

INVESTIGATING HEART RATE VARIATION, ITS CORRELATION WITH CONTINUOUSLY SELF-REPORTED EMOTIONS AND ITS CLINICAL APPLICATIONS WITHIN PSYCHIATRY

1)ABSTRACT

This study investigates the correlation between heart rate variability (HRV) and continuously self-reported emotions with intent to develop its clinical applications within psychiatry. In this study, 20 participants were fitted with two different types of heart monitoring devices (an ECG and Polar HD band) whilst they were shown emotionally stimulating videos. They were asked to continuously report their emotions using the SentiZent app, developed by Dr Jonathon as their HRV was monitored by the two devices. The results indicate correlations between HRV metrics (e.g. pNN50 and RMSSD) and self-reported emotions, especially in videos that induced heightened emotional arousal. The findings indicate that HRV could serve as a physiological marker for emotional states, with potential applications within clinical psychiatry. The development of a device that incorporates HRV data and self-reported emotions could provide healthcare providers within psychiatric facilities to predict and monitor emotional crises in patients, reducing rates of self-harm and suicide and providing healthcare providers and patients the opportunity to work together alongside the device to investigate triggers, and crisis warning signs and patterns in complex presentations and history. Further research and development are required to develop the data collection and analysis to progress to the development of its clinical applications

2)INTRODUCTION

Heart Rate Variability (HRV) is the variation in time between your heart beats. It can only be detected by specialist heart monitoring devices such as electrical cardiograms (ECGs) but when analysed, the HRV patterns can provide much insight into the health status of the heart and emotional state of the individual. Research demonstrates that HRV can be utilised as a psychological stress marker.

This research begins to fill the many gaps in HRV and continuous self-reported emotion research, as this research field is limited for a multitude of reasons. Research that endeavours to investigate emotions often produces heterogeneous results due to the subjective, individual experience that emotions provide. There is yet to be an objective definition of the term "emotion" and a precise system of measuring emotions that accurately encapsulates and replicates the reported experience between participants. Other research studies often entail participants being shown stimuli and are then asked to report their emotions and then reporting on their emotions after the fact. This method introduces

retrospective bias and invites the potential of cognitive processing and hindsight to distort the self-reported emotions. There exists no reliable way to measure emotions in real time while watching stimuli and there has also been no attempt to utilise physiological variables, such as heart rate variability, to predict emotions, much less to predict emotions in real time. Therefore, the question of how well participants will be able to report their emotions continuously in real time, how well continuously self-reported emotions correlate with heart rate variability metrics, and the clinical application of this information remains mostly unanswered within the body of knowledge.

Psychological stress impacts the body via two main pathways, hypothalamic-pituitary-adrenal (HPA) axis and sympathetic nervous system (SNS) which are immensely coordinated and interconnected (Kim et al., 2018.) The autonomic nervous system (ANS) is comprised of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS), when the SNS is activated, the “flight or fight response” is achieved. During this process, physiological changes occur such as increased heart rate and blood pressure, and the ceasing of gastrointestinal peristalsis. Whereas the PNS activates the “rest and digest” process where the heart rate and blood pressure decrease and digestion restarts (Abai, 2019.) The SNS and PNS work together to activate the flight or fight response when needed, such as in a threatening situation that requires fight or flight to survive. Once the situation requiring “flight or fight” has been escaped or resolved, the PNS initiates the “rest and digest” process.

In individuals experiencing mental disorders characterised by high states of stress and anxiety e.g. Post-Traumatic Stress Disorder, the balance between SNS and PNS processes often dysregulated, causing untimely, inappropriate activation of the SNS response resulting in avoidant, anxious behaviours and acute episodes of panic (Martin, Preedy and Patel, 2015, pp.1–15.) In psychiatric patients that experience extreme emotional responses, HRV can illustrate the interchange between sympathetic and parasympathetic nervous system activity and can additionally illustrate physiological responses to emotional states; therefore, HRV can be utilised as an autonomic marker to provide insight into the HRV patterns that correlate to emotional distress (Agorastos Agorastos et al., 2023.)

My endeavour for these research findings is to combine the physiological and psychological aspects of HRV, and continuous emotion reporting to consider the potential of developing a system that can predict emotional crises in psychiatric patients and the impact that it would make. Psychiatric patients residing in psychiatric facilities that experience states of extreme emotional distress and mental health crisis can be at significant risk to themselves. Their risk to self and emotional state can be immensely challenging for healthcare providers to calculate and monitor. Many instances of suicide and self-injurious behaviours within

psychiatric facilities could be prevented, providing that healthcare providers are aware of their change in emotional and autonomic nervous system state, allowing them to accordingly adjust risk management, and implement crisis support to prevent a further deterioration in state of mind. This could be especially helpful in reducing instances of self-harm and suicide in patients that are on reduced observations, transitioning from high observations, and to grant privacy and preserve dignity during toileting and personal hygiene. By encouraging patients to record their emotions frequently with Dr Jonathan's app, whilst wearing a heart monitoring device, the HRV data provided by the heart monitoring device and app data can provide insight into the HRV pre crises and midst crises patterns in individual patients. Their specific HRV patterns could be compiled and analysed so that when detected, they can alert healthcare professionals when a crisis pattern is detected, allowing them to intervene efficiently, preventing self-harm and suicide. The HRV data alongside emotion reporting can be additionally utilised to help healthcare professionals and patients identify triggers that induce psychological distress and cause physiological responses, which can be difficult to identify in patients with complex presentations and severe trauma history.

3)METHODS

Participants

We recruited 20 participants from the wider Durham University community. There were 5 males and 15 females ranging in age from 19 to 42 ($M = 24$, $SD = 5.92$).

Measures

Participants watched 9 videos.

For the present report, we selected 3 videos to analyse in-depth: Mom, Conjuring, and Sandy Hook. These videos were chosen because they represent a range of various emotions, from positive to negative. Links to the YouTube videos are in correlation tables below.

Participants self-reported their emotions using an app (SentiZent) developed by Dr McPhetres. The SentiZent app facilitates participants to self-report their emotions in real time by applying pressure to the touch screen, and moving their finger to the axes quadrant that best represents their emotion at the time. The upper right quadrant represents active positive emotions e.g. excitement, inspiration etc. The lower right quadrant represents passive positive emotions e.g. content, relaxed etc. The lower left quadrant represents passive negative emotions e.g. sadness, bored etc and the upper left quadrant represents active negative emotions e.g. disgust, anger etc. The X axis represents the valance of the emotion, and the Y axis represents how active the emotion is. Figure 2.1 pictures the axis described, below.



Figure 2.1) Image displaying the UI of the SentiZent app.

Emotion reports were converted into two scores to represent the X and Y coordinates with a single value:

- Z-order curves (Morton Codes)
- Index scores

Procedure

The study design is experimental, with the stimuli being manipulated to evoke an array of emotions. The participants were provided with consistent stimuli and were asked to record their self-reported emotions in real-time continuously via the SentiZent app.

Participants were invited to the lab where they were first encouraged to read about the experiment, ask any questions, and further consent to the experiment taking place. They were then connected to the ECG Biopack MP160 with a wireless ECG module and a Polar HR band, and the EliteHRV app began recording their HRV, and the SentiZent app began recording their self-reported emotions. The participants were shown how to use the SentiZent app, and how to record their self-reported emotions within the appropriate axis via a recorded test run to calibrate their understanding of the app and their self-reported emotions. The experiment then officially began by starting the videos. Every experiment began with the baseline video to ensure consistency and to obtain a baseline metric of each participant's self-reported emotions.

4)RESULTS & DISCUSSION

Overall, across all videos, the ECG and the Polar HR Band (“PHRB”) correlated at $r = .66$, $p < .001$, meaning that both methods of measuring heart rate variability produce agreeable results, but overall correlations with raw IBIs were poor, as were correlations between the Morton code and the index score. Correlations are displayed below in Table 4.1)

Table 4.1) Pearson’s correlations between raw heart rate and emotion-location scores.

| Variable | X1 | X2 | X3 | X4 | X5 |
|-----------------|-------|-------|-------|--------|--------|
| 1.ECG IBI | - | | | | |
| 2. PHRB IBI | .66** | - | | | |
| 3. Morton Code | .05** | .03** | - | | |
| 4. Index Score | .03** | .03** | .06** | - | |
| 5. X coordinate | .01 | .02* | .05** | 1.00** | - |
| 6. Y coordinate | .14** | .13** | .07** | -.11** | -.20** |

The raw inter-beat intervals (IBIS) were not useful as they are sensitive to variation caused by movement, respiration rate, and electrolyte and hydration status. This can cause inaccurate results that are difficult to interpret; therefore, they were converted into HRV metrics to examine any potential correlations between HRV and self-reported emotion. pNN50 and RMSSD have been utilised, measuring acute heart rate variability. SDNN has additionally been utilised as it measures both acute and long-term HRV. We look at the correlations with these metrics within each video separately below.

Participant consistency across time

Intraclass correlation coefficients were computed across time for all participants. The average coefficients are shown in the figure below. These are very low to moderate correlations (with the exception of X for the Sandy video, which is very high at .557).

Below are the ICC values for the Index score and the Morton Code, which are similar to the scores above. In general, there was low agreement among participants according to each of these scores.

Table 4.2) Intra-class correlation scores for raw X and Y coordinate values for three videos.

| Dataset | Coordinate | ICC |
|----------------|-------------------|------------|
| Sandy | Index | 0.5458 |
| Sandy | Morton | 0.1422 |
| Conjuring | Index | 0.0770 |
| Conjuring | Morton | 0.0365 |
| Mom | Index | 0.0540 |
| Mom | Morton | -0.0104 |

Investigating overall correlations between metrics within each video

Next, we looked at the correlation between each metric within each video. This is because each emotion report (and possibly therefore HRV metric) must be calculated and viewed within the context of the stimuli that elicited it. However, raw values for each HRV metric are low. A few metrics stand out consistently across the three videos as being around $r = .20$, particularly with the index score and the X (valence) score.

Table 4.3) Correlations for Mom video

<https://youtu.be/bQoJqDi8490?si=ddHOVSToMYdNx-Lr>

| Variable | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 | X14 | X15 | X16 | M | SD |
|-------------------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------|------------|
| 1. index | - | | | | | | | | | | | | | | | | -37.87 | 27.17 |
| 2. morton | -.07** | - | | | | | | | | | | | | | | | 2197189.78 | 1240131.21 |
| 3. x | .99** | -.09** | - | | | | | | | | | | | | | | -4.23 | 2.87 |
| 4. y | -.36** | .14** | -.47** | - | | | | | | | | | | | | | 4.38 | 3.64 |
| 5. ibi | .30** | .05* | .28** | .08** | - | | | | | | | | | | | | 733.34 | 124.73 |
| 6. ecg | .30** | .04* | .28** | .04* | .74** | - | | | | | | | | | | | 741.63 | 124.92 |
| 7. pnn50_band_10 | .32** | .11** | .29** | .07** | .77** | .66** | - | | | | | | | | | | 12.65 | 19.04 |
| 8. pnn50_band_30 | .35** | .12** | .32** | .08** | .82** | .73** | .90** | - | | | | | | | | | 12.54 | 17.00 |
| 9. sdnnd_band_10 | .25** | .03 | .23** | .07** | .65** | .54** | .66** | .61** | - | | | | | | | | 32.73 | 20.73 |
| 10. sdnnd_band_30 | .24** | .01 | .21** | .10** | .65** | .60** | .58** | .64** | .76** | - | | | | | | | 38.44 | 22.35 |
| 11. rmssd_band_10 | .28** | .11** | .26** | .06** | .74** | .59** | .83** | .77** | .81** | .65** | - | | | | | | 30.22 | 20.83 |
| 12. rmssd_band_30 | .27** | .09** | .25** | .08** | .75** | .61** | .75** | .84** | .68** | .74** | .84** | - | | | | | 30.95 | 19.36 |
| 13. pnn50_ecg_10 | .22** | -.01 | .21** | -.01 | .63** | .63** | .63** | .65** | .50** | .50** | .59** | .57** | - | | | | 18.89 | 19.47 |
| 14. sdnnd_ecg_10 | .06** | -.04* | .05* | .06** | .35** | .37** | .31** | .34** | .29** | .28** | .30** | .29** | .53** | - | | | 39.32 | 29.95 |
| 15. sdnnd_ecg_30 | .07** | -.07** | .06** | .08** | .43** | .46** | .36** | .41** | .35** | .38** | .36** | .38** | .44** | .71** | - | | 46.92 | 29.96 |
| 16. rmssd_ecg_10 | .11** | .03 | .10** | .05** | .41** | .41** | .39** | .41** | .32** | .33** | .38** | .37** | .61** | .88** | .59** | - | 39.85 | 30.90 |
| 17. rmssd_ecg_30 | .13** | -.01 | .11** | .08** | .48** | .49** | .45** | .49** | .39** | .40** | .48** | .48** | .54** | .66** | .86** | .70** | 42.34 | 28.52 |

Table 4.4) Correlations for Sandy video

https://youtu.be/b5ykNZl9mTQ?si=v0SdKkj_laNzgK-F

| Variable | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 | X14 | X15 | X16 | M | SD |
|-------------------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------|------------|
| 1. index | - | | | | | | | | | | | | | | | | -16.45 | 38.32 |
| 2. morton | -.22** | - | | | | | | | | | | | | | | | 1404280.71 | 1260526.23 |
| 3. x | 1.00** | -.24** | - | | | | | | | | | | | | | | -1.71 | 3.87 |
| 4. y | -.08* | .28** | -.16** | - | | | | | | | | | | | | | 0.61 | 3.13 |
| 5. ibi | .15** | .05 | .17** | -.22** | - | | | | | | | | | | | | 734.09 | 125.88 |
| 6. ecg | .07 | .11** | .08* | -.17** | .84** | - | | | | | | | | | | | 762.69 | 124.63 |
| 7. pnn50_band_10 | .04 | .04 | .05 | -.16** | .65** | .66** | - | | | | | | | | | | 11.71 | 16.92 |
| 8. pnn50_band_30 | .07 | .04 | .08 | -.15** | .78** | .79** | .83** | - | | | | | | | | | 11.48 | 13.59 |
| 9. sdnnd_band_10 | .07 | -.07 | .09* | -.21** | .38** | .35** | .63** | .45** | - | | | | | | | | 33.60 | 19.91 |
| 10. sdnnd_band_30 | .16** | -.10** | .18** | -.24** | .53** | .48** | .48** | .57** | .61** | - | | | | | | | 41.52 | 19.35 |
| 11. rmssd_band_10 | .06 | -.09* | .08 | -.17** | .41** | .45** | .75** | .59** | .80** | .53** | - | | | | | | 32.82 | 24.55 |
| 12. rmssd_band_30 | .05 | -.09* | .06 | -.13** | .48** | .54** | .60** | .74** | .58** | .71** | .77** | - | | | | | 34.64 | 22.18 |
| 13. pnn50_ecg_10 | -.17** | .11** | -.17** | .04 | .35** | .40** | .30** | .37** | .12** | .13** | .18** | .23** | - | | | | 21.81 | 21.22 |
| 14. sdnnd_ecg_10 | -.09* | .09* | -.10** | .11** | .14** | .22** | .08* | .20** | .01 | .15** | .06 | .13** | .55** | - | | | 39.47 | 26.16 |
| 15. sdnnd_ecg_30 | .13** | -.09* | .12** | .05 | .17** | .21** | .10* | .17** | .13** | .14** | .18** | .15** | .42** | .62** | - | | 48.00 | 24.49 |
| 16. rmssd_ecg_10 | -.18** | .11** | -.19** | .16** | .17** | .25** | .12** | .25** | .04 | .12** | .10** | .16** | .58** | .90** | .53** | - | 41.36 | 33.70 |
| 17. rmssd_ecg_30 | -.02 | -.03 | -.02 | .07 | .22** | .30** | .22** | .27** | .12** | .08* | .24** | .22** | .53** | .60** | .80** | .65** | 44.63 | 30.64 |

Table 4.5) Correlations for Conjuring video

https://youtu.be/LQ90iDDBksA?si=6JZVbi6Ags_tUf--&t=31

| Variable | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 | X14 | X15 | X16 | M | SD |
|-------------------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------|------------|
| 1. index | - | | | | | | | | | | | | | | | | -37.87 | 27.17 |
| 2. morton | -.07** | - | | | | | | | | | | | | | | | 2197189.78 | 1240131.21 |
| 3. x | .99** | -.09** | - | | | | | | | | | | | | | | -4.23 | 2.87 |
| 4. y | -.36** | .14** | -.47** | - | | | | | | | | | | | | | 4.38 | 3.64 |
| 5. ibi | .30** | .05* | .28** | .08** | - | | | | | | | | | | | | 733.34 | 124.73 |
| 6. ecg | .30** | .04* | .28** | .04* | .74** | - | | | | | | | | | | | 741.63 | 124.92 |
| 7. pnn50_band_10 | .32** | .11** | .29** | .07** | .77** | .66** | - | | | | | | | | | | 12.65 | 19.04 |
| 8. pnn50_band_30 | .35** | .12** | .32** | .08** | .82** | .73** | .90** | - | | | | | | | | | 12.54 | 17.00 |
| 9. sdnr_band_10 | .25** | .03 | .23** | .07** | .65** | .54** | .66** | .61** | - | | | | | | | | 32.73 | 20.73 |
| 10. sdnr_band_30 | .24** | .01 | .21** | .10** | .65** | .60** | .58** | .64** | .76** | - | | | | | | | 38.44 | 22.35 |
| 11. rmssd_band_10 | .28** | .11** | .26** | .06** | .74** | .59** | .83** | .77** | .81** | .65** | - | | | | | | 30.22 | 20.83 |
| 12. rmssd_band_30 | .27** | .09** | .25** | .08** | .75** | .61** | .75** | .84** | .68** | .74** | .84** | - | | | | | 30.95 | 19.36 |
| 13. pnn50_ecg_10 | .22** | -.01 | .21** | -.01 | .63** | .63** | .63** | .65** | .50** | .50** | .59** | .57** | - | | | | 18.89 | 19.47 |
| 14. sdnr_ecg_10 | .06** | -.04* | .05* | .06** | .35** | .37** | .31** | .34** | .29** | .28** | .30** | .29** | .53** | - | | | 39.32 | 29.95 |
| 15. sdnr_ecg_30 | .07** | -.07** | .06** | .08** | .43** | .46** | .36** | .41** | .35** | .38** | .36** | .38** | .44** | .71** | - | | 46.92 | 29.96 |
| 16. rmssd_ecg_10 | .11** | .03 | .10** | .05** | .41** | .41** | .39** | .41** | .32** | .33** | .38** | .37** | .61** | .88** | .59** | - | 39.85 | 30.90 |
| 17. rmssd_ecg_30 | .13** | -.01 | .11** | .08** | .48** | .49** | .45** | .49** | .39** | .40** | .48** | .48** | .54** | .66** | .86** | .70** | 42.34 | 28.52 |

Despite inconsistencies in self-reporting across participants, and weakness in correlation between raw IBIS and HRV, the results in table 4.3-4.5) do demonstrate some significant correlations between co-ordinates X and Y, and HRV.

The correlation between pNN50 Band_30 and Y as displayed in table 4.3) is of the most significant correlations within this data set. With an r value of 0.35**, this data indicates that as arousal increases, so does HRV, hence inferring a relationship between HRV and self-reported emotions. In table 4.4) the pNN50 Band_30 and IBI (X8 & X9) has a correlation of $r=0.79$, indicating a strong positive correlation and indicates that as one variable increases, the others tend to too. This implies that as arousal increases, HRV increases too, and the clinical implications of this information are significant. This data infers the potential of utilising pNN50 as a biomarker for measuring the emotional states of patients and investigating the relationship between HRV, arousal and how they impact the emotional state of patients. In table 4.5) the pNN50 Band_30 correlates with X at an r value of 0.35**

demonstrating that the participant's HRV is positively correlated to self-reported emotions for this video.

In conclusion, the raw HRV and IBI scores correlate weakly with the raw or indexed emotion scores, and further research is required to examine further treatment to the data. The results indicate that there is a correlation between HRV and self-reported emotions, but in order to demonstrate that relationship and generate results that display a stronger correlation, the data collected and the way in which it is collected needs to be refined. The data had two primary factors that contributed to a weak correlation: Raw IBIs being un-useful, and low participant consistency. Whilst the data was then converted into HRV metrics, this process can be taken further to develop an algorithm used to treat the data so that it is more consistent across participants by smoothing, removing trends and common response patterns. We will additionally need to investigate why people vary in the way that they respond. Can this variation be attributed to the uniqueness in which emotions are experienced and interpreted across individuals and is there a more refined way to standardize that categorization and introspection across participants? Reflecting on the way in which SentiZent is explained and instructions are delivered to participants is an additional factor to consider.

There was additionally a correlation of $r= 0.66$, $p< 0.001$ between the ECG and the Polar HR Band ("PHRB") which demonstrates that both methods of measuring HRV produce agreeable results, indicating that both are suitable methods of measuring HRV in the context of self-reported emotions. This is noteworthy, considering the cost difference between the two equipment pieces. This information is especially useful for the continuation of this research and the development of clinical applications e.g. the psychiatric monitoring device, as it determines that neither piece is necessarily significantly more or less effective at capturing HRV, and the more cost-effective option (Polar HR Band) can continue to be utilised, cutting down on larger scale research costs and the cost to develop the clinical device.

Therefore, by continuing to utilise HRV metrics such as pNN50 and developing an algorithm to treat the data, alongside investigating why people vary in the way that they respond and what about the procedure and instructions can be refined to increase participant consistency across time, the correlation between HRV and self-reported emotions can be illustrated more clearly, and can then be utilised to develop applications within psychiatry.

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