (IOS) for the iPhone to download heart rate data from Apple Health Kit.
4. Myndplay Brainband XL to record RAW EEG and Brainwave data.
5. Myndplay Pro software package (Windows) to receive and record EEG data from Brainband XL.
6. Apple iPad to play the arcade and puzzle games.
7. Apple IOS free meditation/games to stimulate satisfaction – frustration -Flow Free [21], Angry Birds RIO, iPause.

C. Pre-experiment Setup Procedure

1. The location of the experiment was undertaken on a 1–1 basis with any distractions like mobiles, emails, people or outside activity.
2. The participant was given a general introduction and aims of this experiment and disclosures was made about the confidentiality, anonymity of their information and data that is collected. In addition they were informed that information collected such as their heart rate and EEG data was not medical grade, and was not to be viewed from a medical perspective.
3. The questionnaire was presented to the participant and were asked to read it, the experimenter would fill out the questionnaire based on feedback received thorough out the session.
4. Apple Watch was fitted on the wrist to ensure it sat snug as to capture an accurate reading of the heart rate. The Myndplay Headband will be fitted with sensors placed on the forehead and ear clip for ground.
5. To calibrate the Apple watch the standard exercise app was be turned on and a minute will be recorded to test for correct capturing of heart rate. Heart rate Information via Bluetooth was automatically transmitted to the Apple iPhone application HeartGraph for checking.

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6. To calibrate the Myndplay headband, the Neurosky mobile app on the iPhone was connected via Bluetooth, a check was done on signal quality, blink detection (linked to correct sensor placement) and attention/meditation variables.

7. A laptop computer was connected via Bluetooth connection to the Myndplay Headband and checked for correct transmission and recording on the Myndplay Pro software.

8. Great care was taken not to show in any great depth readouts in terms of heart rate and brainwave activity on the laptop. The information could initiate a process of biofeedback and could influence the participants' state of mind.

9. The experiment started once all the above mentioned steps were completed. It was critical to initiate both the Apple Watch sport activity recorder and Myndplay Pro recorder on the laptop at the same as to synchronise the timestamps heart rate and EEG data.

D. *During Experiment Procedure*

1. Conversations were kept calm and notes taken to record each phase of the experiment and time a particular game or relaxation activity was started or completed.

2. During the experiment there was a sense of flow between tasks and the participant did not feel stressed or hurried to complete a task in a particular time. It can be overwhelming for some people to wear two foreign devices without any prior experience so some time should be taken to ensure they are calm and comfortable.

3. To capture baseline data around 5 minutes was spent listening to classical music such as Chopin or Mozart with the eyes closed.

4. The following games and meditation apps was played in order. Before starting the application a brief demonstration was done. Throughout each activity the participant was quizzed about the experience and information was written on the interview questionnaire.

5. Flow Free was the first application to be played on the iPad. This is a join the dots game which slowly become difficult. In the initial stages the board is arranged in 5x5 squares and then in progresses to 9x9 squares where it become frustrating to join the dots. The participants were permitted to build their skills at the lower levels and then were encouraged to jump to increasing harder levels peaking at 9x9 level 30. There was no set time limit deliberately to remove the aspect of time pressure.

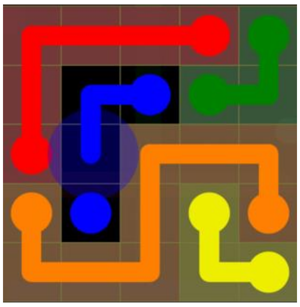

Fig. 1. Example of the Flow Free App [21].

6. Angry Birds was the second application to be played. This is a classic shoot them up or throw them arcade game franchise that can be satisfying. The player has to shoot birds at particular structures and with great fanfare and sound these structures a brought down. At the initial stages no skill is required however as you progress more and more strategy is required otherwise you have to repeat the level which may lead to frustration.

7. iPause was the final application to be used. This is a meditation app which allows the user to navigate using their finger inside a labyrinth. Labyrinths have been used both for physical and mental meditation to achieve a calm state of mind [22]. This app doesn't have levels however it can be relaxing or frustrating depending on the person and how fast they want to get to the centre. The number of labyrinths completed was recorded and at what time each labyrinth was completed.

8. At the end of the experiment, all recording were stopped, files checked, exported from the devices and final thoughts from the participant recorded.

IV. Scope of Emotional Detection

Frustration is categorised as a negative emotion closely related to anger. Situations in day to day life can bring about the feeling of frustration where it builds up slowly when you are not able to achieve a personal goal due to your own actions, other people or outside factors like computers/software [23].

Research in emotions and games [24] indicates that frustration can be experienced by participants. Games provide a common platform of simulating a task oriented environment where participants as they progress through various levels can face frustrating obstacles. For this study subjects were observed playing on an iPad a puzzle app called flow free, angry birds an arcade game and iPause a meditation app to ascertain their emotional responses ranging from satisfaction/happiness to frustration.

A. *Using Heart Rate Data to Get Heart Rate Variation (HRV)*

The heart rate of a person is under constant change due to constant changes to the sympathetic and parasympathetic balance, i.e. the autonomous nervous system that performs involuntary vital functions such as breathing. By calculating the fluctuations around the mean heart rate, we are able to acquire heart rate variability (HRV) measurement. In Fig. 2 below the diagram represents heart rate recorded over a period of seconds. Beat to beat short rate variability (STV) and long term variability (LTV) are indicated [25]. The benefit of HRV measurements is that it is a non-invasive procedure which is derivative of heart rate data.

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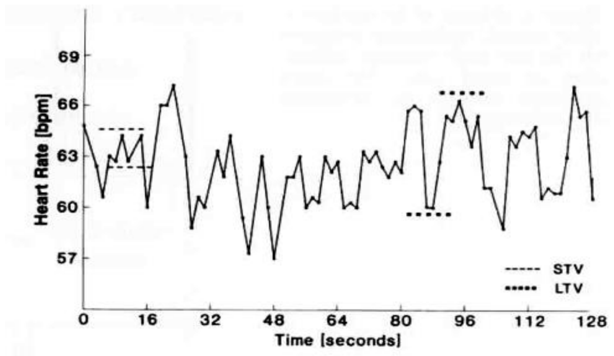

Fig. 2. Example of an adult heart rate trace [25].

In a similar study using an ear clip HRV monitor Chen and Wang [26] observed how learners interacted with a range of material and how their emotional response effected their performance. They found when participants were stressed heart rhythms had an irregular, jiggered pattern and conversely had a smoother, wave-like pattern when in a positive state.

A number of EEG studies firstly identify a brainwave signal from a particular part of the brain and then correlate it as an indicator of emotional arousal. The studies often identify arousal states for emotions such as happiness, anger or disgust by exposing participants to external stimuli. In a study by Judith and Merlin Teodosia [27] student's emotions such as frustration whilst undertaking learning tasks were mapped using EEG, their approach is illustrated in Fig. 3 below. Baseline values of different emotional states were recorded prior to a particular tutorial, the differences were highlighted.

A similar approach was followed with this experiment using the Myndplay EEG headband. An EEG baseline (resting state) and completion of a task measurement was recorded and EEG data from the device was exported to excel. The data was subsequently converted into a set of tables and graphs and analysed for the frustration – satisfaction signature patterns. In addition correlations was made using the time stamped information with HRV data to unearth any relationships.

B. Pre-Experiment Data Modelling

Once the apparatus was tested and working, the experiment proceeded to recording heart rate and EEG data and modelling the information on excel for analysis. The data provided by the HeartGraph app exported the heart rate in a CSV flat file format in beats per minute with a sampling rate of 12 samples per minute from the Apple Health App. The Myndplay application exported EEG wave, Meditation and Attention variables per second (60 samples per minute). The final transformation involved up sampling the raw heart rate and EEG data from per second to per minute. Since the raw data is made up of continuous statistical variables it possible to resample the data via averaging to per minute level, Table 1 contains the result of the sampled data.

V. Experiment Analysis

A small number of close associates (~ 3) was observed performing relaxing and challenging tasks to ascertain their emotional responses to frustrating activities such as playing a game as outline in Section III. The following figures have emerged from the dashboard and accompanied graphs for the three participants 1, 2 and 3.

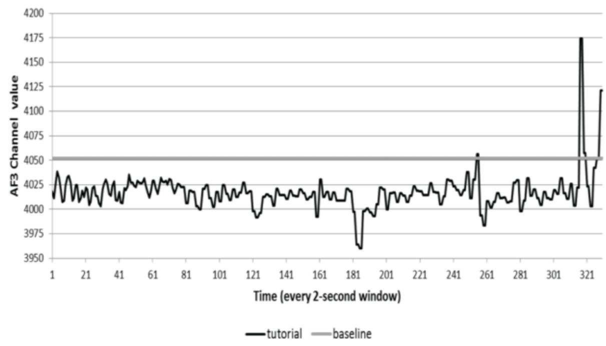

Fig. 3. Baseline of signal level for sensor AF3 is represented by grey line and tutorial by moving line [27].

A. Significant Changes in Attention/Meditation Variables Indicate Key Moments

The following figures plot the Neurosky EEG **attention** variable represented by the red graph and **meditation** variable represented by the blue line. These variable generated via a proprietary Neurosky method, according to vendor publications, the attention variable is created by combining productive EEG waves such as BETA and GAMMA measuring the active focus a person has on a task. Whereas the meditation variable is generated from the dream like waves such as ALPHA, THETA and DELTA where the mind is not particularly focused on anything.

The largest changes in meditation and attention for participant 1 (Fig. 4) involved listening to Chopin from 4-9 minutes, interesting enough both variables moved up pushing the zone variable at the 5 minute mark to 70% the highest point in the session. This emotional response was subjective, with no equivalent peak in other participants. A significant drop in attention occurred after the 30 minute mark which was the point that the 9x9 Flow Free level 30 was completed.

In terms of frustration – satisfaction the only point where the two variables deviated from each other was from 30 – 40 minutes when the hardest section of Flow Free was completed and participant had to familiarise themselves with Angry Birds. Satisfaction perhaps is reflected when both variables are staying within a close range from each other. The largest changes in meditation and attention for participant 2 (Fig. 5) ranged from 25-35 minutes.

TABLE I. Up Sampled per Minute Heart Rate / EEG Data

HH:MM	Min	Attention	Meditation	Zone	Heart Rate (BPM)
4:07:00 PM	1	40.7	62.0	51.1	87
4:08:00 PM	2	24.4	50.3	37.2	86
4:09:00 PM	3	27.9	52.6	40.0	87

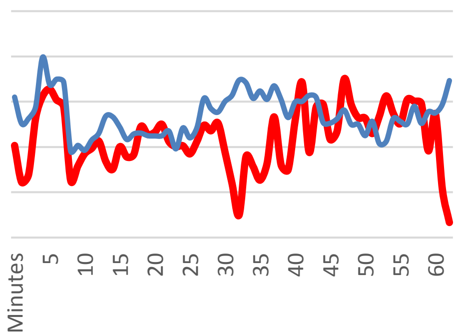

Fig. 4. Attention / meditation plot participant 1.

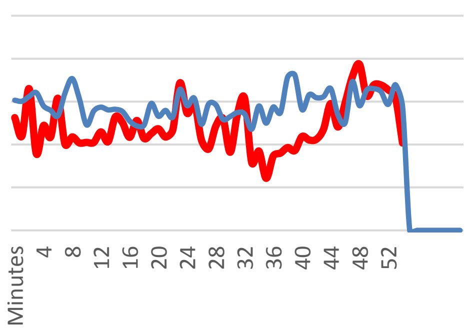

Fig. 5. Attention / meditation plot participant 2.

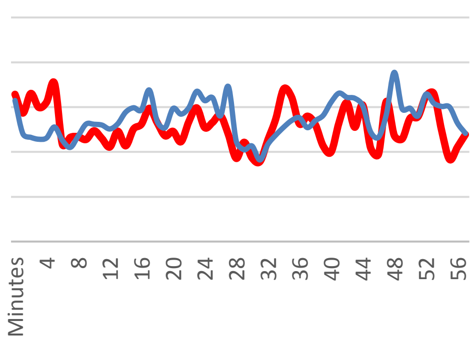

Fig. 6. Attention / meditation plot participant 3.

The classical music (2-7 minutes) did not produce a large response, the participant found Mozart not relaxing. Flow Free caused frustration from around the 25th minute to the time the hardest level was completed. At the 28th minute mark the participant was ready to abandon the 9x9 level 30 but pushed through. Interesting enough the participant found the iPause music relaxing (49-55 minutes) and from the graph both variables were closely tracking.

The largest changes in meditation and attention for participant 3 (Fig. 6) ranged from 27-32 minutes with both collapsing at the point where the participant was asked to jump to 9x9 level 30. The classical music session with Chopin from 5-8 minutes actually caused a large drop on the attention variable from 70% - 43% to match the meditation variable of 45%.

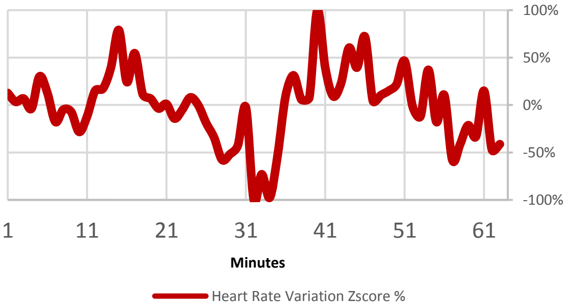

Fig. 7. Heart rate variation participant 1.

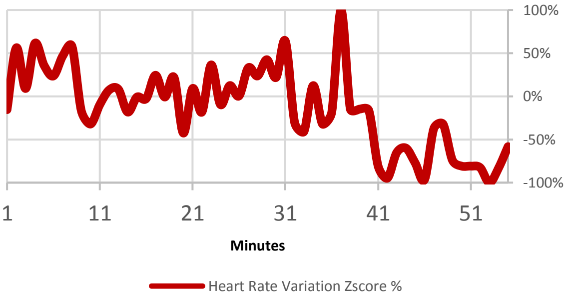

Fig. 8. Heart rate variation participant 2.

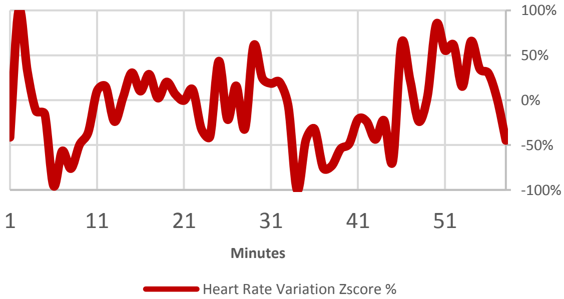

Fig. 9. Heart rate variation participant 3.

B. Large Changes in Heart Rate Variation Signifies Lack of Emotional Coherence

The literature indicates that large variations of the heart rate (HR) from the mean HR signify changes emotional state. The heart rate variation for this study has been calculated from the changes in individual z-scores of the HR. Consequently during a period of time when there are no outliners the amplitude of the waves will be small, in addition positive or negative changes in the z-score are reflected by a +100 to -100 HRV range. Small positive – negative changes to HRV indicate satisfaction, business as usual, large drops in HRV into the negative territory are the result of relaxation and the very large positive increases can indicate excitement.

The heart rate variation percentage graph for participant 1 (Fig. 7) illustrated a very large changes in the HRV from 30-41 minutes. This correlated at 32 minute mark when the participant finished the frustrating Flow Free section leading to a -100% drop in the HRV and then starting the exiting Angry

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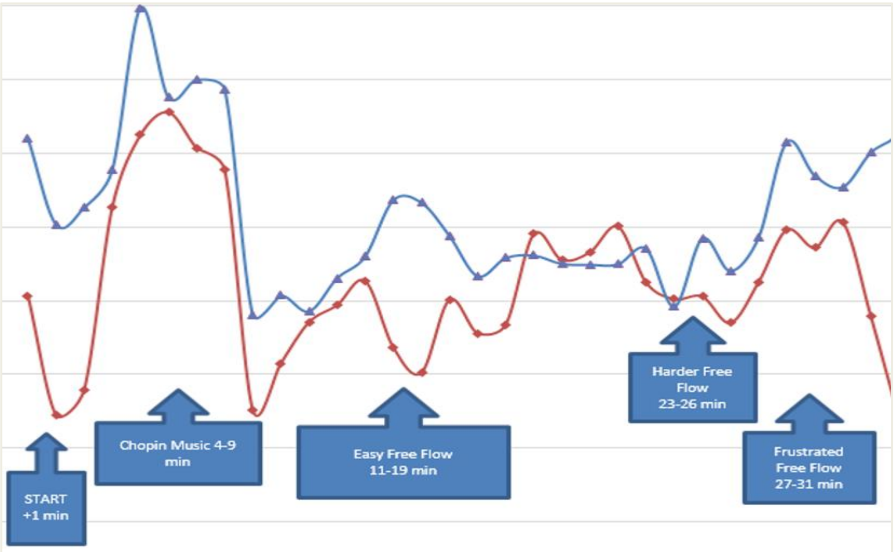

Fig. 10. Attention/meditation with comments - participant 1

Birds leading to a +100% increase to the HRV. Interesting enough the 4-9 minute Chopin session had a low HRV rate indicating relaxation/satisfaction.

The heart rate variation percentage graph for participant 2 (Fig. 8) illustrated very large changes in the HRV from 28-41 minutes. The participant was ready to abandon Flow Free 9x9 L30 at 28 minutes but persevered completing it at 33 minutes, the HRV changed during that period from +60% to -40%. During relaxation from 34-37 minutes the HRV normalised and then spiked to 100% at the commencement of Angry Birds. The classical music session with Mozart from 2-7 minutes (Fig. 8) was not relaxing but exciting with a few HRV peaks touching +50%. Interesting enough for participant 2 in the 38-42 minute segment during Angry Birds task their HRV dropped from +100% to -100%. This indicates an actual drop in their HR and the fact that is stayed low it would seem to indicate relaxation. In addition it would seem the exciting and rapidly changing nature of Angry Birds caused large changes to HRV in a relaxing type of way which explains why it is such an addictive game for people wanting to get away from challenging and frustrating tasks. The final section from 41-51 minutes indicates much lower heart rate changes but also lower hear rates relatively to the prior period.

The relaxation period from 47-48 minutes and the meditation app iPause seemed to subdue the HRV. The heart rate variation percentage graph for participant 3 (Fig. 9) illustrated very large changes in the HRV from 2-6 minutes changing from +100% HRV to -100% HRV during the Chopin music period. A negative HRV change signified a dropping heart rate that indicated relaxation. The second period of interest is from 24-29 minutes as the participant entered the last stage of Flow Free (9x9 L30) causing some frustration, the amplitude of the HRV increased up to the completion at 29 minute. At the start of relaxation from 30 to 36 minutes the HRV changed from +61% HRV at 29 minutes to -100% by 34 minutes.

VI. Preliminary Findings and Conclusion

Both the literature review and research conducted point toward that it is viable to use wearable technology to detect changes to EEG brainwaves and heart rate and correlate these changes to underlying base emotions. The degree of accuracy and precision that emotions such as satisfaction/happiness or frustration can be detected requires further studies with a larger sample. Gaps in the current literature about the accuracy of detection using wearables have been identified in comparison to medically grade laboratory equipment. Further work can compare wearables to research grade equipment.

A. *Interview Questionnaire Helped with Triangulation*

The interview questionnaire provided valuable insight as illustrated in Fig. 10 by mapping subjectively how the participant was feeling while undertaking tasks. The wearables have provided objective data in the form brainwave wave relationships and heartrate variability. The method of triangulation of data has improved the accuracy of this study. One important theme that has emerged is that what constitutes as frustrating or satisfying varies from person to person depending on the prior experience with the task or interest in the activity. That is the reason no two graphs are exactly the same, every person reacted to their task in a different way. However using games as simulation of real world tasks has proven to be successful. The Flow Free puzzle game caused both satisfaction and incredible frustration across all 3 experiments.

B. *Big Data*

The 3 experiments have produced 176 minutes of up sampled data, 10,560 seconds of raw data or 5 million lines of EEG data. Further work can be done analysing this information for additional findings and developing algorithms that automatically can detect key moments during the experiment. An important consideration is that wearables produce a lot of data and handling this data will require advanced database and

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data mining techniques which will make the process of analysis more productive and timely.

C. Ethical Considerations

This type of research interacts with humans on an emotional and physical level. The use of questionnaires or interviews will engage with participants on an emotional/psychological level and wearable technology receives information on a physical level. The APA ethics code [28] suggests a number of important strategies for creating an informed consent document for research participants. At minimum the participants should know the purpose of the project, and the researcher should take steps to minimise risks to the participant's confidentiality and privacy.

D. Experimental Improvements

In future larger trials the experiment could be shorter with 30 minutes more the adequate to have a musical period utilising perhaps dedicated meditation music to lower HRV and EEG signal levels and Flow Free at prescribed increasing levels of difficulty. The interview questionnaire can be improved to have accurate per minute tick boxes of emotions for the experimenter to fill out whilst talking to the participant. Also the interview audio of the session can be recorded for future reference. Finally once apparatus and mathematical models have been fine-tuned future research could utilise wearables in a work environment and study emotional awareness in the context of EQ theory from an organisational productivity perspective.

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