Illuminating novel predictors of psychosis: Investigations of environmental and bioelectromagnetic predictors of psychosis symptoms in healthy adults

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Human Studies & Interdisciplinarity

The Office of Graduate Studies
Laurentian University
Sudbury, Ontario, Canada

THESIS DEFENCE COMMITTEE/COMITÉ DE SOUTENANCE DE THÈSE
Laurentian Université/Université Laurentienne
Office of Graduate Studies/Bureau des études supérieures

Title of Thesis Titre de la thèse	Illuminating novel predictors of psychosis: Investigations of environmental and bioelectromagnetic predictors of psychosis symptoms in healthy adults
Name of Candidate Nom du candidat	Hossack, Victoria
Degree Diplôme	Doctor of Philosophy
Department/Program Département/Programme	Human Studies
Date of Defence Date de la soutenance	June 29, 2023

APPROVED/APPROUVÉ

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ACCESSIBILITY CLAUSE AND PERMISSION TO USE

Abstract

Schizophrenia is a debilitating disorder, which often results in irreversible tissue loss in the brain, making it a difficult disorder to treat. The defining feature of schizophrenia is psychosis, which also occurs in schizoaffective disorder, substance use disorders, bipolar disorder, delusional disorder, and dementia. We are slowly getting a better understanding of schizophrenia as novel biomarkers are discovered and we learn what influences its prevalence rates. For example, many studies have shown that schizophrenia is positively correlated with latitude. This knowledge compliments our understanding of the importance of inflammation and vitamin D deficiency as risks for schizophrenia. The purpose of the current thesis was three-fold: first, to determine seasonal variability of background photons as a novel environmental variable to use as a psychosis predictor. Second, to determine if the relationship with latitude was present with psychosis symptoms in healthy adults. And third, to investigate a novel biomarker, biophotons, as a predictor of psychosis/schizotypy symptoms in healthy adults. There were three different studies completed to investigate these questions. The first measured background photon over the course of a year to understand seasonal variations and correlations with other geophysical variables. In the second study, online psychological questionnaires were administered to a global sample. The results suggested the symptoms of psychosis were negatively correlated with latitude, opposite of the previous findings with schizophrenia. Negative correlations were present in spirituality and hypomanic scores, but not depression or anxiety. Additionally, regression analysis revealed that in females but not males, components of the Earth's electromagnetic field were better at predicting psychosis symptoms. In the third study, biophoton emissions from the hands (BPEs), quantitative electroencephalographic (QEEG), electrocardiographic (ECG), and psychological questionnaires were measured from participants in Sudbury, ON, Canada. The psychological questionnaires used

were the Millon Clinical Multiaxial Inventory (MCMI-IV) and the Temperament Character Inventory (TCI-R). The results suggested that biophotons showed some specificity, with overall BPEs from the hands predictive of affective scales in females, and the absolute difference between hands predictive of Schizotypal, Paranoid, and Schizophrenic Spectrum scores in females. Surprisingly, there were very few significant correlations in males. We also found that BPE and QEEG variables combined were able to predict scores on a Depression/Somatic Symptom factor. These results demonstrate that biophotons could be a potential biomarker for mental health disturbances. Taken together, these results demonstrate the importance of investigating the environmental electromagnetic and bioelectromagnetic variables to predict and understand psychosis.

Acknowledgements

Firstly, I would like to thank my supervisor, Dr. Blake Dotta, for taking me on as a student. I am so appreciative of your dedication and support for the projects within this thesis. I would not have made it to the finish line without your help. Thank you to my committee members, Dr. Cynthia Whissell and Dr. Michel Larivière, for their helpful comments and feedback on this document. Additional thanks to Dr. Larivière for collaborating with us on Chapter 4 so that we could use the MCMI. I'd also like to thank Dr. Frank Mallory and Dr. Neil Fournier for reviewing my document and providing helpful feedback.

Thank you to my family for their support throughout my entire academic career.

The NRG, both past and present, deserve a big thank you for supporting me along my graduate school journey. I am grateful for the relationships, however short, that I formed with every single member. Special thanks to KS and DV for their help with data analysis in Chapter 4. Special thanks also to SK and RL for their support over their years. And finally, special thanks to MS for her personal support and insightful knowledge of QEEG and consciousness.

Last but not least, thank you to Dr. Michael Persinger for giving me the opportunity to fall in love with research and the pursuit of the unknown. The following was written in memory of you.

Dr. P

To say you had a touch of defiance
Would be a gross understatement
Not everyone liked you
Could be why they put you in the basement

You did not need sunlight in the lab
To do extraordinary things
Only enthusiasm and creativity
Like the discovery of Saroka's "Pings"

If only we could travel in time
To when they called you Dr. House
And witness your first findings of Burst X
With an intensity of 10 milligauss

Please visit me when you like
Now that I've had to go
So I can feel your sense of presence
Koren Helmet or no

Dr. P
You impacted so many
More than I could possibly determine
You're a part of each and every one of us
Of that, I'm certain.

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Abbreviations

Abbreviation	Meaning
°C	degrees Celsius
ALSPC	Avon Longitudinal Study of Parents and Children
APF	alpha peak frequency
AVH	auditory-verbal hallucinations
BACS	Brief Assessment of Cognition in Schizophrenia
BAI	Beck Anxiety Inventory
BDI	Beck Depression Inventory
BPE	Biophoton emission
BPRS	Brief Psychiatric Rating Scale
CAT-PD	Computerized adaptive assessment of personality disorder
CCD	charge-coupled device
CIHR	Canadian Institute of Health Research
CIS-R	Clinical Interview Schedule Revised
DHA	docosahexaenoic acid
ECG	electrocardiography
EEG	electroencephalography
EMCCD	electron-multiplying charge–coupled devices
EMF	electromagnetic field
EPA	Eicosapentaenoic acid
GAD	generalized anxiety disorder
GAF	Global Assessment of Functioning
HF	high frequency
HPS	Hypomanic personality scale
HRV	Heart rate variability
Hz	hertz
ICD	International Classification of Diseases
ICV	intracranial volume
ID	interdisciplinarity
IR	infrared
J	Joule
LF	low frequency
MATRICS	Measurement and Treatment Research to Improve Cognition in Schizophrenia
MAG	Microsoft Academic Graph
MCMI	Millon Clinical Multiaxial Inventory
mGAF	modified Global Assessment of Functioning
MRI	magnetic resonance imaging
NEO-PI	NEO-Personality Inventory
nm	nanometer
nT	nanoTesla
NAPLS	The North American Prodome Longitudinal Study
NCPE	non-clinical psychosis-like experiences

PMT	photomultiplier tube
PANSS	Positive and Negative Syndrome Scale
PSYRATS	Psychotic Symptom Rating Scales
PUFA	polyunsaturated fatty acids
QEEG	Quantitative electroencephalography
R	resultant
RRM	Resonant Recognition Model
SANS	Scale for the Assessment of Negative Symptoms
SAPS	Schedules for the Assessment of Positive Symptoms
SCID	The Structured Clinical Interview for DSM-5
SIPS	Structured Interview for Prodromal Syndromes
SPD	spectral power density
TCI	Temperament Character Inventory
TCM	Traditional Chinese Medicine
TD	Transdisciplinarity
TDC	typically developing controls
UHR	ultra-high risk
UHR-NR	ultra-high risk – not resilient to psychosis
UHR-R	ultra-high risk – resilient to psychosis
UHR-NT	ultra-high risk – did not transition to psychosis
UHR-T	ultra-high risk – transitioned to psychosis
UV	ultraviolet
VIA	Values in Action scale
W	Watt
W/m2	Watts per metre squared
X	X-component
Y	Y-component
YMRS	Young Mania Rating Scale
Z	Z-component

Chapter 1.0: Introduction

In the recorded history, individuals with mental illness were typically neglected, and no attempt at treatment was made. There was a widespread belief that nothing could be done for those suffering from "madness". There were asylums (the first asylum is thought to have opened in the 13th century), but they were only places to remove the mentally ill from the general public. And they were mostly found in urban centres. In rural areas, "insane" persons were usually chained in barn stalls, basements, or confined areas. There was an Irish member of the House of Common's who said:

> There is nothing so shocking as madness in the cabin of an Irish peasant... When a strong man or woman gets the complaint, the only way they have to manage is by making a hole in the floor of the cabin, not high enough for the person to stand up in, with a crib over it to prevent his getting up. This hole is about five feet deep, and they give this wretched being his food there, and there he generally dies.

That was the conventional thinking for the time. This changed in the mid 1700's when a physician named William Battie, published a document called the Treatise on Madness. In this document he puts forth the idea that asylums should be used as therapeutic tools for patients. The father of psychiatry is considered to be Philippe Pinel. He published a book in 1801 where he talks about asylums needing to become places of treatment "for the purpose of developing and strengthening their faculties of reason" (Shortley, 1997).

Pinel had a student named Jean-Etienne Esquirol who studied under him and spent his career carrying on Pinel's idea of making asylum's into therapeutic environments. One of these ideas was trying to foster a community feeling in the asylum. In 1802, Esquirol opened his own private asylum where the patients would have dinner with him and his family. He also wrote about

the importance that patients were isolated from their friends and family. Esquirol was considered to be a romantic psychiatrist, meaning that he focussed on the psychosocial aspect of disorders. In contrast, biological psychiatrists would focus on what was different in the body that would give rise to the mental health disorder (Shortley, 1997). Biological psychiatrists of those times would be the neuroscientists or physicians of today, while the romantic psychiatrists would be the psychologists or clinical psychologists.

The doctor-patient relationship is usually an oppressive relationship. In western medicine, the patient usually has little to no control over their treatment, which gives the doctor power over the patient. Lack of communication and openness on the treatment plan are complaints that have been found among individuals with schizophrenia (Gray et al., 2005). One of the core principles of naturopathy is that the doctor is a teacher and guide to the patient. In fact, the word doctor comes from the Latin word docere which means "to teach" (Lloyd, 2009, p. 33). This is also found in Indigenous healing methods (Marks, 2006). This seems to be something that psychiatry lost somewhere along the way. It should be noted that not all doctors are oppressive. For example, Oren et al., (2001) reported on a case with an individual who had schizoaffective disorder. Using pharmacological agents alone they could not treat both the thought disorder and seasonal affective disorder. The patient worked with the doctor to decrease his medications over the course of one summer and began bright light therapy in the fall. Not only did they successfully treat his affective disorder, but with his depression treated he did not require as much antipsychotic medication and was able to hold down a job again and provide for his family. This case study represents the epitome of a doctor-patient relationship.

The purpose of this thesis to combine biological and romantic psychiatry approaches to mental health, with a focus on psychosis. In this thesis we hope to determine the predictive power

of environmental photons and biophotons on symptoms of psychosis in healthy individuals. Bringing photons and biophotons into the management of psychosis may have a different appeal to individuals because a lot of the research on biophotons indicate that they could represent a more spiritual aspect of health. This has been done through research investigating if biophotons represent principles of Traditional Chinese Medicine (TCM) (van Wijk et al., 2010). In addition to that research, there has been plenty of research demonstrating that biophotons also represent principles from Western science/medicine, such as biophotons are by products in biochemical reactions (Kobayashi et al., 1999). Individuals with psychosis are more likely to have higher ratings of spirituality (Smith et al., 2008). It is also interesting to note that in countries like India and Ghana, where it is more common to embrace spirituality, individuals with schizophrenia typically experience less harsh and aggressive hallucinations (Luhrmann et al., 2015).

In this paper, I have provided a review of factors that can predict or contribute to the development of psychosis, a summary of findings in human biophoton measurements, and the proposal of my thesis. I begin with psychosis as it is the focus of this thesis and thus understanding its symptoms and etiology is important for determining what measurements to propose of healthy individuals. To be thorough, there are different sections that represent research from different disciplines that have studied psychosis. The first discusses research that has compared schizophrenia and psychosis across cultures. This section is first to underline the role that culture plays in the manifestation of hallucinations, and because this research has quantitative and qualitative components. This qualitative component gives a better perspective of the lived experience of an individual with psychosis or schizophrenia. The second section summarizes research from clinical psychology as this describes behavioural symptomatology correlating with psychosis. After discussing psychological measures, I discuss electrophysiology research in

psychosis, including electroencephalography (EEG) and electrocardiography (ECG). Next, I discuss research that has identified neuroanatomical areas of the brain that can predict the onset of psychosis. This section is critical because the literature review on EEG research in psychosis revealed that it lacked depth and most of the papers were not thorough in identifying brain areas that could predict psychosis. The next section concerned with psychosis describes the biological factors that have predict or have a causal relationship with psychosis. While there are no biological measurements in this thesis, I included this section to provide a more holistic view of psychosis. Finally, this section finishes by summarizing studies that have identified environmental correlations with psychosis and schizophrenia.

Next you will find a summary of almost every research paper published that investigated human biophoton measurements. This is not a popular field of research so this was an attainable task. This section begins by describing how biophotons change over the course of a day and a year, and goes on to show that biophotons are correlated with EEG measurements, and other physiological measurements. This research will be helpful in our statistical analyses because it provides variables, such as time of day and temperature, which might be introducing variability into our dataset and that we can include as covariates. Finally, at the end of this document you will find a proposal of three studies that will investigate this thesis.

1.1 Predicting Psychosis

Psychosis is a term to describe a group of symptoms that are experienced over a standardized threshold. The hallmark symptoms of psychosis are hallucinations with no insight, and delusions (Arciniegas, 2015). Insight refers to an individual's recognition that they have a mental illness, and that the hallucinations they experience are pathological and a result of that mental illness (David, 1990). Psychosis is the defining feature of schizophrenia and also occurs in

substance use disorders and mood disorders (Arciniegas, 2015). Currently, some individuals are considered to be in a clinical high-risk state of developing psychosis. A meta-analysis by Fusar-Poli et al. (2012) calculated the average percentages of transitioning from the high-risk state to psychosis and found that they were: 18% after 6 months of follow-up, 22% after 1 year, 29% after 2 years, and 36% after 3 years. This has created a need to predict which individuals will transition from the high-risk designation to psychosis.

Many papers have reported on the different factors that predict (i.e. are correlated to) rates of psychosis and schizophrenia. Some of these are: genetics (Freedman et al., 2001), latitude (Saha et al., 2006), diet (Kinney et al., 2009), pre-natal infection (Brown et al., 2004), and history of trauma (Bayer et al., 1999). The following sections will describe studies that have investigated variables that predict individuals who will transition from the high-risk state to psychosis. It will also include studies that have compared individuals who already have psychosis or schizophrenia to healthy controls.

1.1.1 Predicting psychosis with social environment: Influence of culture

This section describes differences between countries and cultures in schizophrenia and hallucinations. Bauer et al., (2011) recruited 1080 individuals with schizophrenia (aged 18-62 yrs.) in Austria, Poland, Lithuania, Georgia, Pakistan, Nigeria, and Ghana to investigate the role of culture on type of hallucinations experienced. The local interviewers were either psychiatrists or clinical psychologists that all had the same training. Additionally, they all used a German instrument (Fragebogen zur Erfassung psychotischer Symptome) that was translated and tested for reliability. They used a 1-year prevalence measurement; results are presented as percentage of sample who experienced each type of hallucination and frequency of hallucinations within a one-year window. As expected, auditory hallucinations were experienced the most often (by ~75% of

individuals), followed by visual (~33%), cenesthetic/visceral (~31%), tactile (~8%), olfactory (~8%) and gustatory (~8%). When looking at frequency of occurrence, they found that visual hallucinations were experienced significantly more often in Nigeria and Ghana than the other countries.

Luhrmann et al. (2015) interviewed individuals with schizophrenia about their voice hearing experience in three different locations: San Mateo, California, USA; Accra, Ghana; and Chennai, India. Participants were asked about the phenomenology of their experiences, which included how many voices they heard, how often, and if they had any other types of hallucinations. They were asked if they had had any positive experiences with voices, if they had conversations with their voices, if they had been spoken to by God, if their voices talked about sex, who was speaking, what the voices said, what caused the voices, and what caused their illness. The American sample reported much more negative voice-hearing experiences. Of the 20 participants in that sample, 14 of them were told by their voices to hurt other people or themselves. Half of the participants reported some positive dimension to their voice hearing experiences but no participants reported their voices were predominantly positive. Five participants had heard God speak to them, two women heard the voice of their father that they had been molested by, one person reported her voices were primarily people she knew, and eight participants did not recognize any of their voices.

In the Chennai sample, 13 of the 20 participants reported that their voices were close family members, whose voices often gave guidance, scolded them, and instructed them to do domestic tasks. Only 4 participants did not recognize their voices. In this sample, 4 participants were told by their voices to hurt others or themselves, and 9 described having significantly positive

relationships with their voices. Nine participants considered hearing voices to be a spiritual experience, and 5 had heard a god speak to them.

In the Accra sample, many of the participants perceived voices as spirits, and only 2 reported being instructed by their voices to cause harm to others. Sixteen of the twenty participants had reported hearing God speak to them. Half the participants reported having primarily positive experiences with their voices. Most of the participants reported that their good voice, which was usually God, would help them ignore any bad voices they had.

The authors discuss the relevance of the individualistic Western culture on the how an individual with schizophrenia perceives themselves and their voices. The participants in the American sample seemed troubled that their voices were not able to be controlled, whereas the participants in the Ghanaian and Indian sample were more accepting of this fact. The findings in this article are important for two reasons: first, they demonstrate the power of culture and stigma on how hallucinations manifest, and second, it demonstrates that the violent content of auditory hallucinations that are so well known in the West are not inevitable. For example, there is a novel therapy called avatar therapy, which allows individuals with schizophrenia or a related psychoses and who experience auditory-verbal hallucinations (AVH). In avatar therapy, the patients interact with a computer simulation of their hallucination's voice, which is controlled by their therapist. The therapist alternates between being the voice and themselves and helps the patient establish control over their avatar. A recent paper was published on a randomised clinical trial, where patients with schizophrenia or a related psychoses who's AVH had been unresponsive or only partially responsive to previous treatment (Craig et al., 2016). Avatar therapy led to significant decreases in AVH, both the frequency of hearing voices and the perceived distress at 12 weeks compared to supportive counselling. Avatar therapy demonstrates the importance of the restoration

of power to the individual that they worked to gain themselves. Perhaps the individuals who participate in avatar therapy have learned to embrace their voices similar to Eastern cultures.

1.1.2 Predicting psychosis with clinical psychology

This section describes studies that have investigated the psychological correlates of psychosis and schizophrenia. These articles provide a more in depth understanding of what psychosis is, beyond the broad strokes of hallucinations and delusions. For example, when compared with healthy controls, individuals with schizophrenia or psychosis symptoms scored higher on measures of spirituality (Smith et al., 2008) and openness (Begemann et al., 2020), and lower in histrionic personality disorder (Sevilla-Llewellyn-Jones et al., 2018). Understanding personality differences may inform new approaches to treatment plans, for example individuals who score higher in openness and spirituality may engage with treatment plans that incorporate a dimension of spirituality.

In a study measuring different cognitive domains, Jenkins et al. (2018) predicted auditory-verbal hallucinations (AVH) in psychosis in people with schizophrenia or bipolar disorder. A total of 124 participants were recruited, 53 were diagnosed with schizophrenia, 23 were diagnosed with bipolar disorder, and 48 were control group individuals. Participants were evaluated with the DSM-IV-TR (SCID) to create a binary variable for presence of AVHs. They were also evaluated with the Positive and Negative Syndrome Scale (PANSS) and the Psychotic Symptom Rating Scales (PSYRATS) and the MATRICS (Measurement and Treatment Research to Improve Cognition in Schizophrenia) Consensus Cognitive Battery. The PANSS and PSYRATS evaluate the severity of psychotic symptoms. The MATRICS evaluates cognitive domains that have been found to be relevant to schizophrenia and related disorders. The cognitive battery evaluated the different cognitive domains of processing speed, attention, working memory, verbal memory,

visual memory, and reasoning. They used a hierarchical binary logistic regression to predict the presence of AVHs and a multiple regression to predict hallucination severity (not specific to auditory). Working memory was the only cognitive domain to predict the presence of AVHs, the model had a prediction accuracy of 93.2% (Nagelkerke R^2=0.436). No cognitive domain was able to predict hallucination severity. This is interesting to note as working memory has been correlated with function of the D1 dopamine system in the frontal lobe (Abi-Dargham et al., 2002).

1.1.2.1 North American Prodrome Longitudinal Study

The North American Prodome Longitudinal Study (NAPLS) was started in 2003 to follow individuals who were high risk and determine what variables could predict the onset of psychosis (Addington et al., 2012). The sites involved in the study were Emory University, Harvard University, University of Calgary, University of California, University of California, University of North Carolina, Yale University, and Zucker Hillside Hospital (Addington et al., 2012).

In one study, Cannon et al. (2016) report on their findings from the NAPLS dataset. They used clinical, cognitive, and demographic variables as their predictors because those variables are easy to collect in a clinical setting. Participants in this study were evaluated using the Structured Interview for Prodromal Syndromes (SIPS), which is used to determine if they are at high risk for one of the following syndromes: attenuated psychotic symptoms syndrome, brief intermittent psychotic symptom syndrome, and familial risk and deterioration syndrome. Follow-ups were scheduled every 6 months for 2 years to determine if the participants had transitioned to a psychotic disorder according to the DSM-IV. The final study cohort had a sample size of 596. In their analysis they sought to investigate the predictive capacity of variables that have already shown to predict psychosis, they did not explore new potential variables. The variables they used were age, sum of two items from SIPS (unusual thought content and suspiciousness), Brief Assessment of

Cognition in Schizophrenia (BACS) symbol coding test, the Hopkins Verbal Learning Test-Revised (sum of trials 1-3), decline in functioning from the Global Functioning: Social scale, stressful life event from the Research Interview Life Events Scale, childhood trauma was evaluated with the Childhood Trauma and Abuse Scale, and family history of a psychotic disorder in a first-degree relative. They compared those who dropped out of the study (N=147) with those who did not (N=596) for those 8 variables and found no significant differences ($p>0.05$). Of the 596 participants there were 84 who transitioned to psychosis within the 2-year study, which is 14% of their sample. The average amount of time for this conversion was 7.3 months. They completed a multivariate prediction analysis as well as univariate analyses for each variable on its own. In the multivariate analysis the significant predictors were the summed SIPS items (unusual thought content and suspiciousness), decline in social functioning (Global Functioning: Social Scale) and the Hopkins Verbal Learning Test-Revised. The BACS symbol coding and age were significant in univariate analyses. Stressful life events, family history of psychosis and traumas were not significant predictors. These authors have used their data to create on online calculator for clinical use to determine the risk of transitioning to psychosis (http://riskcalc.org:3838/napls/). These results were replicated in a different sample from the Early Detection, Intervention, and Prevention of Psychosis Program (EDIPPP) (Carrión et al., 2016).

1.1.2.2 Millon Clinical Multiaxial Inventory

The Millon Clinical Multiaxial Inventory (MCMI) was derived from Millon's biopsychosocial theory of psychopathology (Wetzler, 1990). Millon's theory consisted of a 2-dimensional matrix, the first dimension was source of reinforcement (detached, dependent, independent, or ambivalent) and the second was coping pattern (active or passive). This 4 by 2 matrix results in 8 basic personality styles in his first version (Table 1) (Wetzler, 1990). The first

iteration of this test containing those 8 personality styles was created in 1972 and was known as the MISRI (Millon Illnois Self-Report Inventory), pronounced “misery” (Choca & Grossman, 2015). Millon later incorporated 3 pathological personality disorders and 9 clinical syndromes (Table 1.1) (Wetzler, 1990). The pathological syndromes represent the deterioration of a basic personality type from adversity or stress. Together these formed the first version of the MCMI. In the second version, Millon split the Antisocial scale into Antisocial and Aggressive (now: Sadistic), and he also added a scale called Self-defeating (Wetzler, 1990). The MCMI-III saw the addition of scales of Depression, Compulsive, and PTSD (Hsu, 2002). The MCMI-IV added a scale called Turbulent (Choca & Grossman, 2015).

Table 1. 1 Components of the MCMI in its different versions

	Trait/disorder	**Version added**
Basic Personality Disorder Scales	Schizoid[1]	I
	Avoidant[1]	I
	Dependent[1]	I
	Histrionic[1]	I
	Narcissistic[1]	I
	Antisocial[1]	I
	Compulsive[1]	I
	Negativistic[1]	I
	Sadistic[2]	II
	Masochistic[2]	II
	Melancholic[3]	III
	Compulsive[3]	III
	Turbulent[4]	IV
Pathological Personality Disorder Scales	Schizotypal[1]	I
	Borderline[1]	I
	Paranoid[1]	I
Clinical Syndrome Scales	Generalized Anxiety[1]	I
	Somatic Symptom[1]	I

	Bipolar Spectrum[1]	I
	Persistent Depression[1]	I
	Alcohol Abuse[1]	I
	Drug Abuse[1]	I
	Post-Traumatic Stress[3]	III
Severe Clinical Syndrome Scales	Major Depression[1]	I
	Schizophrenic Spectrum[1]	I
	Delusional Disorder[1]	I

[1,2]Wetzler, 1990; [3]Hsu, 2002; [4]Choca & Grossman, 2015

The standardized scores of the MCMI-IV are unique to the test itself and are referred to as Base Rate scores. Scores falling between 60-74 are considered to be in the normal range, 75-84 are considered abnormal traits, and scores of 85+ are considered in the range of a clinical disorder. The MCMI-IV was designed to be a sensitive test used in a mental health setting. The standardization of scores was created and intended to be used with a clinical population. Therefore, administering it to a normal population could produce false positives (Butcher et al., 1998).

One study investigated how personality traits differed between individuals who were at a high risk of developing psychosis and healthy volunteers (Sevilla-Llewellyn-Jones et al., 2018). They administered the MCMI-III, the Positive and Negative Syndrome Scale (PANSS), the Beck Depression Inventory II (BDI-II), the Beck Anxiety Inventory (BAI), and the Global Assessment of Functioning (GAF). In this study only the personality trait scales of the MCMI-III were analyzed. Individuals could be scored as having a clinically significant trait (with a score of ≥75) or a personality disorder (with a score of ≥85). The PANSS evaluates the severity of psychotic symptoms. The BDI-II and BAI were used to evaluate depression and anxiety, respectively. The GAF evaluates symptoms and disability dimensions in the past month. They found that there was a large percentage of individuals in the high risk group that had a clinically significant personality trait, about 97.5% of the sample. From the most to least common there was: depressive (82.5%),

borderline (67.5%), masochistic (57.5%), avoidant (50%), dependent (50%), negativistic (50%), schizotypal (50%), schizoid (32%), and paranoid (22%). Each of those traits were significantly higher than the healthy volunteers. Interestingly, the healthy volunteers had a higher percentage of individuals who had clinically significant personality traits of histrionic (30%) and narcissistic (22%). There were 75% of the high risk group that met the criteria for a personality disorder, mostly depressive (56.7%), borderline (46.7%), and schizotypal (36.7%). There were 32.5% of the healthy volunteers who met the criteria for a personality disorder for compulsive (46.2%), histrionic (23.1%), and narcissistic (15.4%). The BAI and BDI-II scores indicated that on average the high risk group had severe anxiety and moderate depression. The GAF and PANSS scores were lower and higher, respectively for the high risk group which was to be expected. Over a two-year follow-up, only 2 individuals of the high risk group (5% of the sample) had an episode of psychosis, they both had clinically significant personality traits of: schizoid, avoidant, depressive, dependent, masochistic, and schizotypal. They noted that this sample of high risk for psychosis individuals had all sought out help, and that it has been found before that depression and/or anxiety are usually comorbid in high risk individuals who seek out help. They could not compute statistics on predicting patients who would transition to psychosis because only 2 individuals did.

In another study by the same first author (Sevilla-Llewellyn-Jones et al., 2017) they looked at the personality traits/disorders of individuals who had a recent onset of psychosis. To be included in the study, participants had to have developed psychosis within the last five years and stable after hospitalization for at least 8 weeks. They also recruited a healthy control sample. All participants were evaluated with the MCMI-III. A majority of individuals in their patient sample were men who had schizophrenia or schizoaffective disorder. They found that men had an earlier age of onset (22±4.11yrs) than women (24.55±5.27yrs). The average duration of illness in months

was 24.9±19.8. The patient group was more likely to have a lower level of education and to still live with their family of origin. When compared to healthy controls, the patient sample was more likely to have clinically significant personality traits of avoidant (21%), schizoid (14%), antisocial (10%), and dependent (8%). Whereas the healthy controls were more likely to have a clinically significant personality traits of histrionic (20%).

1.1.2.3 Temperament Character Inventory

The Temperament Character Inventory (TCI) is a psychobiological model of personality that was created by Robert Cloninger in the 1980's (Cloninger, 1987). It has evolved over time to include 7 different dimensions: 4 temperament dimensions and 3 character dimensions (Cloninger et al., 1997). The 4 temperament dimensions are Novelty Seeking, Harm Avoidance, Reward Dependence, and Persistence. The three character dimensions are Self-Directedness, Cooperativeness, and Self-Transcendence. Definitions of these dimensions are summarized in Cloninger et al. (1993): Novelty Seeking is the tendency to seek out novel stimuli, engaging in impulsive decision making, and a quick loss of temper. Harm Avoidance is the tendency to avoid behaviours in anticipation of negative stimuli. Reward Dependence is the tendency of continuation of behaviours, such as social attachment and dependence on the approval of others. Persistence is perseverance despite stress and fatigue. Self-Directedness has to do with "will power" and an individual's ability to control and regulate their own behaviour. Cooperativeness has to do with one's acceptance of others and agreeability vs hostility towards others. Self-transcendence is related to spirituality and reflects an individual's sense that they are a part of unitive consciousness, as they are not an isolated individual but part of the universe as a whole.

TCI-R model is based on the idea that its dimensions represent heritable traits. For example, people who score high in Harm Avoidance, a scale that measures aversion to conflict

and strongly correlated with anxiety and depression, were found to have polymorphisms on the promotor region of the tryptophan hydroxylase 2 gene, when compared to people who scored low on Harm Avoidance (Reuter et al., 2007). This gene encodes a protein that is involved with the biosynthesis of serotonin (Saetre et al., 2010).

Fresán et al. (2015) compared responses on the TCI-R for participants who were either at ultra-high risk (UHR) for developing psychosis, were diagnosed with paranoid schizophrenia, or were healthy controls. They also administered the PANSS and GAF to the participants with schizophrenia. The only temperament dimension that was different between groups was Harm Avoidance, where they found both the schizophrenia (100.4±21.6) and UHR (100.4±17.2) groups were significantly higher than the controls (85.2±18.4). The only character dimension that was different between groups was Cooperativeness, which was significantly lower for both the schizophrenia (113.8±14.3) and UHR (116.4±16.0) groups compared to controls (125.6±13.9). Next, they completed correlations between the dimensions and the GAF and PANSS scores that were measured from the participants with schizophrenia. The only significant correlation was between Novelty Seeking and the cognitive dimension of the PANSS (rho = 0.55, p = 0.004). The cognitive dimension of the PANSS is associated with verbal intelligence (Ehmann et al., 2004; Nielson et al., 2014).

Smith et al. (2008) recruited participants with schizophrenia and their non-psychotic siblings, as well as healthy controls and their siblings. All participants were evaluated with the TCI, the SAPS (Scale for the Assessment of Positive Symptoms), SANS (Scale for the Assessment of Negative Symptoms), SIPS (Structured Interview for Prodromal Symptoms), as well as neuropsychological batteries for executive function, working memory, episodic memory, attention, and crystalized IQ. They found that Harm Avoidance and Self-Transcendence were

significantly higher in the schizophrenia group compared to all other groups. Harm Avoidance and Self-Transcendence was higher in the schizophrenia sibling group compared to the controls and their siblings. Reward Dependence, Self-Directedness, and Cooperativeness were all lower in the schizophrenia group compared to all other groups. In terms of the neuropsychological battery variables, they found that the participants with schizophrenia had lower scores than all other groups in all of the domains, and their siblings had lower scores than both control groups in all domains.

Next, they completed correlations between the temperament and character dimensions, with the scores of positive symptoms, negative symptoms, and their variables from the neuropsychological batteries. In the temperament traits, they found that Harm Avoidance was positively correlated with negative symptoms in all four groups (Pearson r ranged from 0.40 to 0.54, $p<0.01$), and with positive symptoms in the participants with schizophrenia ($r=0.54$, $p<0.01$) and the siblings of the controls ($r=0.37$, $p<0.01$). Harm Avoidance was negatively correlated with executive function ($r=-0.47$, $p<0.01$). Self-Transcendence was positively correlated with the positive symptoms in the participants with schizophrenia ($r=0.44$, $p<0.01$), their siblings ($r=0.61$, $p<0.01$), and the siblings of the controls ($r=0.44$, $p<0.01$).

Cooperativeness was negatively correlated with the negative symptoms ($r=-0.48$, $p<0.01$), and positively correlated with working memory ($r=0.59$, $p<0.01$), and crystallized IQ ($r=0.68$, $p<0.01$). The correlations with working memory are interesting because a decrease in working memory capacity is found in individuals with schizotypal personality disorder (Mitropoulou et al., 2005), to be predictive of auditory-verbal hallucinations (Jenkins et al., 2018), and is thought to originate from decreased frontal cortex activity (Thompson et al., 2014; Rosell et al., 2015).

1.1.3 Predicting psychosis with electrophysiology

The human body can be thought of as operating like an electromagnetic machine. The earliest roots of electrophysiology can be traced to Luigi Galvani (1737-1798) who discovered electrical impulses in frog muscles, which he published in 1791 (Piccolino, 1997). Galvani observed muscle contractions in the frog legs when stimulated with artificial electricity and even atmospheric electricity during a thunderstorm (Piccolino, 1997). Later, Carlo Matteucci (1811-1868) was the first to observe that the action potential in frog muscle preceded the contraction of the muscle, which he published in the early 1840's (Collura, 1993).

As the symptoms of psychosis and schizophrenia originate from the central nervous system, it is no surprise that there would be electrophysiological indicators. Research has found general differences in EEG profiles of healthy individuals and those with psychotic disorders (Ranlund et al., 2014), and has also found that baseline EEG profiles in high risk groups can predict the individuals who will go on to develop psychosis (Gschwandtner et al., 2009a; Zimmermann et al., 2010; van Tricht et al., 2014; de Bock et al., 2020; Perrotelli et al., 2021).

1.1.3.1 Electroencephalography

Electrophysiological measurements can be taken of the brain through electroencephalography (EEG) (Bucci & Galderisi, 2011). EEG involves the measurement of small voltage perturbations of neurons within the cerebral cortex (Bucci & Galderisi, 2011). Fast Fourier Transforms are then completed on the recordings to determine the frequencies the neurons are firing at, measured in Hertz (Hz). The frequencies are then averaged into frequency bands, which have been well studied: delta (1.5-4 Hz), theta (4-7 Hz), alpha (7-13 Hz), beta 13-30 Hz), and gamma (30+Hz). These frequency bands do not have agreed upon international standards, and commonly alpha is split into alpha1 (7-10 Hz) and alpha2 (10-13 Hz), while beta is split into beta-

1 (13-20 Hz), beta-2 (20-25 Hz), and beta-3 (25-30 Hz). Delta is typically associated with deep sleep or drowsiness, theta is also associated with drowsiness and is much higher in children than adults, alpha frequencies are associated with restful states while awake, especially when the eyes are closed (Bucci et al., 2011). And finally, the higher frequencies of beta and gamma are associated with alertness and engaging in cognitive tasks (Bucci et al., 2011).

The first EEG recordings were taken by Richard Caton of rabbits and monkeys in 1875 (Collura, 1993). The first human EEG recordings were taken by Hans Berger in 1924 (Collura, 1993). The first clinical use for the EEG came from its use to observe epilepsy by Dr. Frederick A. Gibbs & Erna L. Gibbs in 1935 (Collura, 1993). Herbert H. Jasper and Dr. Wilder Penfield worked on localizing the source of epileptic seizures; in 1939, they measured over 500 epileptic patients (Collura, 1993). Their work provided a foundation for the study of epilepsy with EEG (Reif et al., 2016) and for the usefulness of EEG in a clinical setting (Boutros, 2011).

A full history of the development of electroencephalography can be found below which summarizes Collura's (1993) article of EEG development (Table 1.2). In the review there are a total of 53 individuals described with contributions between 1791 and 1963. Out of those 53, it was possible to find personal histories on 37 of them, including details of what degree(s) they took in university. Table 1.3 is a summary of those individuals, including how they contributed to the development of the EEG technology, and if their contribution matched the field that they were educated in.

Table 1. 2 History of contributions from different scientists in the development of electroencephalography technology

Name (YOB-YOD)	Discipline	Year of contribution	Contribution	Match with education (Y=Yes; N=No)
Luigi Galvani (1737-1798)	Physician & Philosopher	1791	- Used frog nerve-muscle preparation to detect static electricity	Y
Alessandro Volta (1745-1827)	Physicist & Chemist		- Studied frogs' legs as both a conductor and detector of electricity	N
C. L. Nobili (1784-1835)	Physicist	1828	- Constructed galvanometer with a doucle coil of 72 turns and two magnetic needles - Was able to measure from frogs	N
Carlo Matteucci (1811-1868)	Physicist	1830-1865	- First to observe the action potential in frog muscle that preceded the contraction of the muscle	N
Emil Du Bois-Reymond (1818-1896)	Physician & Physiologist		- Constructed his own galvanometer with more than 4000 turns to increase its sensitivity. He also developed non-polarizable electrodes made of clay, these were used in the first animal and human EEG recordings	N
Lord Kelvin (William Thompson) (1824-1907)	Physicist & Engineer	1858	- Refined galvanometer in 1858 but was still a DC instrument	Y
Jacques-Arsène d'Arsonval (1851-1940)	Physician	1870s	- Further refined galvanometer	N
L. Hermann (1838-1914)			- Studied differences between normal and injured tissue - Developed concept of negative variation, showed existence of wave of excitation and interpreted is as signals of self-propagating state that moved from one nerve to the next	

			- He included the use of optical lenses on galvanometers so that you could see weak currents	
John Burdon-Sanderson (1828-1905)	Physiologist		- Refined the electrometer - Initially recorded potentials from frog hearts	N
G. Fritsch (1838-1927) & Eduard Hitzig (1828-1907)	Anatomist& Physiologist Neurologist	1870	- Produced specific motor responses in anesthetized dogs in response to galvanic stimulation	Y
Gabriel Lippmann (1845-1921)	Physicist	1873	- Improved capillary electrometer	Y
Sir David Ferrier (1843-1928)	Neurologist	1873	- Produced movements in apes and other vertebrates in response to faradic stimulation	Y
Richard Caton (1842-1926)	Physician	1875	- Recorded electrical activity from exposed brains of rabbits and monkeys using a mirror galvanometer - He is recognized as the discoverer of the EEG and the first EEG brain mapper as well	Y
V. Y. Danilevsky (1852-1939)	Physician	1877	- Recorded spontaneous and evoked activity from the brains of animals	Y
Augustus Desire Waller (1856-1922)	Physiologist	1880	- Recorded first EKG in dog and man	Y
Fleischl van Marxow (1846-1891),	Physiologist	1883	- Measured the visual cortices of various animals - Turned from anatomy to physiology after his thumb was amputated	Y
V. E. Larionov (1857-1929)	Physician	1899	- Focused on hearing localization	Y
V.V. Pravdich-Nemisky (1879-1952)	Physiologist	1912	- Took first photographic recordings of EEG - Used the Einthoven string galvanometer with moving photographic paper - Described alpha and beta waves of a dog and saw blocking produced by sensory stimulation	Y

N. Cybulski (1854-1919)	Physiologist	1914	- Independently developed photographic attachment to the galvanometer at the same time as Pravdich-Nemisky - Provided tracing of an epileptic seizure of a dog	N
Hans Berger (1873-1941)	Physician	1902-1930	- Published first report of human EEG, describing alpha and beta waves	Y
G. Dietsch		1932	- Published a report on the Fourier transform of human EEG, he provided the theoretical basis for calculating the frequency spectrum	
J.F. Toennies (1902-1970)	Engineer		- Built the first ink writing oscilloscope	Y
		1933	- Developed a differential amplifier - He also improved the electrodes	
E.D. Adrian (1889-1977) & Dr. Detlev Bronk (1897-1975)	Electrophysiologist Engineer & Physicist		- Developed a method for recording single neuron action potentials	Y
Brain Matthews (1952-1973)	Physiologist	1931	- Introduced the use of differential amplifiers to electrophysiology	N
			- Developed two systems for EEG measurement: In addition to the graphic output they (w/ E.D. Adrian) connected a large loudspeaker which produced sound to hear raw EEG waves	
Dr. Alexander Forbes (1882-1965)	MD, Harvard prof and trained in physics		- He developed instruments and techniques	N
Gasser and Erlanger	physiologists		- Developed the first cathode-ray-tube (CRT) oscilloscope	N
George H. Bishop and S. Howard Bartley (1901-1988)	Psychobiologist	1930	- Recorded EEG tracings from dogs - Bartley had built his own amplifiers with transformer coupling	N

Herbert H. Jasper (1906-1999) & Leonard Carmichael (1898-1973)	Psychologist Psychologist	1935	- First in North American to confirm Berger's reports on the human EEG	Y
Herbert H. Jasper		1947	- Appointed to the head of a committee to develop standard for electrode placement, this committee developed the international 10-20 system (Silverman, 1963)	
Jasper & John Hunter	Physician	1949	- Reported a method to record EEG and clinical events simultaneously using a movie camera. This helped localize seizures	
Howard Andrews	physicist and engineer	1935	- Designed and constructed the EEG amplifiers (for Jasper). He also designed a high gain DC amplifier	Y
Dr. Andrew Cipriani	engineer and physician		- Constructed amplifiers for Jasper and Penfield	Y
Alfred L. Loomis (1887-1975)	Mathematics & Law		- Second published electroencephalographer in North America - Developed a method for recording continuous EEG (papers were automatically cut and stacked every 30s)	N
Hallowell Davis (1896-1992)	Physiologist	1930s	- Third American lab to report EEG recordings	Y
Dr. Frederick A. Gibbs (1903-1992) & Erna L. Gibbs	Neurologist	1935	- They recorded seizures - They approached E. Lovett Garceau to design a single channel portable EEG system using the Western Union Morse code ink writing, but this attempt failed - They then approached Albert M. Grass in 1935, who was an engineer at MIT who designed seismographs for the detection of earthquakes	Y

Dr. Lee Travis (1896-1987) & Theodore Hunter	electrical engineer	1936	- Established the fourth American EEG lab, Hunter built equipment measuring muscle potentials, work that was carried out in the 1920s	Y
Hunter and Paul E. Griffith		1935	- Designed and built a system for recording EEG	
Albert M. Grass (1910-1992)	Engineer	1935	- Grass Model I was produced in 1935, it had 3 channels, with the first inkwriters in 1936. The pen deflection circuit used the same basic principle as the d'Arsonaval galvanometer. The design also drew on knowledge from Matthews' and Toennies'	Y
Franklin Offner (1911-1999)	Physicist	1935	- Began producing machines in 1935	Y
		1950s	- Produced the first transistorized EEG amplifiers (the transistor had been invented at Bell lab in 1947). He produced a portable EEG system. The transistor offered a huge improvement to EEG measurements and eventually become indispensable for high quality EEGs	
Dr. Reginald G. Bickford (1913-1998)	Physician		- Developed a portable EEG unit that could be brought to accident sites	N
Dr. Charles D. Ray (1927-2011) and Dr. Bickford	Both Physicians	1963	- Were able to transmit an EEG from Minneapolis to W. Grey Walter's lab in Bristol, England	N

Table 1.3 summarizes the total number of individuals who contributed within their field, or out of their field. There was a total of 61% who contributed within their discipline, and 39% who contributed outside of their discipline. This demonstrates the importance of interdisciplinary collaborations for the production and development of effective technologies. It also demonstrates the importance of exploring disciplinary fields outside of the ones we were formally trained in. The interdisciplinary collaboration seen in the development of EEG technology is what the study of biophotons likely requires.

Table 1. 3 Summary of scientists who contributed to the development of electroencephalographic technology

Contributors	N	%
Stayed in their discipline	23	61%
Worked out of their discipline	14	39%
Total	37	

Gschwandtner et al. (2009a) investigated EEG abnormalities in psychosis and the ability of these abnormalities to predict individuals who will go on to develop psychosis from a high risk designation. In their study they had healthy controls, individuals who were at risk of developing psychosis, and individuals who'd had a first episode of psychosis. Baseline measurements were taken of EEG, SANS mean summary score (Scale for the Assessment of Negative Symptoms) and BPRS global score (Brief Psychiatric Rating Scale). The group that was at risk for psychosis was followed-up with at regular time intervals for a maximum of 7 years to determine if they had developed psychosis. Of the 42 in that at baseline, 12 (28.6%) went onto to develop psychosis while in the study. Pathologies that were looked for in the EEG data were focal slowing of delta and theta frequency bands, and pathological sharp waves. The most EEG pathologies were found

in the at-risk group when compared to controls. There was no association between number of pathologies and score in the SANS or BPRS. Two models were used to predict individuals who would develop psychosis from the at risk group. In the first model with just BPRS scores had a prediction accuracy of 59%. The second model had BPRS scores and the number of EEG pathologies, which had a prediction accuracy of 73%.

Zimmermann et al. (2010) analyzed the data of 28 high risk individuals, of which 13 had developed psychosis. They had baseline measurements of EEG, BPRS and SANS. EEG power was calculated as an average of the Fp1, F3, C3, Fz, Cz, Fp2, F4, and C4 sensors for the following frequency bands: delta (0.5–4 Hz), theta (4–8 Hz), alpha1 (8–10 Hz), alpha2 (10–12 Hz), beta1 (12–15 Hz), beta2 (15–25 Hz) and beta3 (25–30 Hz) bands. In their prediction analysis, none of the frequency bands were different at baseline in the participants who developed psychosis and those who did not. There was a significant different in age, where the participants who developed psychosis were significant older (M=28.7, SD=7.5) than those who did not (M=23.1, SD=6.9). There were, however, EEG differences between the two groups when the power within the frequency bands were correlated with SANS scores. There was a negative correlation between the SANS scores and delta, theta and beta1 power in the participants who did not transition, whereas these variables were positively correlated in the participants who developed psychosis. Positive correlations between these three frequency bands and SANS scores were also found in participants who were measured after having a first episode of psychosis (Gschwandtner et al., 2009b).

Ranlund et al. (2014) compared resting EEG data from healthy controls, individuals at risk for psychosis, individuals who had a first episode of psychosis, individuals who had chronic psychosis (>3 years) and healthy relatives of individuals with psychosis. They had a total sample size of 107, which is approximately the same number of participants in each group. They analysed

the delta, theta, alpha and beta frequency bands across the Fz (frontal cortex), Cz (motor cortex) and Pz (parietal cortex). They only significant differences they were found were between the chronic group and healthy controls in the delta and theta frequency bands. They discuss that this may be due to pharmacological treatment or the long term effects of the illness.

van Tricht et al. (2014) recruited individuals who were clinically at risk for psychosis (n=113) and healthy controls (n=54) to determine EEG characteristics that would predict individuals developing psychosis. EEG power was calculated for the traditional frequency bands: delta (1.5–3.5 Hz), theta (4–7.5 Hz), lower alpha (8–10 Hz), upper alpha (10–12 Hz), and beta (14.5–30 Hz). They also determined each individual's alpha peak frequency (APF) by looking for the peak frequency between 6-13Hz for the occipital-parietal region (sensors: O1, O2, Oz, P3, P4, & Pz) and for the frontal region (sensors: F3, F4, & Fz). After their EEG measurement they were followed up with at 9 months and 18 months later for an evaluation to determine if they had developed psychosis. In their sample of high risk individuals, 19.4% of them went on to develop a psychotic disorder. When comparing the EEG variables, they found that those who developed psychosis had higher frontal delta, frontal theta and a lower APF (8.98Hz) in the occipital-parietal region than those who did not develop psychosis (9.91Hz) and the healthy controls (9.87Hz). Those variables showed no significant difference between the healthy controls and those who did not develop psychosis.

These studies demonstrate that how EEG data are analyzed can determine the results. Zimmerman et al. (2010) did not find any EEG characteristics that could predict the onset of psychosis, however in their analysis they averaged each frequency band across 8 sensors that measure the left and right frontal cortices. This may have been due to their small sample size; however, it is possible by taking an average of the left and right hemisphere they missed a potential

effect. Additionally, they did not look at measurements from the temporal or parietal cortices. Ranlund et al. (2014) had a large enough sample size to look at more than three sensors. They potentially missed more subtle predictors because they only used central sensors in their analysis, which means they did not look at the temporal lobes. They could have completed a less conservative analysis and found novel biomarkers to direct research. The results from van Tricht et al. (2014) provide biomarkers that will be easy for future studies to investigate.

One of the reasons of using EEG instead of MRI is that because MRIs measure whole brain structure volume, if a significant difference is found then it is already too late, the tissue is gone and will never come back. However, EEG may be able to pick up abnormal firing in neurons that predict tissue loss and give an opportunity for preventative medicine.

1.1.3.2 Electrocardiography

Electrophysiological measurements of the heart are taken through electrocardiography (ECG or EKG) (Phillips & Feeney, 1973). The first ECG recordings were taken by Augustus Desire Waller of a dog and man in 1880 (Collura, 1993). The traditional method for measuring ECG (and the one used in hospitals) is a 12-lead clinical standard that has sensors placed in various areas on the chest, wrists, and ankles. Heart rate variability (HRV) is a value that represents the variability in time between successive heartbeats and is most commonly measured by only using Lead II from the 12-lead clinical standard (Jeyhani et al., 2019). The Lead II setup involves placing a sensor on the right wrist, left ankle, and right ankle (Kumar et al., 2020).

Fast Fourier transforms of heart rate variability measurements have been used to infer the relative activation of the sympathetic and parasympathetic systems through the spectral power density of the low (0.04-0.15 Hz) and high frequency (0.15-0.4 Hz) components, respectively (Berntson et al., 1997). The high frequency component has been shown to be related to vagal tone

(Billman & Dujardin, 1990); however, whether the low frequency component represents sympathetic activity has been questioned (Houle & Billman, 1999; Billman, 2013; Reyes del Paso et al., 2013).

Benjamin et al. (2020) measured electrocardiography (ECG) activity from participants with schizophrenia, bipolar disorder, or healthy controls. Bipolar and schizophrenic participants were also evaluated with the PANSS (Positive and Negative Syndrome Scale), which measures positive, negative, and general symptoms, as well as with the GAF (Global Assessment of Functioning) scale, which evaluates symptoms and functioning, and finally the YMRS (Young Mania Rating Scale), which evaluates severity of manic and hypomanic symptoms. ECG measurements were taken during a mismatch negativity paradigm, which involves the participants sitting in front of a computer. In their analysis of the ECG they used the high frequency (HF) heart rate variability (HRV) because of its associations with the parasympathetic nervous system (Berntson et al., 1997). They found that HF HRV was reduced in both patient groups compared to healthy controls, but there was no difference between the participants with schizophrenia or bipolar disorder. In a series of bivariate correlations between HF HRV and the symptom assessments, they found that HF HRV was negatively correlated with the general symptoms in the PANSS and the YMRS scale, and it was positively correlated with the GAF symptom and functioning scales. These results are consistent with the literature of decreased HRV in psychiatric disorders (Jung et al., 2019), and that HRV is a biomarker of mental health resilience (Perna et al., 2020).

1.1.4 Predicting psychosis with neuroanatomy

Developing schizophrenia will normally result in a loss of brain tissue over time (Cahn et al., 2002) and there are differences in neuroanatomy that can predict which individuals will develop psychosis. Mechelli et al. (2011) completed a multicenter, longitudinal study with ultra-

high risk (UHR) individuals to see if neuroanatomical differences could predict who transitioned into psychosis compared to who did not. Participants had an MRI scan at first clinical presentation of being UHR and then followed up with at an average of 2 years to determine if they had transitioned to psychosis. Healthy participants were recruited to compare baseline MRI scans. Compared to the controls, the UHR group had significantly less grey matter in the bilateral medial orbital gyrus, bilateral gyrus rectus, and the right anterior cingulate. In the analysis of those who transitioned (UHR-T) compared to those who did not (UHR-NT), the authors picked three regions of interest to analyze, the left parahippocampal gyrus, the left superior temporal gyrus, and the right inferior frontal gyrus. Only the left parahippocampal gyrus had a decreased grey matter volume in the UHR-T when compared to UHR-NT. Specifically, the anterior portion of the parahippocampal gyrus, close to the uncus. Neither analysis showed any effect for medication use.

In another longitudinal study, Ziermans et al. (2010) recruited adolescents (12-18 years old) that were either deemed at UHR for developing psychosis or were healthy controls. The total length of study was 2 years, participants had an MRI measured at the time of recruitment and after two years. The UHR individuals were clinically monitored to determine if they had developed psychosis during the study. At the 2-year time point 19% of the UHR individuals (8 of 43) transitioned to psychosis (UHR-T), the rest did not transition (UHR-NT). They measured grey matter volumes, volume of white matter, and cortical thickness. When analysing the baseline measurements, there were no differences between groups. When looking at changes in volumes over time, they found that there was an increase in white matter volume for all groups, but that this increase was significantly less for the UHR-T group. There was also a significant total brain volume decrease for the UHR-T group. There were no other volume effects. When looking at cortical thickness they found that there a decrease in cortical thickness in the left middle temporal

gyrus, left anterior cingulate, left precuneus, and left temporo-parieto-occipital area. These changes were only found for the UHR-T group compared to controls, and not the UHR-NT group. The temporo-parieto-occipital area they listed contained parts of the superior temporal gyrus, angular gyrus, and fusiform gyrus.

de Wit et al. (2016) recruited adolescents who were deemed ultra-high risk (UHR) for developing psychosis. They also recruited gender and age matched controls, which they called typically developing controls (TDC). They completed follow-up assessments at 9 months, 18 months, 2 years, and 6 years. Participants had MRIs taken at baseline, and at the 2 and 6 years follow up. They were also assessed with the mGAF (modified Global Assessment of Functioning) and used those scores to split the UHR participants into two groups: resilient and non-resilient. At the 6-year follow up they classified 17 participants as resilient and 18 participants as non-resilient. They look at differences between UHR individual and healthy controls, differences between resilient (R) and non-resilient (NR) individuals, as well as interactions with brain volume and age. The differences between the UHR risk group and the TDC group, mostly occurred in the temporal, occipital, and cingulate lobes. The differences between the UHR R and NR participants mostly occurred in the frontal, parietal, and temporal lobes.

Nenadic et al. (2015) tested the hypothesis that there would be structural differences in UHR individuals who had a genetic disposition to schizophrenia when compared to those with no family history of the disorder. They also recruited healthy control participants, as well as participants who had a first episode of schizophrenia (but who had not started any anti-psychotic medication). All participants had an MRI scan taken of them, these scans were used to compare grey matter volumes in different areas of the cerebral cortex (e.g., frontal lobe) and subcortical structures (e.g., hippocampus, thalamus). They found that the left frontal lobe, postcentral gyrus,

and lingual gyrus all had similar differences to those found by de Wit et al. (2016). It was also interesting to note that when compared to the healthy controls, the three groups all had differences in the frontal lobes (in addition with subcortical structures), but when distinguishing between the participants who had schizophrenia, UHR, or genetic disposition, the differences were primarily found in the hippocampus, cerebellum, and putamen (Nenadic et al., 2015).

In terms of overall differences between healthy controls and individuals with schizophrenia, van Erp et al. (2016) completed an analysis with over 2000 participants in each group. This was a meta-analysis of MRI scans of healthy and schizophrenia brain morphology produced by the ENIGMA Schizophrenia Working Group. Their analysis focused on the intracranial volume (ICV) and the following subcortical structures: nucleus accumbens, amygdala, caudate, hippocampus, lateral ventricles, pallidum, putamen, and thalamus. The found that individuals with schizophrenia had smaller hippocampi, amygdalas, thalami, nucleus accumbens, and ICVs, but larger lateral ventricles and pallidums. There were no differences for the caudates or putamens. Unfortunately, since this study solely focused on subcortical structures, we do not know what cortical differences they may have found.

In another meta-analysis study by Chan et al. (2009), they compared grey matter volumes measured with MRI scans between individuals who had chronic schizophrenia, first episode schizophrenia, or who were a non-psychotic first or second degree relative of someone with schizophrenia. In their analysis they found that there were less grey matter volume reductions in the non-psychotic genetic risk groups than the two patient groups. The areas that were different in all three groups when compared to controls were: left amygdala, bilateral anterior cingulate, and left inferior frontal gyrus. The areas that were different for their patient groups that were similar

to other studies (de Wit et al., 2016; Nenadic et al., 2015) were: post central gyri, amygdala, and the frontal lobes.

The findings among the studies in this section are not entirely consistent; however, the frontal lobes, postcentral gyri, anterior cingulate, and temporal lobes have appeared in multiple studies, which will provide regions of interest for our electroencephalographic data analyses.

1.1.5 Predicting psychosis with biological factors

The psychological aspect and biological aspects of psychosis are inextricably linked. The symptoms of psychosis are characterized with psychological methods, and new research is demonstrating the cause may lie within genetics and the immune system.

Multiple studies have found that components of the immune system are altered in schizophrenia (Momtazmanesh et al., 2019), or can predict the onset of psychosis (Mongan et al., 2021a; Heurich et al., 2021). A review by Heurich et al. (2021) summarized studies that looked at how biomolecules involved with inflammation (complement and coagulation proteins) could predict psychosis. For example, a study by Mongan et al. (2021a) compared blood plasma samples from individuals that were in a clinical high-risk state of developing psychoses. They identified biomarkers associated with complement and coagulation biomolecular pathways that were able to predict if high-risk individuals would go on to have a psychotic episode. The review by Heurich et al. (2021) identified a pattern among studies that suggested in the development of psychosis there will be an increased inflammatory response and a decreased likelihood for the body to re-establish homeostasis. While most of the complement and coagulation proteins are produced by the liver, it is interesting to note that the complement proteins are produced in a small amount in the brain as well (Veerhuis et al., 2011).

One of the most common studied sources of an increased pre-natal inflammatory response is influenza. Brown et al. (2004) found that maternal influenza infection in the first trimester increased the risk for schizophrenia by a factor of 7. An association between maternal pre-natal influenza and schizophrenia was identified after pandemics, such as when births during the 1957 influenza pandemic in Uusimaa County, Finland were analyzed (Mednick et al., 1988; Cannon et al., 2014). Female mice that were infected with influenza while pregnant gave birth to offspring with behavioural abnormalities similar to schizophrenia models (Shi et al., 2003).

In the study of psychosis there is a theory called the "two-hit" hypothesis, where the "first-hit" is a genetic mutation that increases the individuals susceptibility to psychosis and the "second-hit" is an environmental stressor, such as infection or trauma (Bayer et al., 1999; Heurich et al., 2021). In this theory having the two hits would significantly increase the likelihood the individual will develop schizophrenia, or psychosis, in their early adult years. This hypothesis is supported by the Mongan et al. (2021a) findings, where complement and coagulation plasma proteins that were measured at baseline were able to predict individuals who would later go on to have a psychotic episode. The abnormal complement and coagulation proteins would represent that the individual had had a "second-hit".

Further evidence of the role of the immune system and inflammation in the development of psychosis is the association of fatty acid levels with the development of psychosis (Mongan et al., 2021b). Participants were recruited through the Avon Longitudinal Study of Parents and Children (ALSPAC), which involved recruiting mothers in Avon, UK who were expected to give birth between 1991 and 1992. Participants were invited back for measurements at regular time intervals, and used measurements taken of the children at the ages of 17 and 24. Blood samples were collected and used to measure the following polyunsaturated fatty acids (PUFA): total

omega-6 fatty acids, total omega-3 fatty acids, omega-6: omega-3 ratio, and DHA (docosahexaenoic acid) percent of total fatty acids. DHA is the most abundant omega-3 fatty acid that is found in the body (Hsu et al., 2020) and has been shown to modulate microglial cells in the brain (Heras-Sandoval et al., 2016). Participants were also evaluated for psychotic disorder, depressive disorder, and generalized anxiety disorder (GAD). At 17 years 1.7, 5.0 and 5.8% of the participants met the criteria for psychotic disorder, depressive disorder, and GAD, respectively. At 24 years 1.2, 7.7 and 9.8% of the participants met the criteria for psychotic disorder, depressive disorder, and GAD, respectively. In this study they completed cross-sectional as well as longitudinal analyses, cross sectional compares disorders at a specific point in time, whereas longitudinal compares how disorders change over time. They used logistic regression for their analyses and adjusted their models to include covariates for confounding variables, such as: age, sex, BMI, and average number of cigarettes smoked per day. In their cross sectional analyses at 17 years there were no significant differences in the PUFA in any of the disorders. In their cross sectional analysis at 24 years, total omega-3 fatty acids were a significant predictor for depressive disorder, the ratio between omega-6 and omega-3 fatty was a significant predictor for all three disorders, and the percent of DHA was a significant predictor for psychotic disorder. In their longitudinal analyses, the percent of DHA was a significant predictor for psychotic disorder.

In a case study (Puri & Richardson, 1998), a drug-free male schizophrenic was given a daily supplement of 2grams of EPA (eicosapentaenoic acid) and monitored at baseline and then monthly for psychotic symptoms with the Schedules for the Assessment of Positive Symptoms (SAPS) and Negative Symptoms (SANS). His scores improved dramatically over time (SAPS: 46, 45, 14, 9, 8, 8, 7 and SANS: 16, 15, 7, 5, 4, 3, 3). Qiao et al. (2020) completed a double-blind study with schizophrenics with violent tendencies. Participants were either given a daily omega-3

supplement (containing 540 mg of EPA and 360 mg of DHA) or a placebo (containing 10mg of vitamin E) and were followed up with at 4- and 8-week time points. They did not find any significant differences between the two groups; however, they found that their measurements of positive symptoms, negative symptoms and hostility decreased over time for both groups. In their discussion they state future studies should not use vitamin E as a placebo, as this vitamin has the potential to reduce offences by young adult prisoners (Gesch et al., 2002).

Christensen & Christensen (1988) completed an analysis on the relationship between fat consumption and outcomes in schizophrenia. Fat consumption data was obtained from the Food and Agriculture Organization of the United Nations. The fat consumption was converted into daily average calories obtained from either fat from land animals and birds (which is primarily saturated fats) or fat from vegetables, fish and seafood (which is primarily unsaturated fatty acids). They had four measurements of outcome: the percentage of time in the 2 year follow up the participants were in a psychotic episode, percentage of participants with severe social impairment, mean days spent out of the hospital and the total outcome score. There were 8 different centers that participated in the study (Denmark, India, Colombia, Nigeria, United Kingdom, USSR, United States, and Czechoslovakia). They used a multiple regression to predict the total outcome score with the two fat consumption variables. In their model, both fat consumption variables were significant, fat from land animals/birds had a positive regression coefficient and fat from vegetables/fish/seafood had a negative regression coefficient. These two variables accounted for 97% of the variance in the total outcome score.

In addition to this, omega-3 supplements may be a prophylactic for psychosis (Amminger et al., 2010). Amminger et al. (2010) recruited 81 adolescents and young adults who were determined to be at risk of developing psychosis, they were randomized into two groups: a group

that received 1.2grams of omega-3 supplement, and a group that received a placebo of coconut oil, vitamin E and 1% fish oil to mimic the taste. Both groups took their sample daily for 12 weeks, and were assessed weekly for 4 weeks, then at 8 weeks, 12 weeks, 6 months, and 12 months. Participants were primarily monitored for the development of a psychotic disorder. At 12 months, they found that 4.9% of the omega-3 group had developed a psychotic disorder, compared to 27.5% of the placebo group.

Interestingly, Naudí et al. (2017) measured the average concentrations of omega-3s and omega-6s in the spinal cords, brainstems, and brains that had been removed post mortem from 28 healthy individuals. They found that the highest concentrations of omega-3s were in the frontal, temporal, and occipital cortex. This trend was not seen in the measurements of the omega-6s. This study could shed light on the literature reviewed in this section that found omega-3s to be correlated with psychotic disorder and present as a potential prophylactic to prevent the onset of psychosis. It is also interesting to note the Peet et al. (1995) and Glen et al. (1994) found decreased DHA and arachidonic acid in individuals with pervasive negative symptoms, which have been demonstrated to be correlated with reduced frontal lobe activity (Wolkin et al., 2003).

1.1.6 Predicting psychosis with latitude

The influence that weather has on human disease was discussed as early as 400 B.C.E. by Hippocrates in *On Airs, Waters, and Places* (http://classics.Mit.Edu/hippocrates/airwatpl.1.1.html). Hippocrates discusses how the warm and cold winds will affect human health differently depending on geographical location. He discusses certain diseases that will be more common in certain areas depending on wind and location. He also discusses the impact of cleanliness of water, rainfall, and the changing of the seasons.

1.1.6.1 Latitude

Latitude values indicate how far away you are from the equator. The equator has a latitude value of 0°, Sudbury, Canada has a latitude value of 46°, and Sydney, Australia has a latitude value of -33°. It is important for studies on latitude and human behaviour to consider the other confounding variables, such as temperature, sunlight exposure, and magnetic field intensity. As you move away from the equator and toward the poles there is a decrease in annual temperature and increase in background geomagnetic field intensity.

Latitude has been positively correlated with multiple sclerosis (Kinoshita et al., 2017; Mekers, 2017), seasonal affective disorder (Rosen et al., 1990), and major depression episodes in Canada (Patten et al., 2017). The primary hypothesis for these findings is the vitamin D hypothesis, where a vitamin D deficiency at higher latitudes can cause, or make someone more susceptible, to one of these disorders. Multiple studies have also found positive correlations between schizophrenia and latitude (Lehtinen et al., 1990; Saha et al., 2006; Kinney et al., 2009). For example, Lehtinen et al. (1990) completed a study of schizophrenia prevalence within Finland across 40 different sites between 1978 and 1980. They found that schizophrenia was higher in northern areas. These findings are important because when completing an analysis with latitude there will be confounding variables between countries such as healthcare. That this correlation exists within a single country reinforces the idea of a biologically based mechanism.

Kinney et al., (2009) obtained schizophrenia 1-year period prevalence rates and correlated them with latitude, fish intake from 25 years previous, and the daily average minimum temperature from the coldest month of the year for each prevalence rate. They used fish intake rates from 25 years previous because the peak age for the onset of schizophrenia is in the early to mid-20s and those two variables were assumed to be related to pre-natal development. Infant mortality rates were used to represent the state of the healthcare system. Fish intake was included because this a

source of dietary vitamin D. They computed correlations for the entire combined sample (N=49) and for different continents: Europe (N=18), North America (N=10), Asia (N=15) and Africa (N=4). There were no significant correlations in the Africa data most likely because of its sample size. Schizophrenia was positively correlated with latitude in the entire sample (r=0.46), Europe (r=0.58), North America (r=0.75) and Asia (r=0.58). Schizophrenia was negatively correlated with fish intake in North America (r= -0.64). In the latter paper they brought up an interesting point that if the latitude effect is driven by pre-natal vitamin D deficiencies, then this could explain why the prevalence of schizophrenia is higher for Africans and Caribbeans who migrate to northern European countries. And in fact, this increase in rates is exaggerated in those who were born in the European country when compared to those who born at lower latitudes and then moved (Sugarman & Craufurd, 1994).

One of the main hypotheses of the schizophrenia/season of birth correlations is that it is driven by temperature (Battle et al., 1999). To investigate this hypothesis, Parker et al. (2000) looked at the date of birth of those diagnosed with schizophrenia compared to the general population in Singapore. Singapore is close to the equator and has warm tropical weather that is fairly consistent throughout the year. In their study they found that the monthly number of births of schizophrenics followed the same trend as the general population, meaning they did not find the typical excess of births in the winter/spring seasons.

A recent biological experiment used dopaminergic tissue culture samples to demonstrate that a lack of vitamin D during differentiation resulted in a decrease in the amount of dopamine the cells were able to produce (Pertile et al., 2023). Taken together, these studies all reinforce the idea of an increased prevalence of schizophrenia at higher latitudes due to vitamin D deficiencies. However, while the evidence supporting the vitamin D hypothesis is compelling, it does not mean

there are no other mechanisms working in parallel that contribute to the findings of increased schizophrenia prevalence at higher latitudes.

1.1.7 Predicting psychosis with the Earth's electromagnetic field

That atmospheric electricity can influence electrophysiology was first discovered by Luigi Galvani in the 1700's when he observed muscle contractions in frog legs during a thunderstorm (Piccolino, 1997). More recently it has been demonstrated that brain activity is correlated with atmospheric electricity as well (Mulligan et al., 2010). An interesting observation is that the intensity of environmental electromagnetic field is not proportional to the intensity of response (Piccolino, 1997). This has been described as the "spark-gunpowder" analogy (von Haller, 1755 as cited in Piccolino, 1997).

1.1.7.1 The Earth's geomagnetic field

The Earth's geomagnetic field is generated by the movement of liquid iron in Earth's core (Press & Siever, 1974). The geomagnetic field was first described by the astronomer Halley in 1701 (Delobeau, 1971). It can be visualized as a bar magnet located inside the Earth, and its equator and poles do not exactly line up with the geographic equator and poles (Delobeau, 1971). The intensity of the geomagnetic field is strongest at the North and South Pole and weakest at the equator (Sears & Zemansky, 1964). This is because the geomagnetic field is composed of flux lines that travel from the South Pole to the North Pole and are the most spread out from each other as they pass the equator (Sears & Zemansky, 1964). These flux lines are lines of force that charged particles travel along. At the poles, you have stronger magnetic fields because the flux lines are closer together which means more charged particles moving per unit area (Delobeau, 1971). These flux lines represent one of the three components of Earth's magnetic field and are referred to as the X component of the horizontal field. The X component runs North-South. There is also a Y

component of the horizontal field that runs East-West. Finally, there is a vertical component that is referred to as Z and it runs perpendicular to the surface of the Earth.

Mekers (2017) completed a meta-analysis that confirmed the positive relationship between multiple sclerosis prevalence rates with latitude. He also demonstrated that background magnetic field intensity values could explain variability in the multiple sclerosis prevalence rates that latitude alone could not. This demonstrates that background magnetic field values should be considered in studies of the relationship between latitude and health.

Earth's magnetic field can be influenced by solar wind, a stream of plasma that originates from the Sun. This compresses the geomagnetic field, increasing its intensity (Persinger, 1980). There have been many studies finding correlations between mental state and geomagnetic activity. The first was in 1963 and it reported on an increase in hospital admissions relating to psychosis that was associated with geomagnetic storms (Friedman et al., 1963). Other researchers have found decreases in mood scores of males (Persinger, 1975a), increased psychotic depression in males (Kay, 1994), decreased melatonin metabolite (Burch et al., 1999), increased suicide rates of males in Japan (Tada et al., 2014), increased risk of stroke (Feigin et al., 2014), and increased blood cortisol levels depending on the time of year (Breus et al., 2015).

One paper identified that the number of births of schizophrenics was correlated with geomagnetic storms, but whether the correlation was positive or negative depended on the country (Kay, 2004). In that paper the author looked at birth rates of schizophrenia in Sweden, England, Scotland, USA, Netherlands, Denmark, Finland, and Japan. He found that average geomagnetic storm activity was negatively correlated with monthly births of schizophrenia for Sweden, England, Scotland, and Denmark. Those two variables were positively correlated for Finland.

There were small, or null correlations, for Japan and USA. The author proposes that latitude may explain the different results between countries.

Geomagnetic activity has also been found to be related to brain activity. When measuring electroencephalographic (EEG) activity during geomagnetic storms there were decreases in gamma (35–45 Hz) in the right frontal lobe and in beta (13–35 Hz) in the left parietal lobe (Mulligan et al., 2010). Interestingly, an experimentally applied geomagnetic storm field produced similar changes (Mulligan & Persinger, 2012). Taken together, the studies in this section demonstrate a relationship between the Earth's geomagnetic field with the brain and mental health.

1.1.7.2 Photon Activity

Measuring background photons is common in physics, such as in preparing for experiments with the Large Hadron Collider (Gschwendtner et al., 2002) and even to help with the detection of dark matter at the SNOLAB (Singhrao, 2015). Background photon counts have also been found to predict earthquakes in Japan and Chile (Persinger et al., 2012). The background photon counts were found to begin increasing about 7-11 days before each earthquake and took about 15 days to return to the normal baseline values. This prediction was found for earthquakes that occurred from 2012 to 2014 as well (Persinger et al., 2015a).

Persinger (2015b) found that over the course of a year, background photons had a gradual peak up until the fall equinox, after which they began to decrease until the spring equinox when they would increase again. The behavioural relevance of this finding is not yet known. To this author's knowledge there have been no published investigations into the relation between background photon activity and psychosis.

1.2 Bioelectromagnetics

The idea that external electromagnetic fields can influence human behaviour and physiology is not surprising when considering that biological tissues can produce electromagnetic fields. Understanding electromagnetic interactions is required in the study of physiology (Hammerschlag et al. 2015) and consciousness (Keppler, 2021). Electromagnetic field theory states that the movement of charge in space creates an electric field, which in turn creates a magnetic field (Guru & Hiziroglu, 2009). This occurs in biological organisms from the movement of charged ions across the cell membrane resulting in bioelectric fields (Levin, 2014). Not all the cells in the body transmit information via electrical impulses like neurons and cardiac cells, but all cells do rely on a disparity of charge around their cell membrane to function (Levin, 2011). For example, when a wound forms there is a unique bioelectric charge created by the skin cells, which is critical to the healing process (Zhao, 2009).

The bioelectric and biomagnetic fields of the human brain have been well established with the development of electroencephalography and magnetoencephalography, respectively. Biofield physiology is a novel discipline in human health research, including tools such as electroencephalography and biophoton measurements (Hammerschlag et al. 2015). This field seeks to integrate different forms of bioelectromagnetic information (i.e. bioelectric, biomagnetic, and biophotonic).

1.2.2 Biophotons

A photon is a particle of light (Shortley & Williams, 1971). Biophotons are simply particles of light that are emitted by living organisms (Galle et al., 1991; Albrecht-Buehler, 2005; Fels, 2017). Kobayashi et al. (1999) demonstrated photons being emitted from an organelle inside of cells called the mitochondria. His group (Kobayashi et al., 1994) also demonstrated that different

biological fluids, such as blood plasma and urine, emitted different amounts of photons and had different peak wavelengths. Wavelength is important to consider in the measurement of biophotons because it corresponds to the energy level of photon being emitted. The energy of a photon and its wavelength are directly proportional to each other. Photons in the visible spectrum have wavelengths in the range of 400 to 800nm, which corresponds to energies of 5.0×10^{-19} J to 2.5×10^{-19} J. The energy intensities of these photons correspond with the energy intensities involved in photochemical and photobiological reactions (Hallett et al., 1977). Subtle differences in the energy and wavelength of photons can have a profound difference on their effects. Cosic's Resonant Recognition Model (RRM) uses the structure of protein molecules to compute a unique photon wavelength that can resonate the molecule (Cosic, 1994). Experiments have shown that this model is valid and accurate (Dotta et al., 2014).

As mentioned above, Kobayashi et al. (1999) determined that photons are emitted from the mitochondria inside of cells. But this does not mean that they are only emitted by the mitochondria. Biophotons have also been demonstrated to be produced by the cell membrane (Dotta et al., 2011). Biophotons are a known biomarker for increased reactive oxygen species (ROS) (Kobayashi et al., 1999). ROS are increased during oxidative stress but are also important signalling molecules in cognition (Kishida & Klann, 2007). It has been hypothesized that biophotons may be more than just by products of metabolic processes, and their signalling may have a role in cognition that parallels that of ROS (Rahnama et al., 2011).

Discussing which part of the cell produces biophotons is a conversation taking place at the biological scale. At a chemical scale biophotons are produced in chemical reactions that result in the release of energy, this energy is released in the form a photon (Hallett et al., 1977). This thesis will be considering biophotons at a whole organism level scale, which we will call physiological,

because we will not be studying the source of the biophotons, only measuring their characteristics, and determining correlates.

1.3 Measurement of biophotons

The following sections will focus on studies that have measured biophotons from humans. The section will summarize how biophotons are measured, the history of the field, general characteristics of human biophotons, correlations of biophotons with disease, and significant peak wavelengths that have been measured from humans. Almost all these studies have originated from different laboratories worldwide, each with a unique methodological approach to their measurements. For example, some studies describe asking participants to wash their hands with ethanol before measurement (Jung et al., 2005). Others state that participants waited in the dark room for up to an hour before measurement (van Wijk & van Wijk, 2005). The ethanol would kill any bacteria which themselves could produce biophotons. And the skin gives off more photons after being exposed to sunlight, so asking participants to sit in the dark for one hour would potentially reduce noise in the measurements (Cohen & Popp, 2003). Additionally, some studies specify the distance the photon measurement device was from the body (Cifra et al., 2007) while others do not. For that reason, the methodology for each study is described in detail as it may have influenced the results.

In biophoton research, photons are most commonly measured with either photomultiplier tubes (PMTs) (Jung et al., 2005; van Wijk & van Wijk, 2005; Dotta et al., 2012) or electron-multiplying charge–coupled devices (EMCCD) cameras (Kobayashi et al., 2016; Ortega-Ojeda et al., 2018). Most of these devices measure in the visible range, with some devices also measuring in the ultraviolet (UV) and/or infrared (IR) ranges. The technique of human CCD imaging was

developed by Masaki Kobayashi, who is a prominent scientist in the study of biophotons (van Wijk et al., 2006).

Photomultiplier tubes utilize the photoelectric effect to count the number of photons (Sens-Tech Limited, 2010). The photoelectric effect was first discovered in 1887 by Heinrich Hertz when he noticed that a spark would more easily jump between two charged spheres when the spheres were illuminated by light (Shortley & Williams, 1971). In 1905 Albert Einstein was able to give the correct explanation for the photoelectric effect (Shortley & Williams, 1971), which earned him a Nobel prize in 1921. The principle is this: if a photon is absorbed by metal, the photon will impart its energy to an electron, and if that energy is of a sufficient amount, the electron will penetrate the barrier of the metal and be released from the surface (Shortley & Williams, 1971). The details of how the device functions is beyond the scope of this thesis, but the basic principle is that the more photons that enter the PMT, the more electrons are produced and subsequently measured, which then gives us a higher value as to the number of photons being emitted.

1.3.2 Biophoton measurements from humans

The first measurement of biophotons from a human with a PMT was completed in the 1990's (Cohen & Popp, 2003). However, the first measurements of photons from humans ever were taken in the early 1900's (Kilner, 1911). Walter Kilner (1847-1920) was an English doctor who attempted to create a method by which to view the human aura, which he referred to as the "Human Atmosphere" (Kilner, 1911). Interestingly, it was just a few years later in 1923 that a Russian scientist named Alexander Gavrilovich Gurwitsch (1874–1954) had discovered biophoton emission from onion roots (Gurwtitsch, 1924 as cited in Volodyaev & Beloussov, 2015).

There are scientists at the time who reportedly tried to replicate Kilner's findings and failed (Review, 1912), and his work has subsequently been labelled as "pseudoscience" (Nickell, 1993).

Unfortunately, it is beyond the time and scope of this thesis to try to replicate Kilner's work. However, even if we do not use the devices he created, we can still gain insight from his ideas. In his book (Kilner, 1911, pg.3), he states: "It would, indeed, be strange if the Aura did not vary under different circumstances, and we firmly believe that a study of its modifications will show that they will have a diagnostic value." It is this idea that fuels most of the human biophoton studies that have been completed in the past few decades.

1.3.3 Biophoton measurements of human hands

Multiple studies have been carried out measuring the biophotons off the hands of humans (Jung et al., 2005; Cifra et al., 2007; Zhao et al., 2016). It has been hypothesized that these measurements can represent overall health (Cohen & Popp, 2003; Jung et al., 2003; van Wijk, 2010). The following studies looked at how photon measurements from the hands of healthy participants varied over 24 hrs (Cifra et al., 2007), one year (Jung et al., 2005), over different measurement spots on the hand (Scholkman et al., 2018) and showed an interaction with gender (Zhao et al., 2016).

Jung et al. (2005) measured the palms and dorsums of the left and right hands of three individuals, once a week for an entire year. On each measurement day, each participant was given 1 hour in a dimly lit room for dark adaptation and to remove effects of delayed luminescence from sunlight. Before measurements participants washed their hands with ethanol soaked cotton, wore white gowns and removed anything metallic. Participants were measured 6 times over the course of 6 hours. Measurements were taken with two identical PMTs to record the left and right hand simultaneously. The PMTs were kept in wooden boxes that were lined with black thin styrene foam. Recordings were taken at a sample rate of 10Hz. When comparing results across the three subjects, one consistent pattern that emerged was higher photon counts in March-April and

decreased photon counts from July-October. Additionally, these differences were more prominent in the dorsum measurements as the palm measurements were relatively stable over the year. Because the dorsum measurements varied more than the palms, their emissions for the most part were higher than the palms in the March-April and lower than the palms for July-October. This is interesting as these seasonal changes are roughly the mirror image of background photon fluctuations associated with the spring/fall equinox (Persinger, 2015a). However, it should be noted that while the current authors did not report the dark count values over the year, they did state that they were stable.

Cifra et al. (2007) measured the palm and dorsa of both hands of 5 participants over the course of 24 hours. They used a PMT (EMI 9235 QB) that had a spectral range of 160-630nm and was setup so that measurements were taken 7 cm away from the skin. Subjects were dark adapted for 1 hour before the experiment and they were measured every 2 hours over a 24-hour period. They found a circadian rhythm in human hand measurements, with the right hand having higher photon emissions between 11am and 9pm, and the left hand having higher photon emissions between 11pm and 9am. The effect was more exaggerated in the dorsum of the hands when compared to the palms. In term of overall photon emissions, the photon counts were lower during the 11am – 9pm period and higher during the 11pm – 9am period.

Choi et al. (2002a) measured the palms and dorsa of the right hand of 20 healthy human participants. They used a PMT (CR120, Hamamatsu, Bejing) with a spectral range of 300 to 650nm and an IR filter with a cutoff of 800nm and above. They took their measurements between the hours of 12pm-6pm in a room that was 10°C. The participant's ages ranged from 14 to 56 and there were 5 females and 15 males. They found no difference between the palms and dorsa, no gender difference and no age difference (ages were grouped as either teen, twenties, or >thirty).

The lack of difference between palm and dorsa is not consistent with previous research, however the room temperature in this study is fairly low and they used an IR filter, which most studies have not done.

In another study, Choi et al. (2002b) measured the palm and dorsa of the left and right hands in 10 healthy college students (aged 18-35 years). The PMTs (R331-05, Hamamatsu, Japan) they used had a spectral range of 300 to 650nm and were housed in a dark chamber located in a room whose temperature and humidity were maintained at 20±2°C and 67±2%, respectively. They measured the palm and dorsum of both hands for all participants. They found that on average, the right hand had higher photon counts than the left hand for both the palm and dorsa. They also found that on average, the dorsum had higher photon counts than the palm for both the left and right hands. One of the participants got a cold after their measurement, so the researchers took two more measurements, when the participant had their cold and after they recovered. The measurements of the left and right dorsa were about double the number of photons when compared to before and after the cold. After the cold, the measurements were no different than before the cold. There was also about a 50% increase in the photon counts of the right palm when the participant had the cold.

Zhao et al. (2016) measured hands of participants simultaneously with two photomultiplier tubes (PMTs), which had wavelength ranges of 160-630nm. They measured a total of 60 healthy volunteers between the ages of 21-69, there were 33 females and 27 males. Measurements from 49 participants were used to build prediction models, and 11 were used to validate it. Before measurements, participants were asked to wash their hands and wear light, tight black gloves to reduce the effect of delayed luminescence. Measurements were taken of the palm side of the fingers, palm side of the hand, dorsum side of the fingers and dorsum side of the hand. In addition

to calculating the average photons being recorded, they also recorded a value called the Fano Factor. This value is supposed to represent the shape of distribution of the photons. When participants were grouped as either older than 40 years old or younger than 40 years old there were significant differences in the number of photons measured. For all four measurement areas, the older group had significantly higher photon emissions than the younger group. When they compared two genders, male and female, they found no significant differences. However, when they looked at the age effect for males and females separately, they found that it was much more exaggerated for the males than it was for the females.

Scholkmann et al. (2018) measured photon emissions of the dorsa of the hands with an EMCCD camera for two participants twice a day in August 2011. The first participant was measured on 4 different days, and the second participant was measured on 1 day. They found a significant parabolic correlation with time of day ($r=0.668$, $p<0.01$), with lowest emissions at noon. When comparing the pictures, it seemed there were "hotspots" at the thumbs and fingernails. The latter is consistent with previous studies with photomultiplier tubes (PMTs) who found that the fingertips are higher photon emissions than the palms and forearms (van Wijk et al., 2006). Participant 1 also seemed to have a hotspot on the lateral side of their left side, which they reported to have dry skin on the days of measurement. The diurnal rhythms were not completely compatible with the findings of Kobayashi et al. (2009) and Cifra et al. (2007) findings; however, they state that the rhythms could be phase shifted based on age of participants. None of the studies had large enough sample sizes to determine the role of age in diurnal photon rhythm.

These studies all demonstrate the importance of planning in biophoton studies because of the circadian variability in biophoton measurements (Cifra et al., 2007; Scholkman et al., 2018), therefore it would be ideal for studies with low sample sizes to measure participants at around the

same time of day. Additionally, Scholkman et al. (2018) demonstrates that consistency in the area of the hands being measured is important because that could also introduce variability into one's sample. Finally, Zhao et al. (2016)'s findings are important because they demonstrate that while there may not be gross differences in genders in biophoton emission, they did find an interaction with age, which means that studies completed with only one gender may not be generalizable to other genders.

1.3.4 Correlations between human health and hand biophoton emissions

Researchers have shown that biophotons can predict the presence of an illness such as cancer (Amano et al., 1995; Murugan et al., 2020), type 2 diabetes (Sun et al. 2017), or to monitor recovery in stroke patients (Chai et al., 2022). The following section discusses research that has been done with illnesses in human participants, such as case studies (Cohen & Popp, 2003), individuals with hemipariesis (Jung et al., 2003), individuals with a cold (Lee et al., 2004; Yang et al., 2015), and individuals with type-2 diabetes (Sun et al., 2017).

Cohen & Popp (2003) measured an individual with multiple sclerosis, who showed disparity between the right and left hand. Measured this same individual over the course of three days, on the second day they were treated with interferon, which seemed to change the hand biophoton measurements, although did not re-balance them. They also measured an individual with psoriasis who had their right arm treated with UV-A therapy. There was a discernible difference in the photon emissions from the right arm 30 minutes after treatment. The effect was also seen in a smaller degree on the left arm, even though it was not treated. They also treated the right arm with a cosmetic treatment, which showed a similar change in biophoton emission as the UV-A treatment except that it only took 5 minutes to take effect. They also discussed measuring

an individual with a liver tumour and found asymmetries between the left and right ear photon measurements.

Jung et al. (2003) took measurements of hands simultaneously with two identical PMTs from Hamamatsu. Participants waited at least one hour after coming in from outside before being measured. Each participants hands were cleaned with ethanol-soaked cotton before measurements. There were 7 hemiparesis patients, 6 males and 1 female. All subjects were right hemiparesis patients except 1. Of the patients, 4 had severe hemiparesis and had acupuncture treatment with photon measurements before and after the treatment. They also had measured the left and right hands of 20 healthy participants. All measurements were taken between 14:00-16:00 in September-November for the hemiparesis patients and in July for the healthy participants. The absolute value differences between the left and right hands were calculated for the palms and dorsa. The healthy participants had differences (M±SD) of 17.3±15.1 and 8.6±8.4, for the palms and dorsa respectively. Of the severe patients who had acupuncture treatment, before treatment they had differences of 106.2±60.5 and 111.2±61.4, for the palms and dorsa respectively. After treatment, their differences were 34.5±53.3 and 20.1±9.8, for the palms and dorsa respectively. The patients with right hemiparesis had higher photon counts in their right hand, whereas the patient with left hemiparesis had higher photon counts in the left hand. In patients with only mild symptoms of hemiparesis (little loss of muscle movement) there was little disparity between the left and right measurements.

Lee et al. (2004) used two Hamamatsu R331-05 PMTs that had range of 300 to 650nm, and a maximum response at 420nm with a quantum efficiency of 28%. They created a rim to keep participants' hands above the PMT to avoid heat transfer from the hands to the PMT. The PMTs were inside of wooden boxes with black Styrofoam and a fan to provide ventilation. Participants

were sitting down for measurements, had been out of the sun for at least an hour before, and washed their hands before and cleaned them with alcohol. They measured the palms and dorsum of 10 individuals who had a cold. When participants had their most severe cold symptoms there was a larger disparity between the left and right hand. When their symptoms improved this disparity went away. The disparity was more obvious in the measurements of the dorsum compared to the palms.

Yang et al. (2015) measured different wavelengths from the fingertips of twenty healthy volunteers (13 females, 7 males) aged 23 to 40 years old, and 10 participants with a common cold (6 female, 4 males) aged 24 to 35 years old. The latter group had all been diagnosed with a wind cold according to Traditional Chinese Medicine (TCM) diagnostic criteria. They used a PMT (Electron Tube 9235QA) with a spectral range of 290-630nm to measure the fingertips of the left and right hand for each participant. The room that the participants were measured in was maintained at 20±1°C. They used cut-off filters to measure the following ranges of wavelengths (with quantum efficiencies in brackets): 290-395nm (27%), 395-455nm (23%), 455-495nm (15%), 495-550nm (6%), 550-610nm (3%), and 610-630nm (2%). Before measurement, participants were asked to wash their hands for 5 minutes, and then they wore light-tight gloves for 30 minutes. For both the left and right hand in the healthy participants, all fingertips had their highest emission in the 495-550nm range. For the participants with a cold, there was a shift in the peak wavelength of the middle, ring, and little finger from the 495-550nm range to the 550-610nm range. This was found in both the left and right hands.

Sun et al. (2017) recruited 44 males who were pre-diabetic. They were screened by three Traditional Chinese Medicine (TCM) physicians who categorized each participant into one of three categories. These categorizations were later found to be supported urine metabolomics that

were completed by a blind and independent group of researchers (Wei et al., 2012). Biophoton measurements were taken of the palms and dorsum of both of the participants' hands with a PMT that had a spectral range of 200 to 650nm. Participants were asked to wear gloves for 30 minutes before measurement to reduce the effects of delayed luminesce. When analyzing the photon data they not only measured the average number of photons counted but they also computed variables that are related to how the photon emissions changed over the 5 minute measurement period. This resulted in a total of 40 biophoton variables, 10 for each site of measurement. In a logistic regression 16 of these variables were significant predictors of the three TCM categories. It is difficult to interpret these results due to the sheer number of variables, but it does indicate that more research should be completed on biophoton predictors in type 2 diabetes.

van Wijk et al. (2010) describe how biophotons may represent Qi, an integral component to Traditional Chinese Medicine (TCM). An analogy of the role of the acupuncture meridians with Qi is that the meridians are the sail of the boat which catch the wind (analogous to Qi). Without the sails the wind would otherwise not be seen. This is based on the ache felt by the patient and tug felt by the acupuncturist when a needle is twisted in an acupuncture point. van Wijk discusses how the wind/sail analogy applies to biophoton research as well. The photomultiplier tube (PMT) is our sail that catch the biophoton emissions that surround biological organisms. The articles in this section demonstrate the ability of biophotons to predict disease and disorder and that with more research they could become a valuable tool for physicians when assessing patients and perhaps even treatment efficacy.

1.3.5 Whole body biophoton measurements

Most of the previous articles discussed focused on taking biophoton emissions from only the hands of human participants. The following section discusses studies that have measured

biophotons from different areas of the body, including Van Wijk et al. (2006) who investigated which areas of the body produced the most photons and Vares et al., (2016) who determined the biophoton variables that were associated with the human presence.

Van Wijk et al. (2006) used both a CCD camera (CCD42-40 NIMO Back Illuminated High Performance CCD Sensor from e2v technologies, UK) and a PMT (9235 QB, selected type from Electron Tubes Limited, Ruislip, England). The CCD camera and PMT had spectral ranges of 400-900nm and 200-650nm, respectively. These devices were located in separate dark rooms, participants were asked to wait for 30 minutes either in the dark room or in a room illuminated with a red lamp to prevent the effects of delayed luminescence. The CCD camera setup was used to take biophoton measurements from one subject at different points on the head, chest, back, arms, and hands. When looking at the head and torso measurements, the photon counts were highest in the neck region and gradually decreased as you moved towards the stomach/lower back. This pattern was seen for the measurements taken on the front and back side of the participant. They also found that the middle of the chest and abdomen had higher photon counts in the middle region than the outer regions. Finally, they found that the photon counts gradually increase as you move from the elbow out to the fingers.

All of these previously mentioned findings were in one male participant measured with the CCD camera. It should also be noted that the participant was not wearing a shirt for the measurements. When they took measurements with the PMT they had 20 male participants whose ages ranged from 20 to 65 years old. In this study they measured from 12 different locations: palm and dorsal sides of both hands, forehead, left and right cheek, neck, center chest (over the heart), stomach, and left and right abdomen. They computed a total of the 12 different sites for each participant than calculated the proportion that each area contributed to the total. They found that

the total admissions from each subject ranged from 51.22 counts per second to 231.97 counts/sec. They found that the cheeks, neck, and palms contributed most to the total photon emission. The average emission values per area followed the same pattern as that for the one participant measured with the CCD camera. While this indicates that there is a common pattern for photon emission from different regions, they noted that not all individuals had recordings that followed this pattern.

To determine the deviations from the common pattern they made predictions of the expected values for each location and then took the percent difference for each participant. They found that the areas that on average had the highest deviation from the common pattern was the left and right abdomen, the forehead, and the dorsa of the left and right hand. The area that was least likely to deviate was the center chest which was over top of the heart. These results are interesting because one of the areas that was most likely to differ was the forehead which is right over top of the frontal lobe, which is the area of the brain that is the last to develop in humans and its electrical activity shows a large amount of variability (Peterson & Harmon-Jones, 2009). Second, the area that showed the least variability was the chest region over the heart, which is the organ that has consistent electrical activity between humans relative to the brain.

1.3.6 Biophoton correlations with brain activity

The following section describes research that has investigated the relationship between biophoton emissions and brain activity. Similar to previous sections the methods for each study are described in detail because they vary between studies and research groups. Most studies correlate brain activity measured with electroencephalography (EEG) with average amount of photons emitted from either the hands (Van Wijk et al., 2008) or the head (Dotta et al., 2012; Persinger et al., 2013).

van Wijk et al. (2008) took electroencephalography (EEG) and biophoton measurements of 18 healthy research colleagues. The average age of their sample was 58.7 years (with a SD of 11.8years). Participants were dark adapted for 45 minutes before measurement. For EEG, they used the P3 and P4 electrodes which measure the left and right parietal lobes, respectively. For the photon measurements, they used Hamamatsu photomultiplier tubes (PMTs) at a sample rate of 50 milliseconds with a spectral range of 300-650nm. Biophoton measurements were taken of the dorsum of the right hand only. In the analysis they correlated the mean number of photons with 1Hz frequency bins in the alpha range (7-13Hz) of the EEG recordings. They found correlations between photon emissions and the EEG 8-9Hz bin. Sometimes the correlations were positive and sometimes they were negative. In addition, the correlations were transient. This indicates there may be coherence occurring between the brain and biophotons may be similar to that of our brain and the Earth's Schumann resonance (Saroka et al., 2016).

In another EEG study, Dotta et al. (2012) measured photons from the right side of the head during white light visualization, with simultaneous EEG measurements in 3 participants. The PMT was ~15cm away from the right side of the head in the temporo-parietal region. Thinking about white light produced a significant increase in the number of photons being measured and accounted for 94% of the variance in the measurements. In the EEG experiment, there was a strong correlation (r=0.95) with global power in the left prefontal region and the number of photons measured. This effect was only present during the white light visualisation and not the resting state. The photon measurements during the light visualisation task were also negatively correlated with beta power (13-20Hz) in the right frontal lobe (r= -0.65) and right temporal (r= -0.40).

Persinger et al. (2013) exposed participants to an LED flash light to either the back of the head or the left side of the head, and then measured photons that emerged from the opposite side

of the head as well as brain activity (measured with electroencephalography). They found that when the flashlight was turned on at the left side of the head, it took about 0.66seconds for the increase in photons to be picked up on the right side of the head. And when the flashlight was turned on at the back side of the head, it took about 1.66 seconds for the increase in photons to be picked up at the front side of the head. Next they would flash the light at different frequencies and determine how it influenced brain activity, they found that flashing light at 7Hz would result in an increase of activity in the right parahippocampal gyrus within the theta frequency band (which is 4-7Hz). Finally they looked at the number of photons measured from the front of the head when they flashed the light to the back side of the head at different frequencies. They found that flashing the light between 3 and 7Hz resulted in a significant increase in photons from the front side of the head, whereas 1, 2, and 9Hz produced no difference.

In a study of rat brain activity, Kobayashi et al. (1999) measured biophotons from rat brains under different physiologic conditions. Photon measurements were taken with a two-dimensional photon counting tube (model IPD 440, Photek, UK), which had a spectral range of 350 to 900nm. Under normal conditions, they found that the photon emission intensity was positively correlated with the theta frequency band (4-7Hz) measured with EEG. They also induced oxidative stress through hyper-oxidation by varying the concentrations of inhaled oxygen. They found that this increased overall photon emission intensity, with the largest increase in the right frontal region.

Caswell et al. (2014) measured participants while they engaged in a task of intentionality. They had a total of 11 participants (8 female, 3 male) whose ages ranged from 22-42 years old. Participants were measured with either a Model 15 Photometer from SRI Instruments (Pacific Photometric Instruments) or a digital photometer Model DM009C (Senstech Ltd.), which were placed about 15 cm from the right side of the participant's head. In this experiment, participants

were asked to intend to change the output of a random event generator (REG) while photon emissions from the right side of their head were being measured. They found a significant increase in photon emissions from the right side of the head when the REG device deviated from its normal output.

These studies indicate that the strongest correlations will be found during a task that increases biophoton emissions (Dotta et al., 2012; Caswell et al., 2014). Additionally, correlations may still exist during the resting state but they are transient (van Wijk et al., 2008) and might not be found depending on the statistical analysis methods. It is also interesting to note that while Kobayashi et al. (1999) were not measuring humans, they found that oxidative stress increased photons from the right prefrontal lobe, which is the side of the head normally measured by our lab (Dotta et al., 2012).

1.3.7 Biophoton correlations with body temperature, heart rate, and cortisol

This section discusses biophoton correlations with induced physiologic changes, such as body temperature and heart rate (Laager et al., 2008) and the stress hormone, cortisol (Kobayashi et al., 2009). Nakamura & Hiramatsu (2005) demonstrated a correlation between hand temperature and photon emissions when the hands were warmed or cooled with hot or cold water bottles. Cooling the hands resulted in a decrease in photon emission, and warming the hands resulted in an increase in photon emission. The PMT they used had a spectral range of 185 to 650nm. They also demonstrated that altering the oxygen concentration around the hands altered the photon emission. When in an environment of high oxygen concentration the photon emissions increased by about 65% from baseline, and when in an environment of low oxygen concentration the photon emissions decreased by about 40% from baseline. The high and low oxygen concentration environments were induced by filling the dark box with oxygen gas or nitrogen gas, respectively.

Laager et al., (2008) measured the temperature and photon emissions from the wrists of individuals during grip strength exercises. They used two PMTs (R331-05S, Hamamatsu Photonics, Japan) with a spectral range of 300-650nm and sample rate of 100ms. The PMTs contained in a dark wooden box for their measurements, the wrists were about 40mm away from the sensor during the experiment. The room was kept at a constant temperature and humidity of 21±2°C and 33±5%, respectively. They had six male participants, two of which also had heart rate measurements taken at the same time as the wrist photon and temperature recordings. Before each experiment, participants cleaned their wrists with 60% ethanol to reduce the noise of photon emissions from microorganisms. They found that the photon emissions increased by about 30% during exercise and were correlated with an increase in temperature but once the exercise was stopped, the temperatures continued to rise while the photon emissions dropped. This indicates that photon emissions represent more than just skin temperature. Interestingly the heart rate of the individuals showed a similar rise and fall trend as the photon emissions.

Kobayashi et al. (2009) used a cryogenic charge-coupled device (CCD) camera. Pictures were taken of participants throughout the day in 20 minute intervals with the CCD camera as well as an infrared camera. They also measured oral temperature and salivary cortisol concentrations. Participants were measured at 10:00, 13:00, 16:00, 19:00 and 22:00 for 3 days. They found increased photon emissions at 16:00 and 19:00 when compared to 10:00. These changes were not seen with the infrared camera, indicating that it's not a change in body heat. They also found that cortisol concentrations decreased throughout the day and were negatively correlated with photons emissions ($r= -0.31$, $p<0.002$). It did appear that there was an increase in oral temperature over the course of the day, however there was no correlation between oral temperature and photon emissions ($r= 0.16$, $p=0.17$).

These studies demonstrate that human biophoton emission is related to induced changes in skin temperature (Nakamura & Hiramatsu, 2005; Laager et al., 2008). Kobayashi et al. (2009) did not find oral temperature was correlated with biophoton measurements, their study was different because there were no induced changes in body temperature, and they did not measure skin temperature. External temperature, which may influence skin temperature, is a fairly simple and inexpensive variable that can be monitored and included in biophoton datasets. Interestingly, Laager et al. (2008) demonstrated that while biophotons are correlated with body temperature, they also demonstrated they are related to heart rate, and therefore temperature may just be a confounding variable, and photons may have a stronger relation to blood flow. Kobayashi et al. (2009)'s findings are important because they found a diurnal pattern in biophoton emissions similar to Cifra et al. (2007). They also demonstrated a relation between cortisol and biophoton emission which is helpful in studies looking to predict mental health measurements with biophotons.

1.3.8 Experiments measuring photons of different wavelengths from humans

Is there a peak wavelength that humans emit? Answering this question is difficult due to the time-consuming nature of measuring participants at one specific wavelength at a time. Ortega-Ojeda et al. (2018) measured the left hand of a human participant with an electron-multiplying CCD (EMCCD) sensor. The measurements were taken through a liquid crystal tunable filter (LCTF), which allowed for the ability for selecting a specific wavelength to measure. The EMCCD camera was cooled with an internal fan and water bath to reduce the effect temperature has on background photon counts. The dark chamber was kept at a constant of 25°C and 45% relative humidity. Measurements were taken at 400, 450, 500, 550, 600, 650 and 700nm of the human hand and of background. The participant was described as being a 46 year old healthy person of Latin

ethnicity with light brown skin. They found that the human hand had its highest photon emissions at 500nm, which corresponds to blue-green light. Additionally, the emissions of the hand were higher than background at all wavelengths measured except 400 and 450nm, which correspond to purple-blue light.

van Wijk & van Wijk (2005) used a photomultiplier tube with a spectral range of 200-650nm and measured wavelengths between 320 to 630nm from the upper leg, forehead, left hand and right hand in one subject (male, 36 years old). The hands and forehead had a peak around 550nm (green light), whereas the upper leg had a peak around 420 to 500nm (blue-green light). They also measured these different wavelengths from the left hand of the same individual after delayed luminescence. To activate the process of delayed luminescence they exposed the hand to a daylight lamp (did not specify amount of time) and then photons were measured directly afterward. They found a similar spectral peak as the spontaneous emission measurements above which was in the range of 500-550nm (green light).

Yang et al. (2015) completed a study comparing peak frequencies measured from the fingertips of participants that were either healthy or who had a cold, as described in one of the sections above. Because their results in the healthy participants is pertinent to this section, they will be re-iterated. They measured different wavelength ranges of: 290-395nm, 395-455nm, 455-495nm, 495-550nm, 550-610nm, and 610-630nm. All fingertips for both the left and right hand had their highest emission in the 495-550nm range. This corresponds to blue-green light.

Kobayashi et al. (2016) used a CCD camera with a spectral range from 400-900nm, with a quantum efficiency of 50%. Wavelength was computed using preliminary measures taken with laser lights and monochromatic sources. Only one participant was measured in this study, who was a healthy 21 year old male with skin type III (refers to colour of skin). The participant was in the

dark room for 20 minutes to allow dark adaptation and to reduce the amount of photons emitted due to delayed luminescence. Measurements were taken of the ventral side of the right index finger. They looked at a spectral range of 450-750nm and found elevations between 600 and 650nm. This corresponds to orange light. In this study they also completed an in vitro experiment by inducing lipid peroxidation in melanin by reacting with reactive oxygen species (ROS). Reactions with ROS are thought to be one of the main sources of biophoton emissions. The reaction resulted in an increase in BPE by about a factor 10. They also looked at the spectral range of this reaction and found it had a different peak of 575nm, which is different than their in vivo measurements, and corresponds to yellow light.

A summary of these studies is provided in Table 1.4 below, with most studies finding green or blue-green light, except the latte study by Kobayashi and colleagues (2016). IT should be noted that most of the participants involved in these studies were males.

Table 1. 4 Summary of studies measuring photon wavelength's from humans

Reference	Body part measured	Measurement device	Peak wavelength (colour)	# of participants
Van Wijk & Van Wijk 2005	Forehead	PMT	550nm (green)	1
	Right and left hands	PMT	550nm (green)	1
	Right upper thigh	PMT	420-500nm (blue-green)	1
Yang et al. 2015	Fingertips	PMT	495-550nm (blue green)	10
Kobayashi et al. 2016	Ventral side of right index finger	CCD camera	600-650nm (orange)	1
Ortega-Ojeda et al. 2018	Left hand	EMCCD camera	500nm (blue-green light)	1

Measuring wavelength of light is important in biophoton research because it complements the results of studies that apply different colours light. For example, Metz et al. (2017) exposed 17 healthy participants to different colours of light and measured activity in the left and right prefrontal cortices (PFC) through fNIRS (functional near-infrared spectroscopy), they also measured mood (multidimensional mood-state questionnaire), and heart rate variability (HRV). Participants were exposed to either red (~630nm), green (~515nm), blue (~450nm), or yellow (mixed from red and green) light for 10 minutes. They found that the left PFC was more effected by the applied light than the right PFC. The left PFC was most affected by yellow light and red light and least affected by blue light, whereas the right PFC was only affect by green light and this effect was less pronounced than its effect on the left PFC. In each case, the light produced an activation. In the mood questionnaire red light was found to reduce alertness, this trend was present non-significantly in the other conditions. Heart rate was found to increase after exposure to all of the light colours, whereas HRV was found to decrease after exposure to all of the conditions. $P_{ET}CO_2$ was found to decrease after exposure to red, blue and yellow light but not green light.

Light application has also shown promise in the treatment of mental illnesses, including mild traumatic brain injuries have been treated with blue light (469nm) (Killgore et al., 2020) and red light (665nm and 819nm) (Wu et al., 2012;). Parkinson's has been treated with red light (670nm) (Al Massri et al., 2017; Liebert et al., 2021), and depression has also been treated with a different wavelength of red light (810nm) (Schiffer et al., 2009). Light emissions and application provide a novel tool for neurofeedback therapy. If we can develop a tool to measure wavelength's being emitted by an individual with specific pathologic symptoms it may provide wavelength target(s) for light therapy.

1.4 Rationale and plan for thesis

There is currently a lack of bioelectromagnetic research that has been completed in schizophrenia and psychosis. For example, the types of analyses used in the quantitative electroencephalographic (QEEG) studies described above (Zimmerman et al. 2010; van Tricht et al., 2014; Ranlund et al., 2014) are much less sophisticated than studies completed with disorders such as depression (Leuchter et al., 2010; Olbrich et al., 2014), bipolar disorder and ADHD (Barttfeld et al., 2014). Another example is photobiomodulation therapy which uses different wavelengths of light as a novel form of treatment. Currently there has been research identifying effective wavelengths for almost every major psychiatric disorder except schizophrenia (Hamblin, 2016).

Currently schizophrenia and psychosis have been studied through the lenses of clinical psychology, culture, electrophysiology, biology, and the environment. This thesis will expand two of these lenses to incorporate the bioelectromagnetics lens. The first two studies will investigate electromagnetic environmental variables, background photon counts and the Earth's electromagnetic field. In the first study we will measure background photon counts of different wavelengths to determine what other geophysical variables they might be related to.

In the second study we will investigate the robust schizophrenia and latitude relationship. However, instead of using prevalence rates of schizophrenia, we will measure psychosis symptoms in the general population to determine if they demonstrate the same positive correlations with latitude. In addition to looking for relationships with latitude like in previous studies, we will also include the X, Y, Z, and Resultant components of the Earth's electromagnetic field. The latter analysis will allow us to compare the variance that the electromagnetic variables explain compared to the geographical location variables (i.e., latitude and longitude).

In the third study we will expand on the type of electrophysiological tools used in the study by including biophoton measurements. Similarly to the second study, we will not be recruiting individuals with schizophrenia or psychosis, instead we will be measuring psychosis symptoms in the general population. We will use principles from the discipline of biofield physiology, meaning we will measure quantitative electroencephalography (QEEG), biophoton emissions (BPEs) and electrocardiography (ECG). Psychosis symptoms will be measured with standardized questionnaires used in clinical psychology. The focus of the analysis will be on the psychosis symptoms; however, we will focus a portion of the analysis on depression as it is much more prevalent among the general population.

Integrating the novel tool of BPEs with the more traditional tools of QEEG and ECG will give us a more holistic view of the individual. Often because the symptoms of mental health disturbances arise from the brain, it becomes the central focus of study. However, there is more than enough evidence in the current Chapter to indicate that schizophrenia and psychoses are whole body disorders. Measuring biophotons from the hands gives us a unique opportunity to investigate factors such as skin, and perhaps even blood, oxidative stress with a non-invasive method that doesn't require much time from the participants.

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Chapter 2.0: Relationship between background photons and geophysical variables

2.1 Abstract

Background photons are particles of light measured in complete darkness. They have previously been shown to be related to global earthquake activity. However, it is unknown what other geophysical variables they might be correlated with. This study set out to understand any seasonal changes in background photons that were a function of wavelength. Background photons were measured with a photomultiplier tube (PMT) in complete darkness. Between July 2019 and July 2020 there were a total of 328 measurements taken with no filter, and 255 measurements taken with one of the following wavelength filters: 370nm, 420nm, 500nm, 620nm, 790nm, and 950nm. Background photons were moderately correlated to outside temperature which seemed to be a result of lack of indoor temperature control during the spring and summer months, with measurements from the 950nm filter being the most sensitive. There were no correlations between background photons and geomagnetic or Sunspot activity. Spectral analysis determined there to be 7-, 14-, and 21-day cycles in the background photon counts.

2.2 Introduction

The influence that weather has on human disease was discussed as early as 400 B.C.E. by Hippocrates in *On Airs, Waters, and Places* (Adams, 2009). Hippocrates discusses how the warm and cold winds will affect human health differently depending on geographical location, an idea that continues to be researched (Schultz et al., 2020). Geophysical weather variables, such as geomagnetic storm activity and barometric pressure are correlated with changes in mood (Persinger & Levesque, 1983) and increased suicide rates (Tada et al., 2014).

A recent study demonstrated that background photon counts were correlated with neural activity in the frontal lobe of human participants (Neufeld, 2022). Previously background photon counts have been associated with earthquakes (Persinger et al., 2012) and in the preparation of physics experiments in the SNOLAB (Singhrao, 2015). Background photon counts are measured in a room that is completely dark. A previous study demonstrated a circannular rhythm in background photon counts, with highest values around the Fall equinox, and lowest values around the Spring equinox (Persinger, 2015).

Photons represent a small portion of the total electromagnetic spectrum. The wavelength of a photon can be determined by the following equation,

$$\lambda = hc/E$$

Where λ represent wavelength, h is Planck's constant of 6.63×10^{-34} J/s, c is the speed of light (3×10^{8} m/s), and E is the energy of the photon (Hallett et al., 1977). From this equation it is evident that the wavelength and energy of a photon are inversely proportionate to each other, meaning the shorter the wavelength of a photon, the higher it's energy. Therefore, a photon that falls within the UV light spectrum would have more energy that a photon of infrared light. Wavelengths of light represent different colours on the visible spectrum, as described in Table 2.1 (Volchko, 2022).

Table 2. 1 Corresponding colours of different wavelengths of photons

Label	Wavelength
Ultraviolet	300 to 400nm
Violet	400 to 420nm
Indigo	420 to 440nm
Blue	440 to 490nm
Green	490 to 570nm
Yellow	570 to 585nm
Orange	585 to 620nm
Red	620 to 780nm
Infrared	780 to 1,000,000nm

Before further investigating the relation between background photons and behaviour, a study was completed to determine which environmental variables can predict daily fluctuations in background photon measurements. Background photon counts were measured regularly over the course of one year to determine if and what other geophysical variables they were related to. Photons were recorded with different wavelength filters to determine if this impacted the relationship with geophysical variables.

2.3 Methods

2.3.1 Photomultiplier tube

Photon measurements were taken with a photomultiplier tube (PMT). The PMT was model DM0089C (Sens-Tech Ltd.), which is most sensitive to photons of wavelengths between 280 to 630nm. The PMT was housed in a black-painted wooden box that was covered in black towels. 1-minute recordings were taken at a sampling rate of 50 Hz. Figure 2.1 shows a sample measurement.

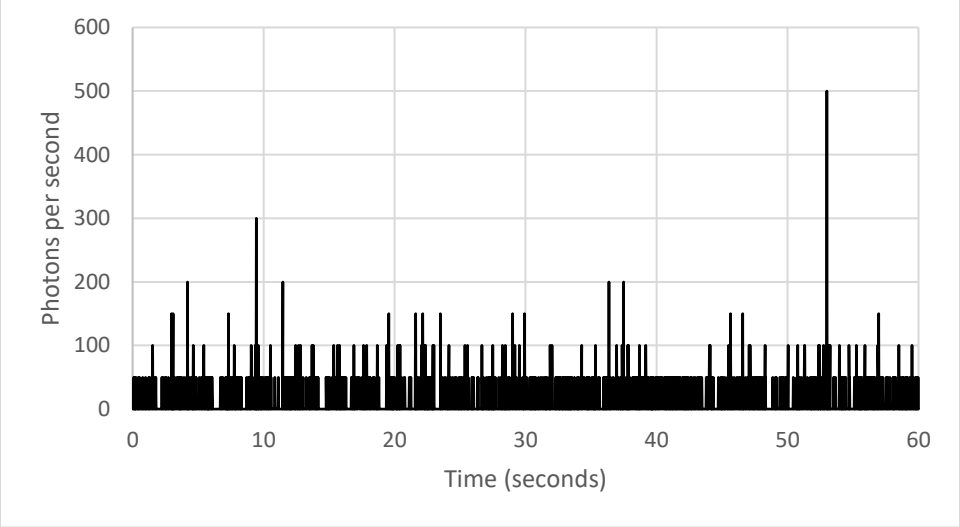

Figure 2. 1 Sample 1 minute recording of background photon counts.

2.3.2 Wavelength filters

Wavelength filters were purchased from Chroma Technology Corporation. There were 6 wavelength filters used, which corresponded to the wavelengths: 370nm, 420nm, 500nm, 620nm, 790nm, and 950nm. The filters have a range of ±5nm from their target wavelength, for example, the 370nm measures wavelengths of light from 365 to 375nm.

2.3.3 Procedure

From July 2019 to July 2020, background photon measurements were taken as many days as possible with the wavelength filters (370nm, 420nm, 500nm, 620nm, 790nm, and 950nm) and a baseline with no filter. In total, there were 328 measurements taken with no filter, and 255 measurements taken with the filters. Up until March 21st, 2020, measurements were taken in a darkroom on the 7th floor of the Science I building on the Laurentian University campus. After March 21st, the PMT was moved to a closet in my personal residence (in Sudbury, ON) to accommodate COVID-19 lockdown restrictions. Neither room had air conditioning, only heating.

2.3.4 Geophysical variables

The geophysical variables that were entered into this dataset were: temperature outside the building, humidity, windspeed, sunspot counts, Ap index, and moon illumination. Temperature, humidity, and windspeed were all obtained from measurements retrieved from the Sudbury Airport located on the Government of Canada webpage (https://climate.weather.gc.ca/index_e.html).

The sunspot counts and Ap index values were retrieved from the Low Resolution OMNI (LRO) dataset (King & Papitashvili, 2005). The OMNI data were obtained from the GSFC

(Goddard Space Flight Center)/SPDF (Space Physics Data Facility) OMNIWeb interface at https://omniweb.gsfc.nasa.gov.

The moon illumination data was retrieved from NASA's Scientific Visualization Studio (SVS) (https://svs.gsfc.nasa.gov/Gallery/moonphase.html). Moon illumination refers to the surface area of the moon that is reflecting sunlight towards Earth. For example, the full moon would have a value of 100%, while the new moon would have a value of 0%.

2.3.5 Statistical Analyses

The values were z-scored because the move in March 2020 of the PMT resulted in a large drop in photon measurements. For correlational analyses we used Pearson R and Spearman rho. All analyses were complete with IBM SPSS Statistics Version 28.

2.4 Results

2.4.1 Correlational Analyses

Background photon counts in all wavelengths showed the highest counts and greatest variability in the summer months (Figure 2.2).

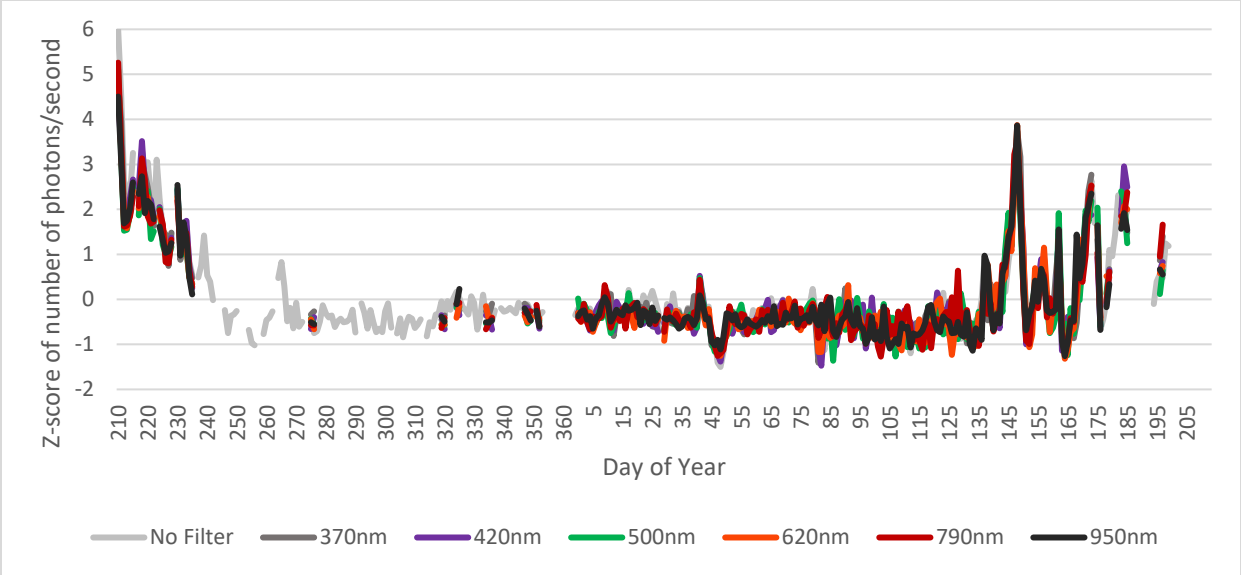

Figure 2. 2 Changes in background photon measurements from July 29, 2019 to July 31, 2020

Bivariate correlation analyses revealed that the No Filter baseline measurements were correlated with daily average temperature ($r=0.572$, $p<0.001$; $rho=0.469$, $p<0.001$) and daily average windspeed ($r= -0.181$, $p=0.001$; $rho= -0.173$, $p=0.002$), but not humidity ($p>0.05$), time of day ($p>0.05$), Ap index ($p>0.05$), or illumination of the moon ($p>0.05$). Similar correlations were found with the wavelength filters (Table 2.2).

Table 2. 2. Bivariate correlations between background photon counts of different wavelength filters with geophysical variables.

	No Filter	**370nm**	**420nm**	**500nm**	**620nm**	**790nm**	**950nm**
Outside Temperature	r=.572*	r=.655*	r=.655*	r=.626*	r=.653*	r=.617*	r=.617*
Humidity	r=.012	r=.002	r=.034	r=.036	r=.043	r=.035	r=.030
Wind Speed	r= -.181*	r= -.204*	r= -.218*	r= -.223*	r= -.204*	r= -.200*	r= -.213*
Time of Day	r=.035	r=.003	r=.019	r=.062	r=.059	r=.031	r=.038

Ap Index	r= -.043	r=.011	r=.009	r=.005	r=.019	r=.038	r=.051
Sunspots	r= -.055	r= -.073	r= -.053	r= -.055	r= -.081	r= -.090	r= -.069
Illumination of the moon	r= -.108	r= -.090	r= -.049	r= -.128	r= -.125	r= -.106	r= -.153

*Correlations were significant in Pearson's r and Spearman's rho

Figure 2.2 indicates that there may be seasonal variations in background photons. To determine how reliable the correlation was between outside temperature and photon counts, correlations were complete for each month separately, to see if the correlation would persist. Correlations are presented in Table 2.3, where correlations were significant in the summer and spring months, but not fall or winter. Because the rooms where the measurements were taken did not have air conditioning, they were not temperature controlled during the summer and spring months, indicating that background photon counts do in fact vary with outside temperatures. When this analysis was repeated with wind speeds, there were no significant correlations for any of the months (Table 2.4) indicating that these correlations were being driven by changes in temperature. And in fact, when a partial correlation is complete with the entire year, between no filter photon counts and wind speed while controlling for temperature, the correlation is not significant (r=-.069, p=.283).

When comparing wavelength filters in the month-to-month correlational data, the 370nm and 950nm filters were the most sensitive to temperature as they had significant correlations more months than the other filters. The 370nm filter falls in the UV spectrum, and the 950nm filter falls in the infrared range which also corresponds to heat.

Table 2. 3 Bivariate correlations between daily outside temperatures and background photons in the 12 calendar months

	No Filter	370nm	420nm	500nm	620nm	790nm	950nm
August	r=.671*	r=.679*	r=.742*	r=.724*	r=.683*	r=.762*	r=.696*
September	r=.408	r=.288	r=.259	r=.185	r=.341	r=.373	r=.122
October	r=.383*	r=.484	r=.180	r=.300	r=.699*	r=.359	r=.806*
November	r=.250	r=.122	r=.227	r=.351	r=.324	r=.374	r=.378
December	r=.279	r=.739*	r=.486	r=.443	r=.256	r=.454	r=.688
January	r=.281	r=-.202	r=-.173	r=.024	r=-.019	r=.065	r=-.302
February	r=.159	r=-.009	r=.094	r=.202	r=.013	r=.109	r=.019
March	r=.114	r=.394	r=.470*	r=.324	r=.360	r=.261	r=.045
April	r=.212	r=.380*	r=.058	r=.186	r=.091	r=-.214	r=.633*
May	r=.656*	r=.680*	r=.631*	r=.688*	r=.708*	r=.612*	r=.692*
June	r=.658*	r=.650*	r=.668*	r=.543*	r=.595*	r=.680*	r=.610*
July	r=.518*	r=.526*	r=.557*	r=.351	r=.544*	r=.478	r=.560*

*Correlations were significant in Pearson's r and Spearman's rho

Table 2. 4 Bivariate correlations between daily outside wind speeds and background photons in the 12 calendar months

	No Filter	370nm	420nm	500nm	620nm	790nm	950nm
August	r=-.260	r=-.022	r=-.066	r=-.024	r=.104	r=-.021	r=.086
September	r=.157	r=.082	r=.583	r=.197	r=.277	r=.334	r=.249
October	r=.106	r=-.110	r=.088	r=-.033	r=.049	r=.076	r=-.219
November	r=-.217	r=-.445	r=.174	r=-.272	r=-.258	r=-.287	r=-.236
December	r=.016	r=.020	r=-.293	r=-.398	r=.049	r=-.348	r=-.350
January	r=-.053	r=.040	r=-.384	r=-.286	r=-.149	r=.047	r=.035
February	r=.113	r=-.157	r=-.104	r=-.076	r=-.047	r=-.256	r=-.027
March	r=.146	r=.142	r=.156	r=.202	r=.242	r=.173	r=.380
April	r=-.084	r=-.017	r=.016	r=-.285	r=.092	r=.313	r=-.163
May	r=.042	r=.187	r=.142	r=.192	r=.113	r=.135	r=.049
June	r=-.240	r=-.145	r=-.221	r=-.062	r=-.167	r=-.151	r=-.160
July	r=.266	r=.353	r=.368	r=.226	r=.340	r=.418	r=.340

*Correlations were significant in Pearson's r and Spearman's rho

2.4.2 Spectral Analyses

Spectral analyses were complete on daily photon measurements that were taken between December 31st, 2019 and June 21st, 2020. Peaks indicate periodicities in photon counts, peaks were found at 1 day, 2 days, 3 days, 7 days, 14 days, and 21 days (Figure 2.3).

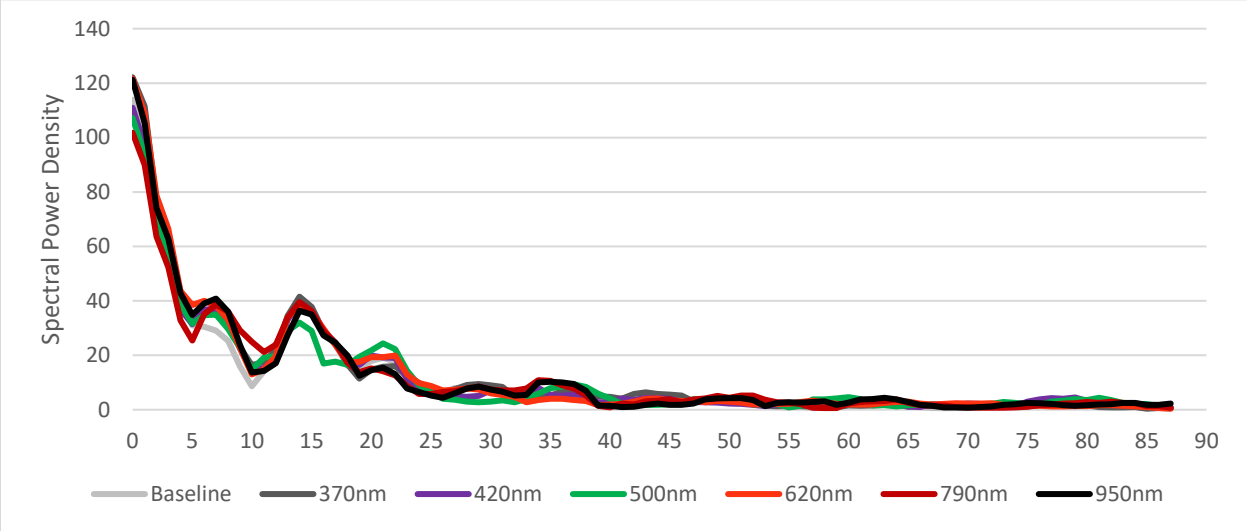

Figure 2. 3 Cycles of change in background photon counts of different wavelengths between December 31st, 2019 and June 21st, 2020.

2.5 Discussion

The results of this study demonstrate that the geophysical variable that background photons are most correlated with temperature. Initially, it appeared they were also related to windspeed; however, partial correlation analyses revealed this was due to a confound with temperature changing simultaneously with windspeed. When the year of measurement was broken down into months, photon counts were correlated with outside temperature during the late spring and summer months, which is the time of year the temperature would have been changing inside as well. This is since the building used for photon measurements had heating but did not have air conditioning.

Background photons measured with PMTs are sensitive to temperature, the higher the temperature of the room, the higher the background photon counts (Nikkel et al., 2007). We did not find any correlations between background photon counts and changes in Sunspot numbers or geomagnetic storm indices, as measured by the Ap index.

The spectral analysis revealed peaks at 1, 2, 3, 7, 14, and 21 days, which indicates that in addition to the seasonal differences, there were also intrinsic cycles in photon counts. Interestingly 7, 14, and 21 periodicities within the data which has been previously found in the photons measured from human hands (Cohen & Popp, 2003). The source of the 7 day periodicities in the photon counts is not known, other research has noted that the moon also has 7 day (Tessaro, 2019) and 14 day cycles (Foster & Roenneberg, 2008) that relate to human behaviours. The 7-day cycle is also present in tidal movements (Bede, 1999). Given the large change in background photons correlated with earthquake activity (Persinger et al., 2012), the 7-day cycle we found here indicates that background photons may be sensitive to moon-tidal interactions.

One of the main conclusions from this study indicated the importance of controlling for temperature changes because of their influence on the background counts of the PMT. More evidence for this come from when comparing to a previous study that measured background photons over the course of year found dissimilar results (Persinger, 2015). The latter study was completed in the basement of a temperature-controlled building.

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Chapter 3.0: Correlates between symptoms of psychosis with geographical location and Earth's electromagnetic field

3.1 Abstract

The incidence and prevalence rates of schizophrenia are positively correlated with latitude. This has also been found with multiple sclerosis and seasonal affective disorder. It is currently unknown if schizophrenia shares a similar mechanism to these other disorders, or if there's something unique to schizophrenia that also varies by latitude. The current study measured personality symptoms of psychosis, depression, anxiety, hypomania, and spirituality worldwide by administering online questionnaires through Facebook advertising. Symptoms of psychosis were negatively correlated with latitude in males and females, and positively correlated with longitude in females. Multiple regression analysis produced an equation with latitude only as a predictor for males, and the X-component and Resultant as predictors for females. These results suggest that the relationship between schizophrenia and latitude is not present, but in fact opposite, in symptoms of psychosis.

3.2 Introduction

Multiple studies have found positive correlations between schizophrenia and latitude (Templer et al., 1990; Templer et al., 1991; Saha et al., 2006; Kinney et al., 2009). Latitude has also been positively correlated with multiple sclerosis (Kinoshita et al., 2017; Mekers, 2017), seasonal affective disorder (Rosen et al., 1990), and major depression episodes in Canada (Patten et al., 2017). In Mekers' (2017) study of multiple sclerosis, they found that the Earth's electromagnetic field was able to explain more variance in changes in multiple sclerosis on a local

scale compared to latitude. This demonstrates the importance for studies on latitude and human behaviour to consider the other confounding environmental variables, such as background magnetic field intensity.

As you move away from the equator and toward the poles there is a decrease in annual temperature and increase in background magnetic field intensity. At the poles, you have stronger magnetic fields because the flux lines are closer together which means more charged particles moving per unit area (Delobeau, 1971). These flux lines represent one of the three components of Earth's magnet field: the X, Y, and Z components. The X-component runs North-South, there is also a Y-component of the horizontal field that runs East-West. Finally, there is a vertical component that is referred to as Z and it runs perpendicular to the surface of the Earth.

The present study was designed to investigate the relationship of background photon measurements as well background magnetic field characteristics with symptoms of psychosis, depression, anxiety, and other personality factors. If symptoms of psychoses showed a similar pattern with latitude as schizophrenia, then it may help elucidate potential mechanisms for the pattern present in schizophrenia. All questionnaires were administered online to a worldwide audience through Facebook advertising.

3.3 Methods

3.3.1 Participants

Participants were recruited with Facebook Advertising between January 2021 and July 2021. Facebook advertisements were purchased through the social media platform and were advertised worldwide. This study was approved by the Laurentian University Research Ethics

Board (File No. 6020762). There was a total of 496 (252 females, 236 males, 6 non-binary, and 2 did not specify gender) participants recruited.

3.3.2 Psychological Questionnaires

Participants were asked demographic questions such as date of birth, gender, the name of the city where they were born, the name of the city where they currently live, and the total number of cities and countries they've lived in. If the assumption is that the background electromagnetic field can affect your development, then the time spent in that field could be critical. For that reason, participants were also asked the amount of time spent in their current and native cities. The location data was used to calculate latitude and longitude values, which was then used to find magnetic field intensity values.

All questionnaires relating to personality and mental health were obtained from the International Personality Item Pool (IPIP; https://ipip.ori.org/index.htm) (Goldberg et al., 2006). The IPIP is designed to give free and full access to a range of personality tests to all scientists. We used the Depression, Anxiety, Unusual Experiences, and Unusual Beliefs scales from the CAT-PD (Computerized adaptive assessment of personality disorder), and we also used the Mood intensity/change scale from a hypomanic personality scale (HPS) (Eckblad & Chapman, 1986). The CAT-PD was created to evaluate personality disorders in the Diagnostic and Statistical Model of Mental Disorders (DSM) (Simms et al., 2011; Thimm, 2022). Research has demonstrated that the Unusual Beliefs and Unusual Experiences scales from the CAT-PD are correlated to measurements of Schizotypy from the PID-5 (Personality Inventory for the DSM-5) and FFSI-SF (Five Factor Schizotypy Inventory-Short Form) (Moorman & Samuel, 2018).

The Hypomanic Personality Scale (HPS) was developed to screen for individuals who are at a high risk of developing bipolar disorder (Eckblad & Chapman, 1986). Individuals who score high on the HPS have been found to have an increase in genetic polymorphisms on the COMT gene, which is involved with regulating dopamine levels (Johnson et al., 2015). For personality we used the Spirituality/Religiosity from the Values in Action (VIA) scale (Peterson & Seligman, 2004). A list of the questions in each scale can be found below in Table 3.1. Valence indicates if the response to each statement would increase or decrease a participant's score for its respective scale.

For all personality and mental health questions, participants were asked if/how often they had experienced each statement by selecting one of the following options: "Never in my life", "Not in the past two weeks", "One time in the past two weeks", "Two time in the past two weeks", or "Three or more times in the past two weeks". These responses were assigned a value from 1 to 5 and summed for each scale.

Table 3. 1 Statements in each scale that evaluated mental health and personality characteristics

Scale	Valence	Statement
Unusual Experiences	+	Feel at times that I have left my body and am somehow outside my physical self.
	+	See strange figures or visions when nothing is really there.
	+	Hear voices talking about me when nobody is really there.
	+	Have had the feeling that I might not be human.
	+	Have had the feeling that I was someone else.
	+	Sometimes think the TV is talking directly to me.
	+	I feel as if my body, or a part of it, has disappeared.
Unusual Beliefs	+	Believe I have supernatural powers.
	+	Can see into the future.
	+	Am able to read the minds of others.
	+	Have the power to cast spells on others.

	+	Can control objects with my mind.
	+	Use magic to ward off bad thoughts about me.
	+	Can predict the outcome of events.
Depression	+	Tend to feel very hopeless.
	+	Am sad most of the time.
	+	Generally focus on the negative side of things.
	+	Dislike myself.
	-	Look at the bright side of life.
	-	Rarely feel depressed.
Anxiety	+	Feel my anxiety overwhelms me.
	+	Am nervous or tense most of the time.
	+	Panic easily.
	+	Feel that my worry and anxiety is out of control.
	+	Am generally a fearful person.
	+	Am easily startled.
	-	Rarely worry.
Mood Intensity/ Change	+	Get into moods where I feel very speeded up and irritable.
	+	Tend to feel happy and irritable at the same time.
	+	Am a person whose moods go up and down easily.
	+	Find that my thoughts are racing.
	+	Am often so restless that it is impossible for me to sit still.
	+	Feel emotions with extreme intensity.
	+	Am considered to be kind of eccentric.
	-	Think that my moods don't change more than most people's do.
	-	Am usually in an average sort of mood, not too high and not too low.
	-	Understand the reasons when I feel very excited or happy.
	-	Can slow myself down when I want to.
Spirituality/ Religiosity	+	Believe in a universal power or God.
	+	Am a spiritual person.
	+	Keep my faith even during hard times.
	+	Have spent at least 30 minutes in the last 24 hours in prayer or meditation.
	+	Am who I am because of my faith.
	+	Believe that each person has a purpose in life.
	+	Know that my beliefs [in a God] make my life important.
	-	Do not practice any religion.
	-	Do not believe in a universal power or a God.

3.3.3 Statistical Analysis

Of the 496 questionnaire responses, there were 140 responses that missed statement(s) in the mental health and personality scales. When there was a missing statement, the scale that statement corresponded to was not calculated for that participant so that it would not be included in any analyses.

Males and females were analyzed separately in the analysis of latitude, longitude, and background magnetic field variables. This is because of previous differences found between males and females in the correlations between schizophrenia prevalence rates and latitude (Saha et al., 2006). Additionally, not all countries show the typical pattern of increased prevalence of schizophrenia in males (Premarajan et al., 1993; Chien et al., 2004). Gender comparisons were made of demographics, latitude, longitude, and psychological scales for two reasons. First, to confirm previously found gender differences in psychological scales. And second, to determine if there were any confounding variables between males and females. All analyses were complete with IBM SPSS Statistics Version 28.

3.4 Results

3.4.1 Gender comparisons of demographics

A univariate ANOVA revealed no significant difference in age between the female, male and non-binary participants [$F(2, 445)=3.00$, $p=.051$] (Table 3.2). Chi-squared analysis showed that there was a gender difference in the number of years participants lived in their native city [$\chi^2(10)=18.8$, $p=.044$] (Table 3.2). There was no significant between genders in the number of cities [$\chi^2(20)=19.3$, $p=.50$] or countries [$\chi^2(12)=20.0$, $p=.066$] (Table 3.2) that participants lived in.

Table 3. 2 Gender comparisons of demographics of participants

Demographic		Female (%)	Male (%)	Non-binary (%)
N		252 (50.8)	236 (47.6)	6 (1.2)
Age Mean (±SD)		36.8 (±14.7)	38.2 (±13.5)	24.5 (±5.9)
Years in native city	Never moved away	76 (30.9)	63 (36.9)	2 (33.3)
	< 1 year	25 (10.2)	10 (4.3)	0 (0)
	1-2 years	16 (6.5)	6 (2.6)	1 (16.7)
	3-5 years	12 (4.9)	18 (7.7)	0 (0)
	6-10 years	13 (5.3)	21 (9.0)	0 (0)
	> 10 years	104 (42.3)	116 (49.6)	3 (50)
Number of cities lived in	1	65 (26.2)	43 (18.3)	2 (33.3)
	2	53 (21.4)	40 (17.0)	1 (16.7)
	3	46 (18.5)	64 (27.2)	1 (16.7)
	4	30 (12.1)	27 (11.5)	1 (16.7)
	5	20 (8.1)	22 (9.4)	0 (0)
	6	10 (4.0)	10 (4.3)	1 (16.7)
	7	6 (2.4)	7 (3.0)	0 (0)
	8	4 (1.6)	7 (3.0)	0 (0)
	9	4 (1.6)	0 (0)	0 (0)
	10	3 (1.2)	3 (1.3)	0 (0)
	>10	7 (2.8)	12 (5.1)	0 (0)
Number of countries lived in	1	143 (59.8)	132 (58.4)	4 (66.7)
	2	59 (24.7)	40 (17.7)	2 (33.3)
	3	15 (6.3)	38 (16.8)	0 (0)
	4	8 (3.3)	5 (2.2)	0 (0)
	5	7 (2.9)	9 (4.0)	0 (0)
	6	6 (2.5)	1 (0.4)	0 (0)
	>10	1 (0.4)	1 (0.4)	0 (0)

A multivariate ANOVA was used to determine that there were significant differences between genders in the latitude [$F(2,474)=6.23$, $p=.002$; $p\eta^2=.026$] and longitude [$F(2,474)=4.26$, $p=.015$; $p\eta^2=.018$] of participant's native city. There were also significant differences in the latitude [$F(2,474)=8.17$, $p<.001$; $p\eta^2=.034$] and longitude [$F(2,474)=4.79$, $p=.009$; $p\eta^2=.020$] of participant's current city. Tukey's HSD post hoc analyses revealed for the latitude of their native city, non-binary participants (M=46.6, SD=2.4) were significantly higher than females (M=18.0, SD=25.7) and males (M=15.0, SD=19.4) ($p<.05$). There were no significant differences between males and females ($p>.05$). For the longitude of where participants were born, non-binary (M=-49.3, SD=56.1) participants were significantly lower than males (M=36.4, SD=77.5) and females (M=22.0, SD=90.7) ($p<.05$), there were no significant differences between males and females ($p>.05$). For the latitude of their current city, non-binary (M=49.4, SD=7.1) were significantly higher than females (M=18.9, SD=25.1) and males (M=14.9, SD=19.1) ($p<.05$), there were no significant differences between males and females ($p>.05$). For the longitude of their current city, males (M=38.8, SD=76.7) were significantly higher than non-binary participants (M=-44.6, SD=52.4) ($p<.05$), and there was no significant difference between females (M=21.4, SD=92.1) and non-binary participants or males ($p>.05$). A visual representation of the geographic spread of participants can be seen in Figure 3.1. These results indicate that it was primarily the non-binary individuals who were driving the significant gender differences of geographic location.

Figure 3. 1 Map of locations for the Facebook survey responses of where participants were born (red markers) and where they currently live (purple markers).

3.4.2 Correlations between psychological scales

Bivariate correlations between the psychological scales were completed to determine how the scales were related to each other. Table 3.3 demonstrates that Unusual Experiences was positively correlated with Unusual Beliefs (r=.486, p<.001; rho=.556, p<.001), Depression (r=.273, p<.001; rho=.273, p<.001), Anxiety (r=.392, p<.001; rho=.427, p<.001), and Mood Intensity/Change (r=.494, p<.001; rho=.530, p<.001). Unusual Beliefs was positively correlated with Mood Intensity/Change (r=.222, p<.001; rho=.245, p<.001) and not correlated with Depression (r=-.128, p=.006; rho=-.086, p=.067) or Anxiety (r=.039, p=.406; rho=.079, p=.094). Depression was positively correlated with Anxiety (r=.687, p<.001; rho=.652, p<.001) and Mood Intensity/Change (r=.541, p<.001; rho=.509, p<.001). Anxiety was positively correlated with Mood Intensity/Change (r=.635, p<.001; rho=.627, p<.001).

Additionally, bivariate correlations revealed that Spirituality/Religiosity was positively correlated with Unusual Experiences (r=.173, p<.001; rho=.202, p<.001) and Unusual Beliefs (r=.410, p<.001; rho=.423, p<.001), negatively correlated with Depression (r=-.371, p<.001; rho=-.365, p<.001) and Anxiety (r=-.130, p=.006; rho=-.107, p=.023), and not correlated with Mood intensity/change (r=.066, p=.166; rho=.083, p=.080). These results indicate that while Unique Experiences and Unique beliefs are moderately correlated with each other, Unusual Experiences is positively correlated with Depression and Anxiety, while Unusual Beliefs is not.

Table 3. 3 Bivariate correlations within the mental health and personality indices used in this study

	Unusual Beliefs	**Depression**	**Anxiety**	**Mood Intensity/ Change**	**Spirituality/ Religiosity**

Unusual Experiences	r=.486*	r=.273*	r=.392*	r=.494*	r=.173*
Unusual Beliefs		r=-.128	r=.039	r=.222*	r=.410*
Depression			r=.687*	r=.541*	r=-.371*
Anxiety				r=.635*	r=-.130*
Mood Intensity/ Change					r=.066

*Correlations are significant with Pearson's r and Spearman's rho correlation analyses

3.4.3 Gender and continent differences in the psychological scales

Gender comparisons were completed to confirm previous consistent findings of increased anxiety and depression scores in females (Eaton et al., 2012). Non-binary participants were included in the analyses; however, there were only 5 individuals so their results should be interpreted with caution. A multivariate analysis revealed there was a significant effect of gender for scores in Unusual Beliefs [$F(3,387)=4.14$, $p=.007$; $p\eta^2=.032$], Depression [$F(3,387)=4.85$, $p=.003$; $p\eta^2=.038$], Anxiety [$F(3,387)=7.57$ $p<.001$; $p\eta^2=.058$], and Mood Intensity/Change [$F(3,387)=2.91$, $p=.035$; $p\eta^2=.023$]. There was no significant difference between the genders for Unusual Experiences [$F(3,387)=1.59$, $p=.191$] or Spirituality/Religiosity [$F(3,387)=1.42$, $p=.236$] (Figures 3.2 and 3.3).

Tukey's HSD post hoc analyses determined that Unusual Belief scores were significantly higher in males (M=14.6, SD=5.6) compared to females (M=12.1, SD=5.3) ($p<.05$), and neither were different from non-binary participants (M=13.4, SD=8.9) ($p>.05$). Depression scores were significantly higher in non-binary participants (M=8.4, SD=6.7) compared to females (M=4.0, SD=5.3), and females were significantly higher than males (M=2.3, SD=4.4) ($p<.05$). Anxiety scores were higher in non-binary participants (M=22.6, SD=2.3) compared to females (M=14.2, SD=6.2), and females were significantly higher than males (M=12.0, SD=5.4) ($p<.05$). Finally,

Mood Intensity/Change scores were not significantly different in non-binary individuals (M=13.4, SD=8.1), females (M=7.6, SD=6.9), or males (M=6.8, SD=6.2) ($p>.05$).

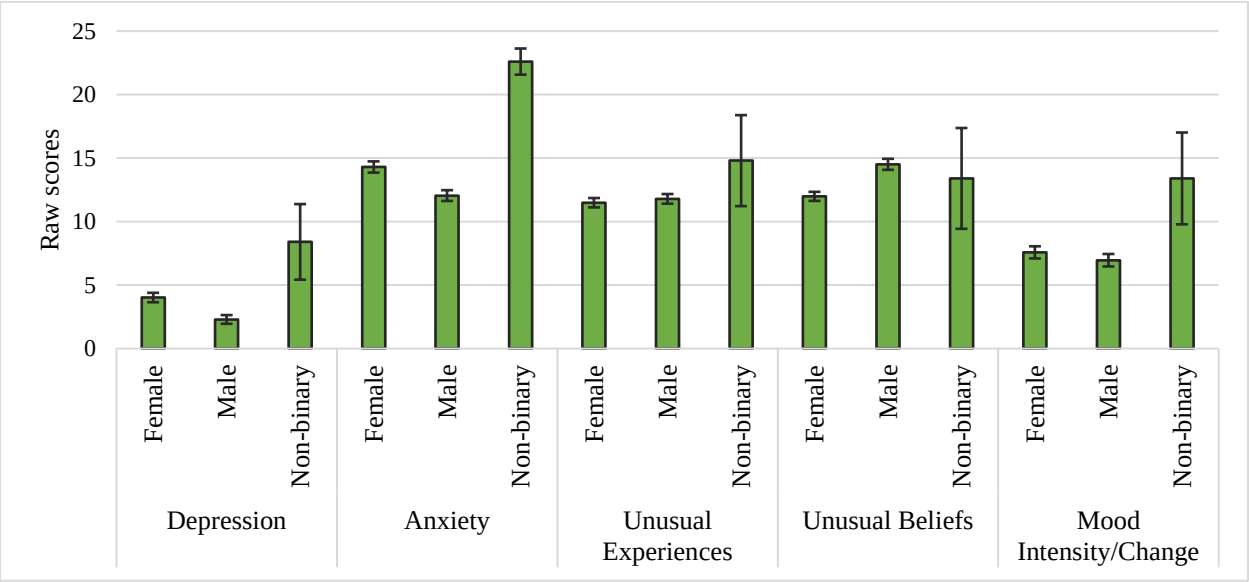

Figure 3. 2 Differences in mental health indices between males, females, and non-binary individuals. Error bars represent the standard error of the mean (SEM).

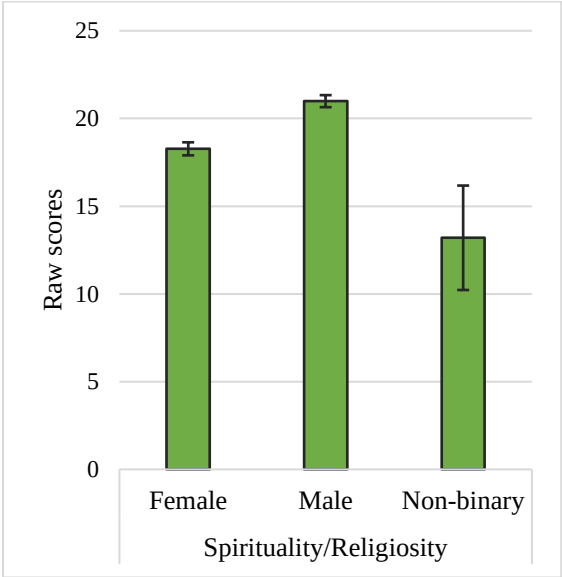

Figure 3. 3 Differences in Spirituality/Religiosity between males, females, and non-binary individuals. Error bars represent the standard error of the mean (SEM).

Multivariate analysis also revealed there were significant differences between the continents participants were born in for Unusual Experiences [$F(5,387)=8.68$, $p<.001$; $p\eta^2=.104$; Figure 3.4], Unusual Beliefs [$F(5,387)=12.1$, $p<.001$; $p\eta^2=.140$; Figure 3.5], Mood Intensity/Change [$F(5,387)=5.51$, $p<.001$; $p\eta^2=.069$; Figure 3.8], and Spirituality/Religiosity [$F(5,387)=15.2$, $p<.001$; $p\eta^2=.170$; Figure 3.9]. There were no differences in Depression [$F(5,387)=1.88$, $p=.098$; Figure 3.6] or Anxiety [$F(5,387)=1.07$, $p=.376$; Figure 3.7]. There were no significant interactions between continent and gender ($p>.05$).

Tukey's HSD post hoc analysis revealed that in Unusual Experiences, North America ($M=9.8$, $SD=4.0$) and Europe ($M=9.0$, $SD=2.8$) were significantly lower than South America ($M=13.3$, $SD=6.3$), Asia ($M=12.8$, $SD=4.8$), Africa ($M=12.8$, $SD=6.1$), and Oceania ($M=12.4$, $SD=5.4$) ($p<.05$). There were no differences between North America and Europe ($p>.05$) or between South America, Asia, Africa, and Oceania ($p>.05$). In Unusual Beliefs, North America ($M=10.0$, $SD=4.3$) and Europe ($M=10.3$, $SD=3.6$) were significantly lower than South America ($M=13.9$, $SD=5.7$), Asia ($M=15.1$, $SD=5.8$), Africa ($M=15.9$, $SD=5.4$), and Oceania ($M=14.0$, $SD=5.5$) ($p<.05$). There were no differences between North America and Europe ($p>.05$). In Mood Intensity/Change, Europe ($M=4.5$, $SD=6.7$) was significantly lower than South America ($M=8.6$, $SD=7.9$) and Asia ($M=8.9$, $SD=6.3$) ($p<.05$). There were no other differences ($p>.05$). In Spirituality/Religiosity, North America ($M=13.1$, $SD=9.3$) and Europe ($M=13.5$, $SD=9.9$) were significantly lower than South America ($M=21.8$, $SD=11.6$), Asia ($M=20.9$, $SD=8.0$), Africa ($M=24.7$, $SD=8.4$), and Oceania ($M=23.8$, $SD=8.3$) ($p<.05$). There were no other differences ($p>.05$). In this analysis Unique Experiences, Unique Beliefs, and Spirituality/Religiosity all show

the same pattern, decreased scores in North America and Europe compared to all other continents. Depression and Anxiety show very different patterns compared to each other.

Next, an analysis of covariance (ANCOVA) was completed to determine if the number of countries or cities a participant lived were significant covariates in the analyses completed above comparing continent differences in the scores on the psychological scales. The number of countries someone lived was a significant covariant for Unusual Beliefs [$F(1,363)=6.89$, $p=.009$] and Spirituality/Religiosity [$F(1,363)=5.54$, $p=.019$]. Both remained significantly different between the continents [Unusual Beliefs: $F(1,363)=16.1$, $p<.001$; Spirituality/Religiosity: $F(1,363)=20.6$, $p<.001$]. The number of cities someone lived in were not a significant covariate for any of the subscales ($p>.05$).

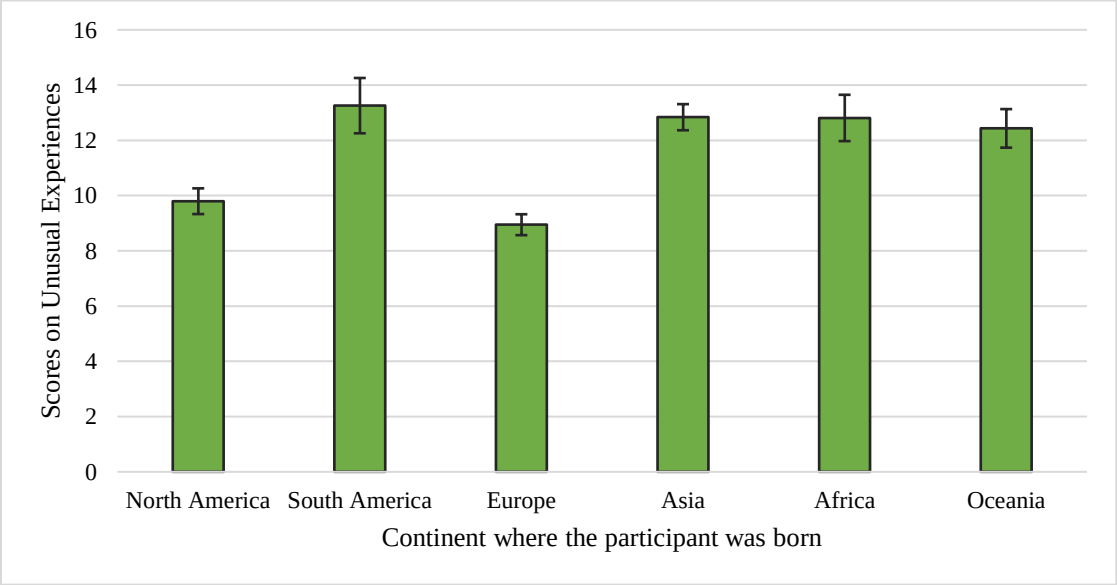

Figure 3. 4 Comparisons between continent of birth in scores of Unusual Experiences. Error bars represent standard error of the mean (SEM).

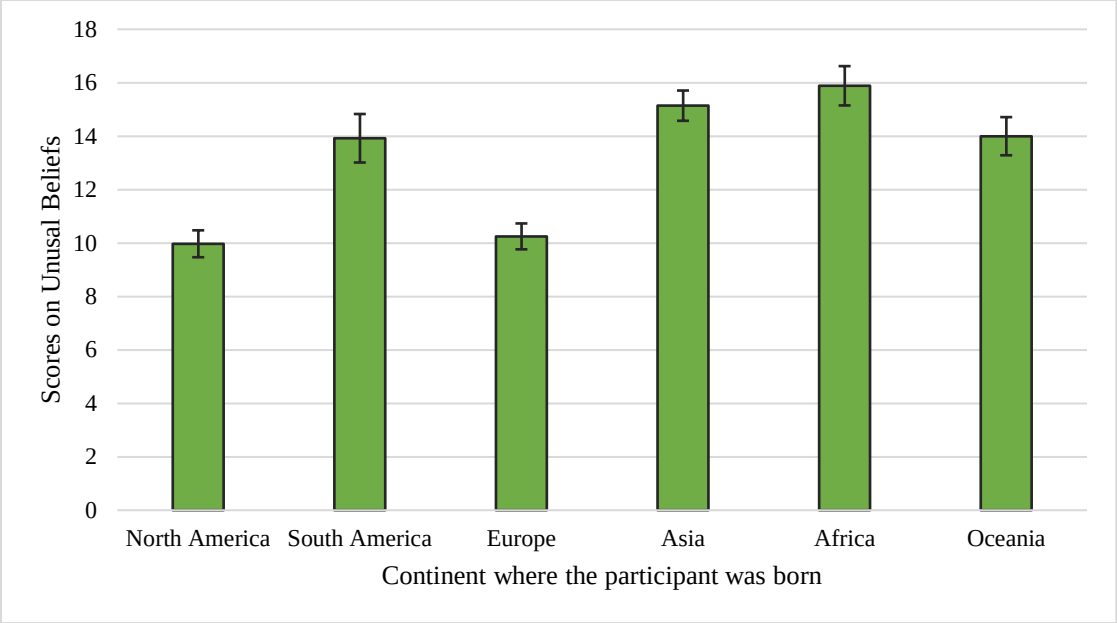

Figure 3. 5 Comparisons between continent of birth in scores of Unusual Beliefs. Error bars represent standard error of the mean (SEM).

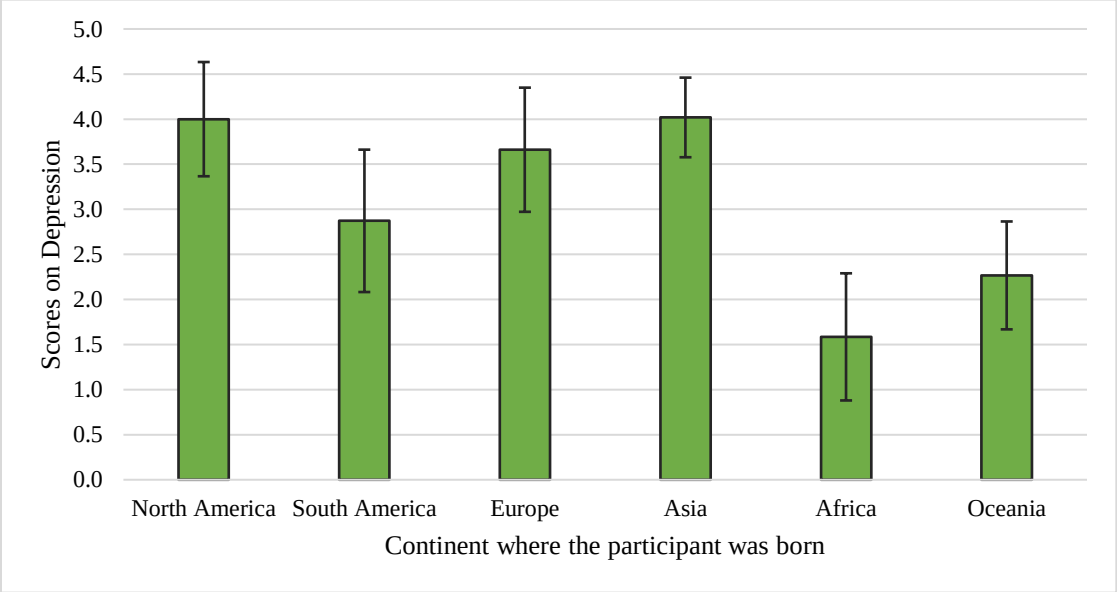

Figure 3. 6 Comparisons between continent of birth in scores of Depression. Error bars represent standard error of the mean (SEM).

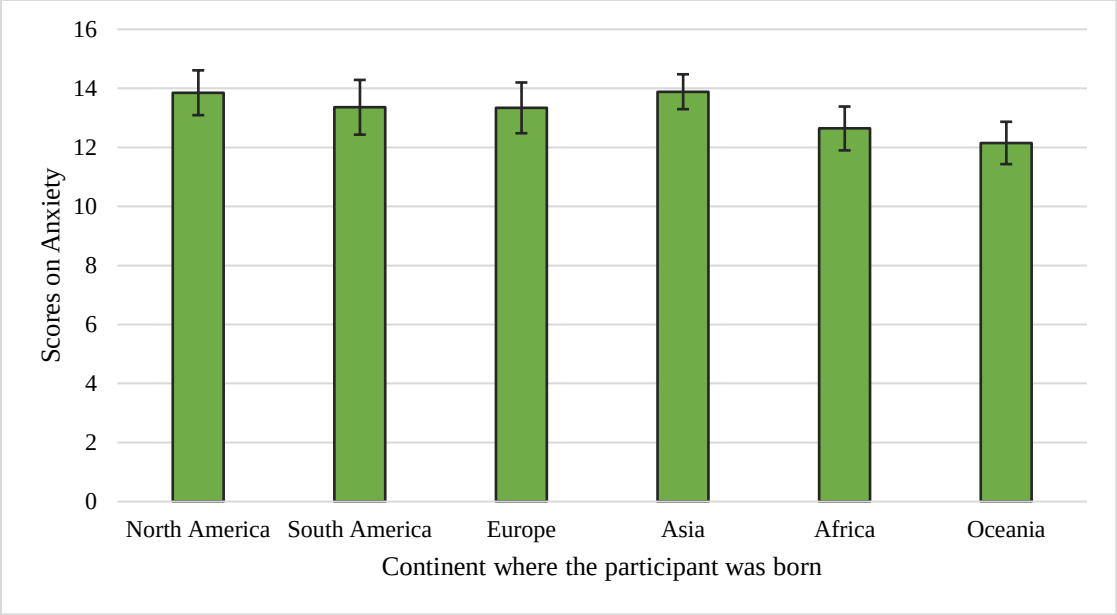

Figure 3. 7 Comparisons between continent of birth in scores of Anxiety. Error bars represent standard error of the mean (SEM).

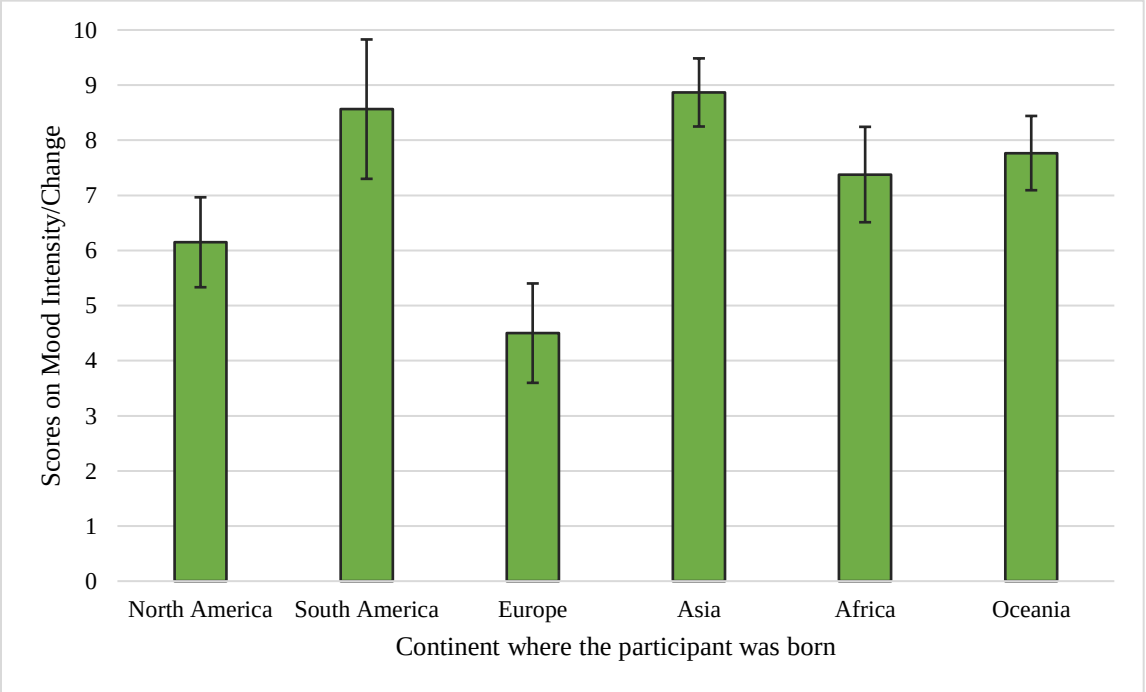

Figure 3. 8 Comparisons between continent of birth in scores of Mood Intensity/Change in the Facebook dataset. Error bars represent standard error of the mean (SEM).

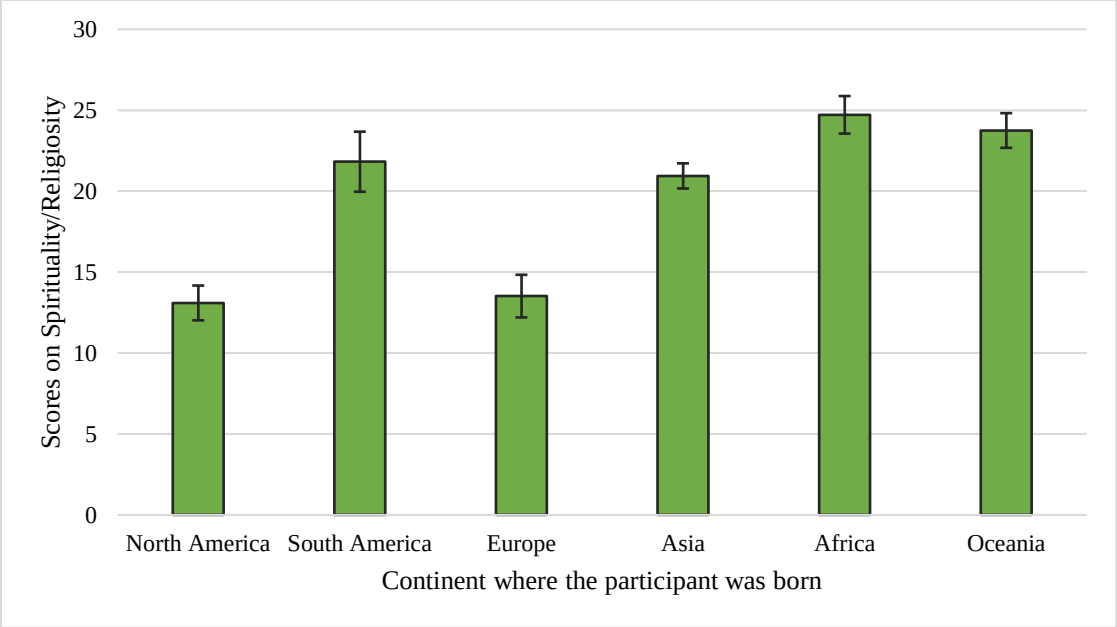

Figure 3. 9 Comparisons between continent of birth in scores of Spirituality/Religiosity. Error bars represent standard error of the mean (SEM).

3.4.5 Predicting psychological scales with latitude, longitude, and background magnetic field variables

Correlation analyses were completed separately for males and females because gender has previously shown to interact with correlations between schizophrenia and latitude (Saha et al., 2006). Latitude, longitude, and the X-component, Y-component, Z-component, and Resultant values were used from the city where the participant was born. Absolute values were used for latitude so that the Northern and Southern Hemispheres could be analyzed together (Table 3.4).

Unique Experiences was significantly correlated with: latitude in females ($r=-.307$, $p<.001$; $rho=-.294$, $p<.001$) and males ($r=-.232$, $p<.001$; $rho=-.238$, $p<.001$), longitude in females only ($r=.267$, $p<.001$; $rho=.314$, $p<.001$), the X-component in females only ($r=.355$, $p<.001$; $rho=.382$, $p<.001$), the Z-component in females ($r=-.255$, $p<.001$; $rho=-.317$, $p<.001$) and males ($r=-.186$,

p=.009; rho=-.222, p<.001), and the resultant in females (r=-.252, p<.001; rho=-.226, p<.001) and males (r=-.172, p=.015; rho=-.177, p=.013). Unique beliefs was significantly correlated with: latitude in females (r=-.300, p<.001; rho=-.311, p<.001) and males (r=-.279, p<.001; rho=-.288, p<.001), longitude in females only (r=.308, p<.001; rho=.375, p<.001), the X-component in females (r=.397, p<.001; rho=.446, p<.001) and males (r=.166, p=.022; rho=.149, p=.040), the Z-component in females (r=-.251, p<.001; rho=-.315, p<.001) and males (r=-.266, p<.001; rho=-.274, p<.001), and the resultant in females (r=-.228, p<.001; rho=-.247, p<.001) and males (r=-.266, p<.001; rho=-.253, p<.001). Depression was significantly correlated with latitude in females (r=.130, p=.045; rho=.145, p=.026). Anxiety had no significant correlations.

Additionally, Mood Intensity/Change was significantly correlated with latitude in females (r=-.174, p=.009; rho=-.148, p=.026) and males (r=-.154, p=.025; rho=-.158, p=.021), longitude in females only (r=.137, p=.039; rho=.169, p=.011), the X-component in females only (r=.174, p=.012; rho=.173, p=.013), and the Z-component in females (r=-.144, p=.040; rho=-.173, p=.013) and males (r=-.146, p=.045; rho=-.165, p=.023). Spirituality was significantly correlated with latitude in females (r=-.479, p<.001; rho=-.458, p<.001) and males (r=-.412, p<.001; rho=-.400, p<.001), longitude in females only (r=.320, p<.001; rho=.323, p<.001), the X-component in females (r=.389, p<.001; rho=.356, p<.001), the Z-component in females (r=-.405, p<.001; rho=-.433, p<.001) and males (r=-.366, p<.001; rho=-.376, p<.001), and the resultant in females (r=-.328, p<.001; rho=-.352, p<.001) and males (r=-.343, p<.001; rho=-.369, p<.001).

Table 3. 4 Bivariate correlations between the psychological scales with absolute latitude, longitude, and background magnetic field components from the city participants were born in

	Absolute	**Longitude**	**X**	**Y**	**Z**	**R**

		Latitude					
Unique Experiences	W	r=-.270*	r=.177*	r=.246*	r=-.038	r=-.214*	r=-.210*
	F	r=-.307*	r=.267*	r=.355*	r=.065	r=-.255*	r=-.252*
	M	r=-.232*	r=.084	r=.120	r=-.131	r=-.186*	r=-.172*
Unique Beliefs	W	r=-.328*	r=.195*	r=.321*	r=-.036	r=-.256*	r=-.273*
	F	r=-.300*	r=.308*	r=.397*	r=.121	r=-.251*	r=-.228*
	M	r=-.279*	r=.053	r=.166*	r=-.116	r=-.266*	r=-.266*
Depression	W	r=.166*	r=-.043	r=-.112	r=-.012	r=.093	r=.078
	F	r=.130*	r=-.108	r=-.105	r=.099	r=.097	r=.010
	M	r=.114	r=.106	r=-.009	r=.044	r=.027	r=.073
Anxiety	W	r=.089	r=-.024	r=-.081	r=-.096	r=.087	r=.055
	F	r=.081	r=-.023	r=.002	r=-.121	r=.104	r=.027
	M	r=-.040	r=.049	r=-.032	r=-.131	r=-.029	r=-.065
Mood Intensity/ Change	W	r=-.131*	r=.094*	r=.103*	r=-.027	r=-.119*	r=-.111
	F	r=-.174*	r=.137*	r=.174*	r=.005	r=-.144*	r=-.157
	M	r=-.154*	r=.093	r=.093	r=-.070	r=-.146*	r=-.135
Spirituality/ Religiosity	W	r=-.465*	r=.240*	r=.312*	r=-.001	r=-.396*	r=-.349*
	F	r=-.479*	r=.320*	r=.389*	r=.108	r=-.405*	r=-.328*
	M	r=-.412*	r=.110	r=.148	r=-.106	r=-.366*	r=-.343*

*Correlations were significant with Pearson's r and Spearman's rho at $p<.05$ (rho values are reported in the text); W, Whole sample; F, Females; M, Males; X, X-component; Y, Y-component; Z, Z-component; R, Resultant

3.4.6 Regression predictions of average scores of Unusual Beliefs and Unusual Experiences in females and males

Multiple regressions were complete on an average score of Unusual Beliefs and Unusual Experiences because they showed near-identical trends in their patterns of correlations with latitude, longitude, and the background magnetic field differences. However, because there were gender differences in the pattern of correlations, multiple regressions were completed separately for males and females.

In females, a multiple regression demonstrated the X-component and Resultant were able to significantly predict the average scores of Unusual Beliefs and Unusual Experiences

[F(2,217)=29.6, p<.001]. The following equation was able to predict 21.6% of the variance: **Average (Unusual Beliefs and Unusual Experiences)** = **X-component** (2.1e-4) – **Resultant** (9.5e-5) + 10.2. The X-component and Resultant had Beta values of .390 and -.179, respectively.

In males, a multiple regression demonstrated that the absolute latitude values were able to significantly predict the average scores of Unusual Beliefs and Unusual Experiences [F(1,203)=25.8, p<.001]. The following equation was able to predict 11.3% of the variance: **Average (Unusual Beliefs and Unusual Experiences)** = **Absolute latitude** (-.110) + 15.7. Absolute latitude had a Beta value of -.336.

3.5 Discussion

This study took advantage of the World Wide Web to collect survey from participants all around the globe to determine geographical variations in mental health and personality, with a focus on symptoms of psychosis. Consistent with previous studies, females and non-binary participants had higher scores in depression and anxiety than males (Eaton et al., 2012; Reisner et al., 2016). First-episode psychosis and schizophrenia are typically more common in males than females (Ochoa et al., 2012); however, in Schizotypal personality disorder, odd belief symptoms are higher in females compared to males (Bora & Baysan Arabaci, 2009), this contradicts our findings of increased Unusual Beliefs in males.

Previous studies have found schizophrenia to be positively correlated with latitude in the Northern Hemisphere, which led to the hypothesis that personality symptoms of schizophrenia would demonstrate the same trend if there was a shared mechanism. However, these results point to the opposite, psychosis symptoms, as measured through the Unusual Experiences and Unusual Beliefs scales from the CAT-PD, were negatively correlated with latitude in both females and

males and were also positively correlated with longitude in females only. Our findings seem to be less about the aspects of psychoses relating to schizophrenia, and more about the aspects of psychosis relating to personality because the Spirituality/Religiosity scale showed the same pattern with latitude, longitude and gender as stated above. This was not surprising as the Spirituality/Religiosity scale was significantly positively correlated with both the Unusual Experiences and Unusual Beliefs scales. Interestingly, the Mood Intensity/Change showed the same pattern with latitude, longitude and gender as well, but was only positively correlated with Unusual Experiences and Unusual Beliefs and was not correlated with Spirituality/Religiosity.

When the analysis was taken further to consider the background magnetic field components, we found a general trend that the scales that were correlated with latitude were likely to also be correlated with the Z-component and the Resultant magnetic field strengths, this was unsurprising as it is well known that these are both correlated with latitude themselves. What was surprising were the correlations in females between the Unusual Experiences, Unusual Beliefs, Mood Intensity/Change, and Spirituality/Religiosity scales with the X-component. The X-component does vary with latitude, so it was expected to find this relationship in males and females. However, this was likely due to the relationship with longitude that was only found in females. While it is not known why the correlations with longitude were only found with females, two previous studies in China (Chien et al., 2004) and India (Premarajan et al., 1993) found roughly equal prevalence rates of schizophrenia in males and females. These studies contradict the typical pattern of increased prevalence of schizophrenia in males (McGrath et al., 2008). If schizophrenia occurs more in women in eastern countries, then there could be more personality traits of psychosis in non-clinical females.

It was surprising that our correlations with psychosis symptoms and latitude were the opposite of those found with schizophrenia. The underlying mechanism for the relationship between schizophrenia and latitude may not be unique to schizophrenia, especially as the same relationship is seen with major depression and multiple sclerosis. It was also interesting to see in the results that depression was positively correlated with latitude in females and the whole sample, as this was expected given the positive relationship between depression and latitude (Rosen et al., 1990; Patten et al., 2017). It is interesting to note that females with major depression are more likely to have vitamin D deficiency compared to males (Zhu et al., 2022), and another study found that vitamin D deficiency was a risk factor for depression in both males and females, the association was stronger in females (Milaneschi et al., 2010).

The mechanism underlying the results found in this study may be partially culture based. When the psychological scales were compared between continents, Unique Experiences, Unique Beliefs, Mood Intensity/Change, and Spirituality/Religiosity all show the same pattern, decreased scores in North America and Europe compared to South America, Africa, Asia, and Oceania. This indicates that these differences may be driven by culture. It is interesting to note that Ghana and India, where the auditory hallucination content is much less violent and negative than in America (Luhrmann et al., 2015), would have higher scores on Unique Experiences and Unique Beliefs, based on these results. It is possible that if the general population experiences more of these symptoms, then there is less stigma towards those with schizophrenia.

The results of this study indicate that there is something unique about the geographical spread of schizophrenia compared to psychosis symptoms. In the multiple regression analysis, we found gender differences in the variables that entered the equation to predict the averages of Unusual Beliefs and Unusual Experiences. In males, it was the absolute latitude values, whereas

in females it was the X-component and Resultant. This result is interesting as it was previously found that latitude was a better predictor of schizophrenia in males compared to females (Saha et al., 2006). These results highlight the importance of considering gender differences when investigating factors that predict mental health symptoms.

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Chapter 4.0: Biophotons from the hands are associated with personality and personality disorder spectrum scores

4.1 Abstract

Biophoton emissions from the hands have shown promise indicating the health state of humans in studies of the common cold, type 2 diabetes, and multiple sclerosis (Cohen & Popp, 2003; Yang et al., 2015; Sun et al., 2017). Biophotons present an opportunity to discover biomarkers and additional targets for which novel treatments can be based on. The current study examined the ability of biophotons to predict spectrum scores of personality and personality disorders as measured with the Millon Clinical Multiaxial Inventory (MCMI-IV) and the Temperament Character Inventory (TCI-R). There was a total of 53 participants that were recruited from the university and general population in Sudbury, Ontario, Canada. Biophoton emissions (BPEs), quantitative electroencephalography (QEEG) and electroencephalography (ECG) were measured to determine their capacities of predicting scales of the psychological questionnaires. ECG measurements were used to calculate commonly used heart rate variability (HRV) measures. Our findings indicate that biophotons are a gender sensitive tool in predicting scores on the MCMI-IV and TCI-R, with a greater number of predictions in females compared to males. The mean number of biophoton emissions (BPEs) from the hands in females were positively correlated to Schizoid, Avoidant, Dependent, Generalized Anxiety, Persistent Depression, and Major Depression scales of the MCMI-IV, and to the Harm Avoidance scale of the TCI-R. Mean BPE was also negatively correlated in females to the Histrionic and Turbulent scales of the MCMI-IV. In males, the mean difference in hand BPE was correlated to the Histrionic scale of the MCMI-IV and the Novelty Seeking and Cooperativeness scales of the TCI-R. Meanwhile, the absolute

difference between the BPE from the left and right hands in females was positively correlated to the Dependent, Schizotypal, Paranoid, and Schizophrenic Spectrum scores. Additionally, a regression combining BPE and QEEG measures demonstrated that the left hand BPE and a factor representing beta activity in the left insula, left temporal lobe, and bilateral parietal/occipital lobes could predict Depression/Somatic symptom scores. These results demonstrate that biophoton measurements are a potential source of biomarkers for psychosis-related personality disorders and depression.

4.2 Introduction

There is a need for novel and innovative technology in the prediction of psychosis because psychotic episodes are not only traumatic (Lu et al., 2017), but also result in irreversible tissue loss in the brain (Ziermans et al., 2012). Current neuroimaging methods of MRI and PET are not sensitive, and function best at detecting areas in which brain tissue has already degenerated (DeLisi et al., 2006). Alternatively, measuring components of an individual's bioelectromagnetic field (i.e., biophoton emissions, electroencephalography, or heart rate variability) may detect energetic changes that precede the degenerative process. Biomarkers from these methods offer an opportunity to increase the diversity of a clinician's toolkit that can be used to identify individuals who are susceptible of having a psychotic episode and/or developing psychosis.

Biophoton measurements are non-invasive, relatively inexpensive, and do not require much time from participants. There have been two findings of biophotons that are relevant to the current study. (1) Biophotons are a by-product of oxidative stress in the mitochondria (Kobayashi et al., 1999), which make them an optimal biomarker for health. And (2) In the past few decades, biophotons measured from the hands have been demonstrated to be a potential diagnostic tool for multiple sclerosis (Cohen & Popp, 2003), the common cold (Lee et al., 2004; Yang et al., 2015),

and type-2 diabetes (Sun et al., 2017). In the first point, increased metabolism in the mitochondria of the cell results in an excess of free electrons and reactive oxygen species (ROS) which causes oxidative stress and increased biophotons. This mechanism has been demonstrated in humans (Hagens et al., 2008), an in vitro model (Fan et al., 2022), and plants (Pónya & Somfalvi-Tóth, 2022). It is also important to note that oxidative stress is related to psychopathology, where anxiety, depression, and psychosis are all found to occur with increased oxidative stress in the blood (Rammal et al., 2008; Bajpaj et al., 2014; Fraguas et al., 2019). From these findings we can hypothesize that individuals who score higher on scales relating to depression, anxiety, and psychosis will have higher biophoton emissions.

In the second point, a disparity of biophotons measured from the hands have been found to be related to severity of multiple sclerosis in a case study (Cohen & Popp, 2003) and the common cold in multiple participants (Lee et al., 2004). However unlike in (1), there is no straightforward mechanism for these findings. Articles discussing the phenomenon relate it back to Traditional Chinese Medicine (TCM) and an imbalance of Yin-Yang energy represented by the left and right hand, respectively (Lee et al., 2004). In TCM, an imbalance in Yin-Yang energy is said to occur in most, if not all, pathological conditions (Sun et al., 2003). These results lead us to the hypothesis that we would expect a greater disparity between the hand BPE in individuals who scored higher on the scales relating to psychosis and schizophrenia.

Two different psychological questionnaires that have been used in the study of psychosis and schizophrenia are: the Temperament Character Inventory (TCI-R), and Millon Clinical Multiaxial Inventory (MCMI-IV). The MCMI-IV is a biopsychosocial theory of psychopathology that contains dimensions were used to describe personality coping patterns that corresponded to official personality disorders found in the DSM-III (Millon, 2011), including Schizotypal and

Schizophrenic Spectrum. The TCI-R is a psychobiological model, its scales of Harm Avoidance, Cooperativeness, and Self-Transcendence are predictive of individuals who either have or are at risk for psychosis (Smith et al., 2008; Fresán et al., 2015).

As a first step in the direction of biophoton diagnostics in the mental health field, we have designed and carried out a study to determine if there was a relationship between biophotons measured from the hands and psychopathology. As stated above, there are no established mechanisms that can explain the phenomenon of a disparity of biophotons between hands. For this reason, we chose to include quantitative electroencephalography (QEEG) and electrocardiography (ECG) measurements, tools that have an established physiological basis. Additionally, both QEEG and ECG have previously demonstrated predictive ability of individuals who are at risk for psychosis (Zimmermann et al., 2010; van Tricht et al., 2014; Benjamin et al., 2020). The first step of this analysis were bivariate correlations to determine if biophotons from the hands were related to the personality and psychopathology scales, as this has not been investigated before. Next factor analyses were used to reduce the number of variables for both the psychopathology and QEEG measures. This was followed up by a multiple regression that combined biophoton and QEEG variables to create a prediction model of a psychopathological factor.

4.3 Methods

4.3.1 Participants

Participants were recruited in Sudbury, ON, Canada through courses at Laurentian University and through word of mouth. Of the 67 participants who were recruited, 57 completed the electrophysiological measures and the online questionnaires (28 females, 24 males, 1 non-binary person, 3 did not report gender). This study was approved by the Laurentian University Research Ethics Board (File No. 6021102).

4.3.2 Quantitative Electroencephalography measurements

The brain and heart activity were measured with quantitative electroencephalography and electrocardiography, respectively. The quantitative electroencephalograph (QEEG) is the digital version of the electroencephalograph and has been used extensively in research to understand the brain's electrophysiological activity. We used a Lenovo laptop computer to record the data with WinEEG software (version 2.127.98). A Mitsar amplifier (Model#M201B) was used to amplify the small signals coming off the brain that were measured with the sensor cap (Electro-cap International Inc., Part#'s E1-M & E1-L). The sensor cap took recordings from 19 different sites (Fp1, Fp2, F3, Fz, F4, F7, F8, C3, Cz, C4, T3, T4, T5, T6, P3, Pz, P4, O1, and O2) spaced around the area of the scalp which encompassed the brain. Applications of the EEG consists of placing a cap on the participant's head, attaching reference sensor clips to the ear, and applying Electro-gel (Electro-cap International Inc., Part#E10) to each of the 19 sensors. Spatial application of the sensors is in accordance with the 10-20 International Standard of Electrode Placement (Khazi et al., 2012). Data was artefact corrected in WinEEG, extracted into LORETA software (version 20221229) and then filtered between 1.5 and 40Hz. Standardized LORETA (Low Resolution Electromagnetic Tomography) analysis software was used to compute the log transformed relative activity scores of 84 different Brodmann areas within the classical frequency bands: delta (1.5-4 Hz), theta (4-7 Hz), alpha1 (7-10 Hz), alpha2 (10-13 Hz), beta-1 (13-20 Hz), beta-2 (20-25 Hz), beta-3 (25-30 Hz) and gamma (30-40 Hz). The Brodmann areas were averaged into the frontal, temporal, parietal, occipital, limbic, or insular lobes for the left or right hemisphere.

4.3.3 Electrocardiography measurements

The electrocardiograph (ECG) used H135SG Covidien disposable surface electrode pads (Cardinal Health) which connected and recorded on the same amplifier and computer as the QEEG system described above. In this study, we used a single lead system that can generate heart rate variability (HRV) scores. This involved using Lead II from the 12-lead clinical standard, Lead II is the most common method that's used in ECG studies of HRV (Jeyhani et al., 2019). The Lead II setup involved placing sensors on the right wrist, left ankle, and right ankle (Kumar et al., 2020). Kumar et al. (2020) have a pictorial representation of where the sensors are placed. A sample of ECG recording can be seen below in Figure 4.1, with labels for the R peaks on each heart beat and the representation of the interbeat interval (IBI).

Figure 4. 1 Interbeat interval (IBI) and R-peak example in a raw ECG recording in WinEEG

HRV analysis was completed with the software called ARTiiFACT. A full description and instructions of ARTiiFACT have been published by the creator (Kaufmann et al., 2011). The ARTiiFACT software is able to compute the following variables: mean HR (heart rate), mean R-R interval (in msec), standard deviation of IBIs (SDNN), root mean square of successive IBIs

(RMSSD), very low frequency (VLF) component (<.04 Hz), low frequency (LF) component (0.04 – 0.15 Hz), high frequency (HF) component (0.15 – 0.4 Hz), and ratio of LF/HF. The frequency components are computed from a Fast Fourier Transform analysis that's complete on the IBIs over time (Figure 4.2). Figure 4.2 shows a screenshot of the program, where the change in IBIs over the recording is shown at the top, and the bottom graph demonstrates the spectral power density in the VLF, LF and HF components.

In this study we chose to analyze the mean heart rate because a previous study demonstrated it may be related to biophotons (Laager et al., 2008). We also included SDNN and RMSSD because they are measures of HRV which we were interested in. Finally, we also analyzed the LF component, HF component, and the LF:HF ratio because they've shown gender differences (Kunikullaya U et al., 2021) and to be related to mental health (Perna et al., 2020).

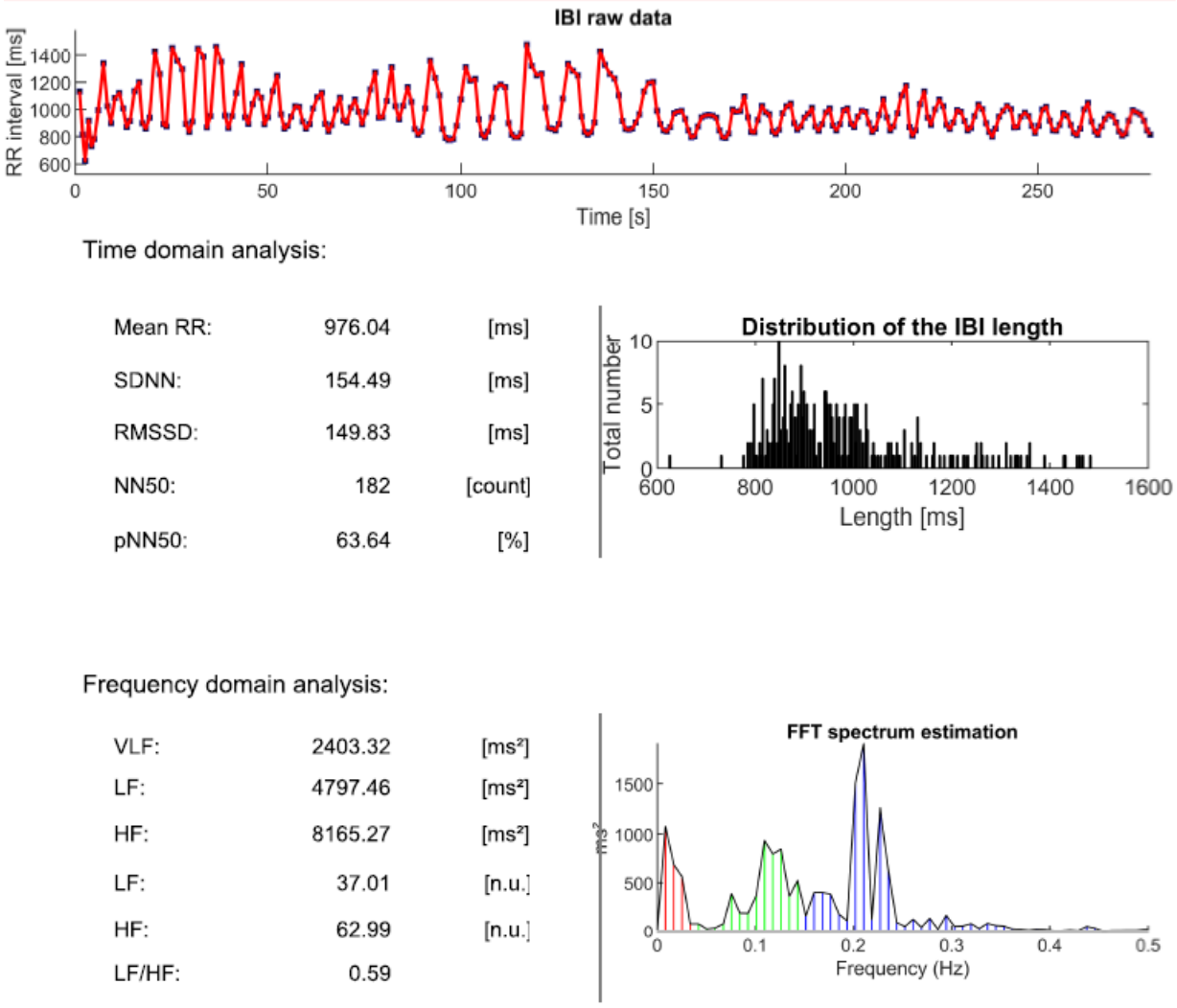

Figure 4. 2 Screenshot of the ARTiiFACT program that was used to compute HRV (heart rate variability) variables. The change in IBIs (interbeat intervals) is shown in the graph at the top, and the bottom graph demonstrates the results of a Fast Fourier Transform on the IBIs which computes spectral power density values of the VLF (very low frequency) component in red, LF (low frequency) component in green, and the HF (high frequency) component in blue.

4.3.4 Biophoton measurements

Biophoton measurements were taken with a photomultiplier tube (PMT). The PMT was model DM0090C (Sens-Tech Ltd.), which records photons of wavelengths between 280 to 850nm and had a peak quantum efficiency at ~460nm. The peak quantum efficiency refers to the wavelength that the PMT is the most sensitive to. The biophoton measurements were taken of the dorsal side of the right and left hands in a small wooden box in the acoustic chamber in complete darkness. The wooden box was covered in multiple layers of black cotton towels. The software was programmed to record biophoton measurements at a sample rate of 50Hz. An example of a biophoton measurement can be seen in Figure 4.3 below. Dark counts refers to background photons that the PMT measures when there was no hand in the box.

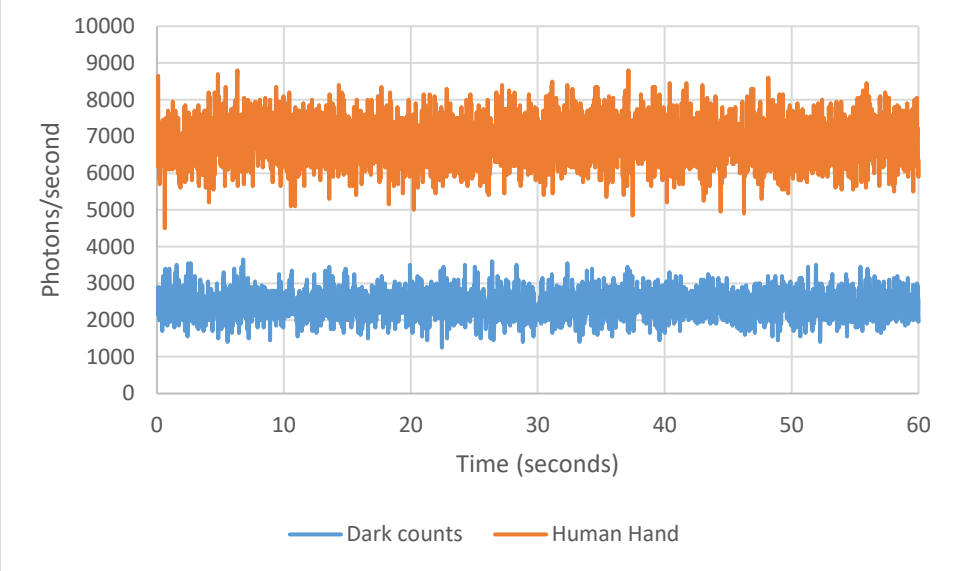

Figure 4. 3 Sample photon recordings of the empty dark box (Dark counts) and a participant's left hand.

There are multiple variables that can be calculated from raw photon recordings: mean, SD, and Fano Factor to name a few. Fano Factor (1) is computed by taking the ratio between the

variance (σ^2) to the mean (μ) in a window (w) of time, in this case of the 1-minute recording. Essentially, Fano Factor is a method to assess the noise in your recording after removing the variability of mean between participants (van Wijk et al., 2010b).

$$F = \frac{\sigma_W^2}{\mu_W}, \quad (1)$$

(1)

In addition to mean and Fano Factor, we also calculated differences between the left and right hands. This was done in two different ways: first, the mean difference was calculated by subtracting the left mean BPE from the right mean BPE (2). Second, the absolute difference was calculated which disregarded which hand had higher photon emissions than the other (3).

(2) Mean difference = Right hand BPE – Left hand BPE

(3) Absolute difference = | Right hand BPE – Left hand BPE |

4.3.5 Psychological Questionnaires

Personality and personality disorders were measured through the TCI-R (Temperament Character Inventory, revised edition), and the MCMI-IV (Millon Clinical Multiaxial Inventory, fourth edition), respectively. The MCMI-IV is comprised of 12 clinical personality patterns, 3 severe personality pathologies, 7 clinical syndromes, and 3 severe clinical syndromes. The 12 clinical personality patterns are: Schizoid, Avoidant, Melancholic, Dependent, Histrionic, Turbulent, Narcissistic, Antisocial, Sadistic, Compulsive, Negativistic, and Masochistic. The 3 severe clinical personality patterns are: Schizotypal, Borderline, and Paranoid. The 7 clinical

syndromes are: Generalized Anxiety, Somatic Syndrome, Bipolar Spectrum, Persistent Depression, Alcohol Use, Drug Use, and Post-Traumatic Stress. The 3 severe clinical syndromes are: Schizophrenic Spectrum, Major Depression, and Delusional Disorder (Grossman & Amendolace, 2017). For the MCMI-IV, the base rate standardized scores were used in analysis.

The TCI-R includes 7 different dimensions: 4 temperament dimensions and 3 character dimensions (Cloninger et al., 1997). The 4 temperament dimensions are Novelty Seeking, Harm Avoidance, Reward Dependence, and Persistence. The 3 character dimensions are: Self-Directedness, Cooperativeness, and Self-Transcendence. For the TCI-R we used the raw scores in our analysis as this was recommended during the training administered from the Anthropedia foundation (the providers of the TCI-R). Participants were also asked demographic questions, and if they have family members with either schizophrenia or an anxiety disorder.

4.3.6 Procedure

Quantitative electroencephalography, electrocardiography, and biophoton measurements were taken in an acoustic chamber in the basement of the Classroom building at Laurentian University in Sudbury, ON, Canada. Participants sat in the chamber and 4-minute EEG and ECG measurements were taken simultaneously (Figure 4.4A). The four minutes consisted of 2 minutes with the participant's eyes open and 2 minutes with the participant's eyes closed. For the biophoton measurements, participants were asked to place their hand inside the dark box and to rest the back of their hand on top of the aperture of the PMT. Black towels were then adjusted and placed around the participants arm to minimize the amount of light that could enter the dark box (Figure 4.4B). There were 2-minute measurements taken of each hand. We alternated starting with the right or

left hand between participants. Participants were asked to relax for all measurements. The questionnaires and psychological evaluations were emailed to the participants to complete at home.

A 

B 

Figure 4. 4 Pictures demonstrating our experimental setup. A. Shows a participant that is ready to have their quantitative electroencephalographic (QEEG) and electrocardiographic (ECG) measured. The participant has one ECG pad on their right wrist and each ankle. B. A participant with their right hand in our darkbox for the biophoton measurements. The back of the participant's hand is resting on top of the aperture of the photomultiplier tube (PMT).

4.3.7 Statistical Analyses

In the analysis of both the biophoton and QEEG data, we used the second minute of the total two-minute recording in our analyses as the participants would have had more time to relax in the second minute. This is because we would talk to the participants before starting the

recordings to ensure they were comfortable and to let them know we were about to begin. The data was skewed for almost all photon, HRV, QEEG and personality variables, therefore non-parametric analysis was used. Outliers were defined as being ±3 Z-scores away from the mean and were removed from their respective analyses. This was to retain as many of the responses as possible with the purpose of increasing the generalizability of the results. Gender comparisons were complete with Mann Whitney U analyses. Correlation analyses were complete with Spearman's rho. All statistical analysis were complete with IBM SPSS Statistics Version 28.

4.4 Results

4.4.1 Gender differences on the demographics and psychological questionnaires

Gender comparisons were made for the demographic variables to determine if there were any confounding variables between males and females. A Mann-Whitney U test showed there were no significant differences between the age of males and females that participated in the study (U=246, Z=-1.62, p=.106) (Table 4.1). There were also no differences between genders in whether the participants had an immediate family member with schizophrenia [$X^2(4)=3.24$, p=.519], extended family member with schizophrenia [$X^2(4)=2.46$, p=.652], immediate family member with an anxiety disorder [$X^2(4)=2.94$, p=.568], or an extended family member with an anxiety disorder [$X^2(4)=2.88$, p=.578] (Table 4.1). There was no significant difference in handedness between males and females [$X^2(2)=.187$, p=.911] (Table 4.1).

Table 4. 1 Gender comparisons of demographic information and psychological questionnaire responses on the MCMI-IV and TCI-R

Demographics	**Females**	**Males**	**p-value**

Age (Mean ± SD)		22.9 ± 4.6	25.0 ± 7.1	.106
Schizophrenia, immediate family	Yes	1	3	.519
	No	26	22	
	Unsure	2	0	
Schizophrenia, extended family	Yes	7	3	.652
	No	19	17	
	Unsure	3	5	
Anxiety, immediate family	Yes	16	10	.568
	No	9	11	
	Unsure	4	4	
Anxiety, extended family	Yes	13	8	.578
	No	8	9	
	Unsure	8	7	
Handedness	Right	25	22	.911
	Left	4	3	
	Ambidextrous	0	0	

SD, standard deviation

In the responses on the MCMI-IV, females scored higher on the Dependent scale (U=223, Z=-2.24, p=.025) and Compulsive scale (U=219.5, Z=-2.3, p=.021) (Figure 4.5). Males scored higher on the Narcissism scale (U=227, Z=-2.17, p=.030), Anti-social scale (U=169.5, Z=-3.20, p=.001), Alcohol abuse scale (U=204, Z=-2.63, p=.008), and Drug abuse scale (U=216, Z=-2.42, p=.015) (Figure 4.5).

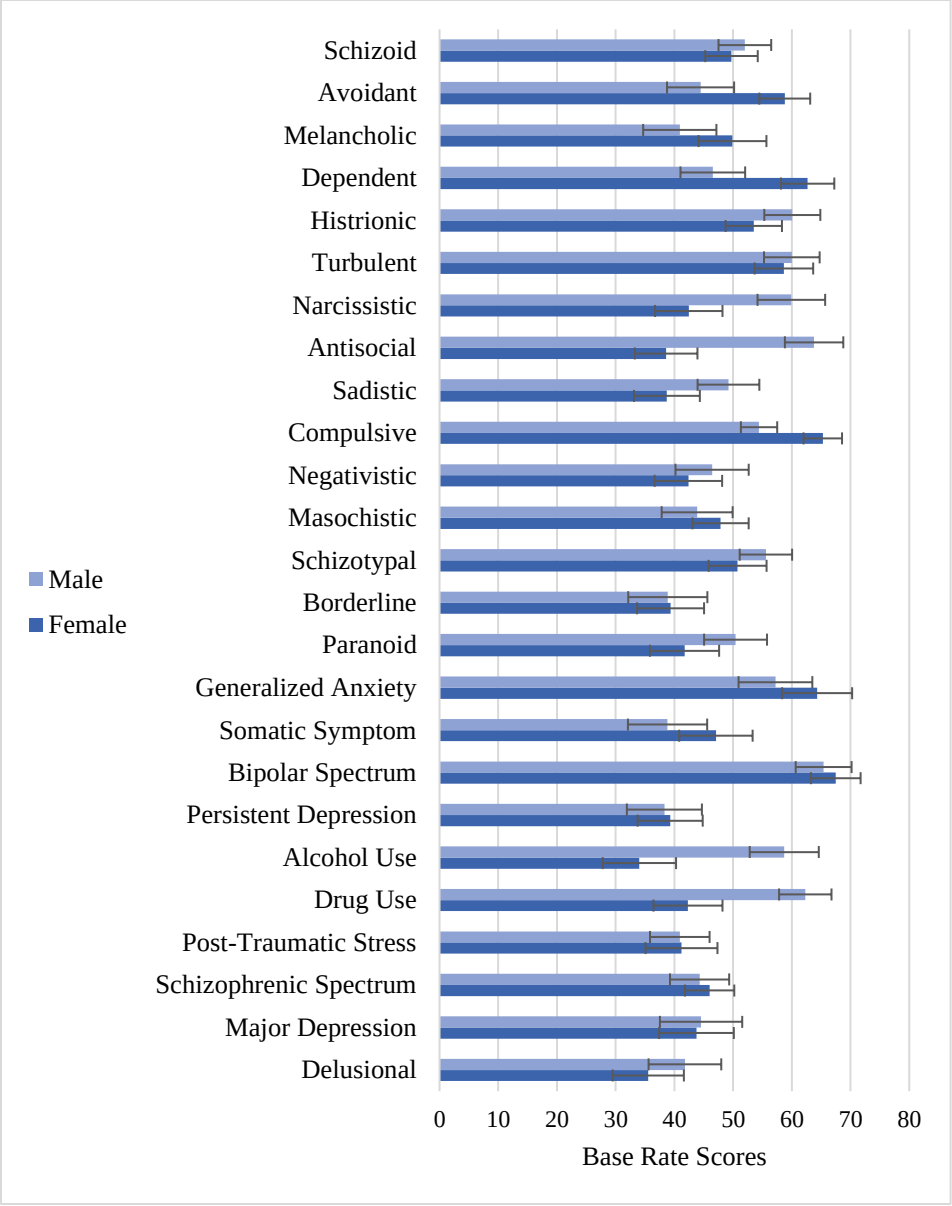

Figure 4. 5 Gender comparisons of the responses on the Millon Clinical Multiaxial Inventory (MCMI-IV). Females scored higher on the Dependent and Compulsive scale, while males scored higher on the Narcissism, Anti-social, Alcohol abuse, and Drug abuse scales ($p<.05$). Error bars represent standard error of the mean (SEM).

In the responses on the TCI-R, females scored higher on Harm Avoidance (U=183.5, Z=-2.80, p=.005), Reward Dependence (U=217.5, Z=-2.19, p=.029), Cooperativeness (U=144.5, Z=-3.52, p<.001), and Self-Transcendence (U=227, Z=-2.00, p=.045) (Figure 4.6).

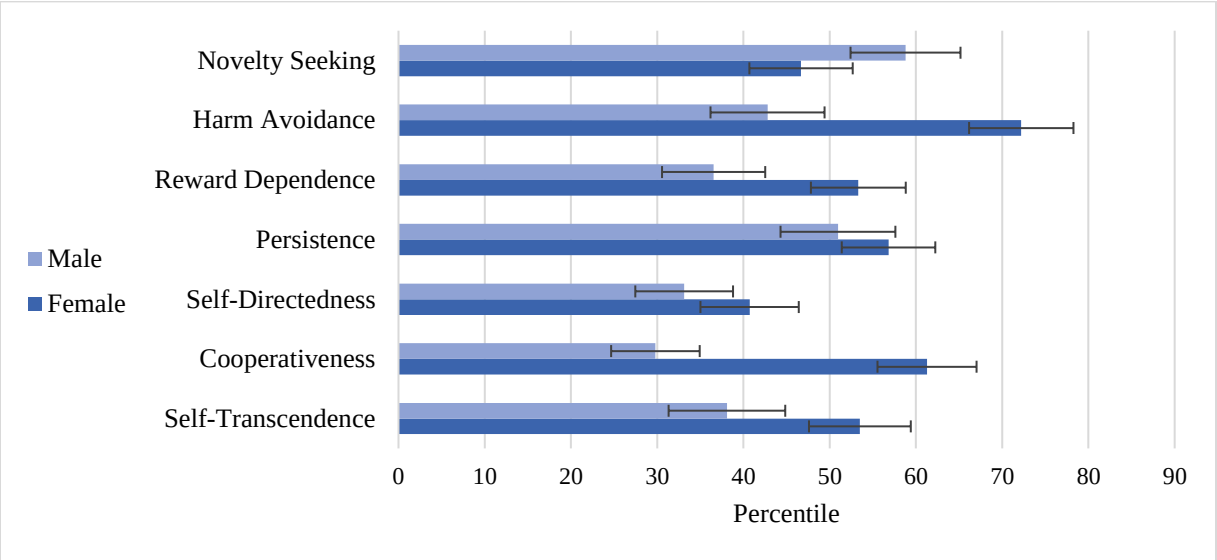

Figure 4. 6 Gender comparisons for the responses on the Temperament Character Inventory (TCI-R). Females had higher scores in Harm Avoidance, Reward Dependence, Cooperativeness, and Self-Transcendence. Error bars represent standard error of the mean (SEM).

4.4.2 Gender differences in Heart Rate Variability (HRV) indices

Gender comparisons were made for the HRV indices to confirm differences between males and females that are typically found (Ramalho et al., 2017). When comparing females and males there were significant differences in the low frequency (LF) component (U=238, Z=-2.16, p=.031; Figure 4.7B) as well as the ratio between low frequency and high frequency (U=225, Z=-2.39, p=.017; Figure 4.7C). There were no significant differences between mean heart rate (U=309, Z=-.928, p=.353; Figure 4.7A), SDNN (standard deviation of interbeat intervals) (SDNN: U=266, Z=-

1.67, p=.094; Figure 4.7A), RMSSD (root mean square of successive interbeat intervals) (RMSSD: U=344, Z=-.321, p=.748; Figure 4.7A), or the high frequency component (HF) (U=362, Z=-.009, p=.993; Figure 4.7B).

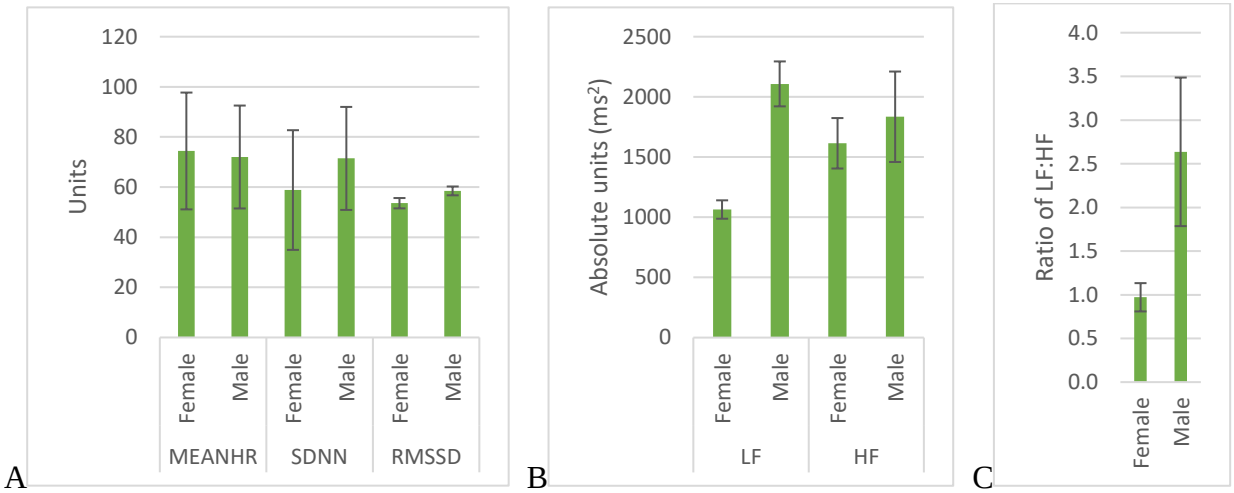

Figure 4. 7 Gender differences between the different indices of heart rate variability (HRV). Error bars represent standard error of the mean (SEM). MeanHR, mean heart rate; SDNN, standard deviation of interbeat intervals; RMSSD, root mean square of successive interbeat intervals; VLF, very low frequency component (ms^2); LF, low frequency component (ms^2); HF, high frequency component (ms^2)

4.4.3 Mean biophoton emission (BPE) variables showed no gender differences

Gender comparisons were made of mean BPE because there has only been one other study to compare this between males and females (Zhao et al., 2016). There was no significant difference between males and females for the mean biophoton emissions from the left (U=287, Z=-1.12, p=.262) or right hand (U=260, Z=-1.60, p=.109), or in the Fano Factor calculations for the left

(U=252, Z=-1.76, p=.079) or right hand (U=272, Z=-1.18, p=.236) (Figure 4.8). These results are consistent with the previous study (Zhao et al., 2016).

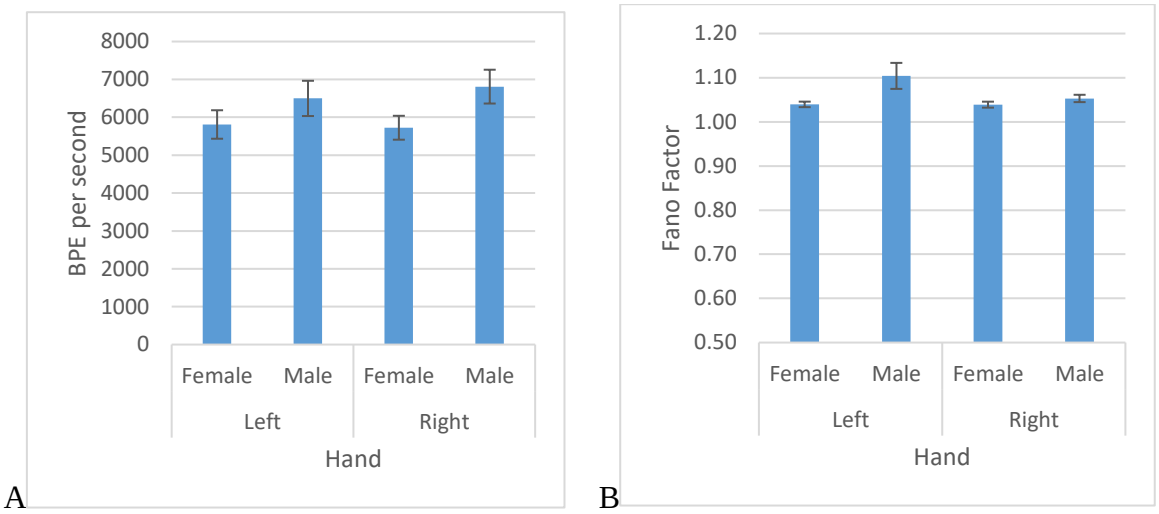

Figure 4. 8 Mean (A) and Factor Factor (B) calculations for biophoton emissions (BPEs) from the left and right of males (N=24) and females (N=28). Error bars represent standard error of the mean (SEM).

When the mean and absolute differences between the left and right hand were analyzed, there were no significant differences found between males and females for either variable [mean difference: U=285, Z=-1.16, p=.236; absolute difference: U=277, Z=-1.30, p=.193; Figure 4.9].

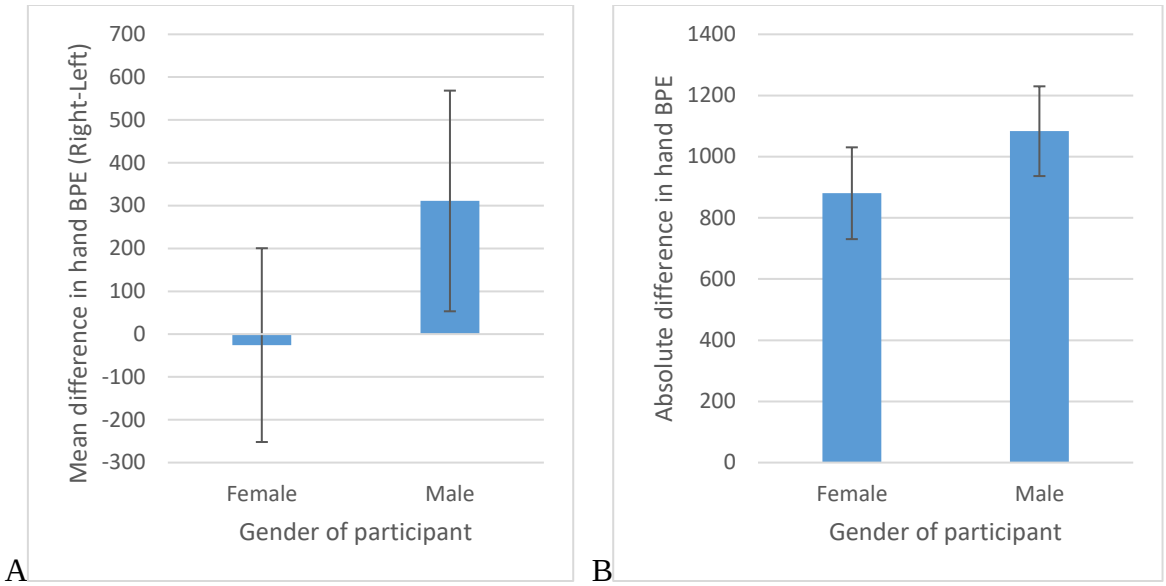

Figure 4. 9 There were no significant differences found between males and females for the mean BPE difference (A) or absolute difference (B) between their hands. Error bars represent standard error of the mean (SEM).

4.4.4 Mean biophotons can predict severity on MCMI-IV and TCI-R scales

In our analysis we found that biophoton emissions (BPEs) were better able to predict scores on the psychological assessments when females and males were analyzed separately (Table 4.2; Figure 4.10). In females hand BPEs were positively correlated with Schizoid (right hand: rho=.436, p=.021) Avoidant (left hand: rho=.478, p=.010; right hand: rho=.407, p=.032), Dependent (left: rho=.568, p=.002; right: rho=.473, p=.011), Generalized Anxiety (left hand: rho=.373, p=.050), Persistent Depression (left hand: rho=.385, p=.043), and Major Depression (left hand: rho=.396, p=.037; right hand: rho=.400, p=.035) of the MCMI-IV and Harm Avoidance of the TCI-R (left hand: rho=.502, p=.008; left hand: rho=.455, p=.017). They were negatively correlated to Histrionic (left hand: rho=-.512, p=.005; right hand: rho=-.516, p=.005) and Turbulent (left hand:

rho=-.508, p=.006; right hand: rho=-.522, p=.004) scores of the MCMI-IV. None of these relationships were found in males (Table 4.1). In males, hand BPE of the right hand was positively correlated with scores on the Compulsive scale of the MCMI-IV (right hand: rho=.431, p=.035) (Figure 4.11). These results demonstrate that mean hand BPE predicts anxiety and depression related scales in females and not males.

Table 4. 2 Summary of bivariate correlations (Spearman's rho) between mean biophoton emissions (BPEs) and MCMI-IV and TCI-R subscales in females (N=27), males (N=24), and the whole sample (N=53)

	Females		Males		Whole sample	
MCMI-IV scales	**Mean hand BPE**		**Mean hand BPE**		**Mean hand BPE**	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**
Schizoid	.357	.436*	-.111	.097	.151	.256
Avoidant	.478*	.407*	-.096	.034	.109	.121
Melancholic	.337	.249	.010	.093	.131	.118
Dependence	.568*	.473*	.201	.162	.298*	.192
Histrionic	-.512*	-.516*	.192	-.073	-.134	-.238
Turbulent	-.508*	-.522*	-.003	-.101	-.222	-.269
Narcissistic	-.182	-.093	.000	-.152	-.065	-.065
Antisocial	-.027	.200	-.084	-.259	.004	.042
Sadistic	.096	.156	.133	.010	.116	.113
Compulsive	.094	-.099	.274	.431*	.049	.053
Negativistic	.302	.272	.203	.223	.251	.248
Masochistic	.215	.257	-.135	.004	.014	.090
Schizotypal	.336	.306	-.104	-.074	.138	.127
Borderline	.269	.238	.109	.174	.187	.196
Paranoid	.262	.341	-.052	.023	.152	.211
Generalized Anxiety	.373*	.303	-.141	-.020	.073	.067
Somatic Symptom	.248	.278	.367	.329	.262	.259
Bipolar Spectrum	-.093	-.134	-.136	-.190	-.059	-.113
Persistent Depression	.385*	.320	.051	.077	.189	.164

Alcohol Use	.022	.169	.163	.110	.116	.154
Drug Use	-.243	-.019	-.068	-.161	-.082	-.054
Post-Traumatic Stress	.194	.208	-.081	-.064	.049	.102
Schizophrenic Spectrum	.210	.234	-.124	.007	.040	.102
Major Depression	.396*	.400*	.247	.282	.297*	.312*
Delusional	.167	.243	-.227	-.095	.028	.091
TCI-R Scales						
Novelty Seeking	-.180	-.297	.247	-.098	.058	-.153
Harm Avoidance	.502*	.455*	-.116	.001	.108	.079
Reward Dependence	-.249	-.311	.403	.292	.014	-.034
Persistence	-.326	-.326	.078	.108	-.127	-.080
Self-Directedness	-.363	-.317	-.198	-.057	-.276*	-.171
Cooperativeness	-.222	-.030	-.146	.158	-.245	-.107
Self-Transcendence	-.237	-.286	-.141	-.264	-.208	-.303*

*p<.05

4.4.5 Fano Factor calculations of mean biophotons can predict severity on MCMI-IV scales

Analyses of the Fano Factor computations of the left and right hand biophoton emissions (BPE) revealed negative correlations in females, between the right hand Fano Factor and Post-Traumatic Stress scale (rho=-.495, p=.007) and Schizophrenic Spectrum (rho=-.415, p=.028). In males there were no significant correlations between Fano Factor of either hand with MCMI-IV or TCI scales (p>.05). Similar to the findings with mean BPE, the Fano Factor correlations were only present in females, however Fano Factor predicted different scales than the mean BPE predicted.

4.4.6 Disparity between biophoton emissions of the right and left hands predicts severity of scores on the TCI-R and MCMI-IV subscales in males and females

One of the biophoton variables that was calculated was the difference of biophotons between the right and left hands, as a measurement of the disparity between hands. This variable was negatively correlated to the Histrionic scale (rho= -.441, p=.031) and Novelty Seeking (rho= -.626, p=.001), and positively correlated with Cooperativeness (rho=.422, p=.040) in males only,

and not females (Histrionic: rho=.126, p=.523; Novelty Seeking: rho=-.226, p=.257; Cooperativeness: rho=.364, p=.062) (Table 4.4; Figure 4.12). In females, this variable was negatively correlated with the MCMI-IV scale Dependence (rho=-.401, p=.034), but not males (rho=.014, p=.947). The direction and correlation strengths indicate that the higher photon emissions from the right hand and lower from the left hand are associated with higher scores on the Cooperativeness scale, whereas lower photon emission from the right and higher from the left are associated with higher scores on the Novelty Seeking, Histrionic, and Dependence scales.

Next, a variable was calculated to represent the absolute difference in biophotons between the right and left hand. This variable was positively correlated to the following subscales in females only: Dependent (rho=.510, p=.006), Schizotypal (rho=.398, p=.036), Paranoid (rho=.458, p=.014), Schizophrenic Spectrum (rho=.473, p=.011) (Table 4.4; Figure 4.13). Indicating the greater the difference between the right and left hand biophoton emissions the more severe the scores, but it did not matter which hand was higher. These correlations were not found in males (Dependent: rho=.153, p=.476; Schizotypal: rho=-.046, p=.830; Paranoid: rho=.149, p=.486; Schizophrenic Spectrum: rho=.058, p=.789) (Table 4.4; Figure 4.13).

Mean difference scores were able to predict scales in males and no females, whereas the absolute difference scores were able to predict scales in females and not males. The absolute difference scores were correlated to scales from the MCMI-IV that are all related to schizotypy.

Table 4. 3 Summary of bivariate correlations (Spearman's rho) between mean and absolute differences of biophoton emissions (BPEs) and MCMI-IV and TCI-R subscales in females (N=28), males (N=24), and the whole sample (N=53).

	Females	**Males**	**Whole Sample**

MCMI-IV scales	Mean diff. (Right-Left)	Absolute diff. | Right-Left |	Mean diff. (Right-Left)	Absolute diff. | Right-Left |	Mean diff. (Right-Left)	Absolute diff. | Right-Left |
Schizoid	-.109	.347	.307	-.091	.157	.185
Avoidant	-.280	.175	.220	-.047	.001	.033
Melancholic	-.333	.137	.156	-.173	-.029	.022
Dependence	-.401*	.510*	.014	.153	-.203	.251
Histrionic	.126	-.193	-.441*	.183	-.165	-.046
Turbulent	.212	-.157	-.129	.178	-.004	-.040
Narcissistic	.081	-.029	-.215	.115	-.028	.072
Antisocial	.159	.075	-.240	.033	.034	.143
Sadistic	-.021	.191	-.134	.000	-.009	.172
Compulsive	-.136	.143	.266	.239	.053	.108
Negativistic	-.280	.270	.187	.264	.032	.297*
Masochistic	-.172	.229	.184	-.289	.099	.014
Schizotypal	-.232	.398*	.090	-.046	-.017	.248
Borderline	-.293	.356	.171	.059	.012	.238
Paranoid	-.088	.458*	.208	.149	.106	.238*
Generalized Anxiety	-.353	.340	.277	.031	-.007	.194
Somatic Symptom	-.156	.275	-.088	.020	-.070	.182
Bipolar Spectrum	-.001	.090	-.041	.140	-.049	.104
Persistent Depression	-.339	.221	.064	-.228	-.058	.061
Alcohol Use	.039	.037	-.182	.023	.002	.096
Drug Use	.141	.036	-.196	.057	-.024	.050
Post-Traumatic Stress	-.221	.367	.171	-.004	.037	.272*
Schizophrenic Spectrum	-.165	.473*	.239	.058	.103	.326
Major Depression	-.233	.309	.063	-.004	-.012	.212
Delusional	-.042	.223	.244	.190	.104	.213
TCI-R Scales						
Novelty Seeking	-.226	.159	-.626*	-.180	-.414*	-.063
Harm Avoidance	-.225	-.120	.163	-.013	-.108	-.093
Reward Dependence	.145	-.251	-.275	-.001	-.113	-.214
Persistence	.175	-.012	.073	.167	.122	.061
Self-Directedness	.284	-.320	.274	.110	.232	-.145
Cooperativeness	.364	-.097	.422*	.136	.222	-.069

Self-Transcendence	.024	-.039	-.209	-.065	-.168	-.124

*p<.05

4.4.7 Comparison of biophoton emission, heart rate variability, and quantitative electroencephalographic predictions of select scales from the MCMI-IV and TCI-R

To compare the predictive ability of different physiological measurements, below is a summary of the variables of biophoton emissions (BPEs), heart rate variability (HRV) components, and quantitative electroencephalography (QEEG) that were able to predict select scales from the MCMI-IV and TCI-R The scales from the MCMI-IV were Schizoid, Schizotypal, and Schizophrenic Spectrum because they are related to schizotypy. The scales from the TCI-R were Harm Avoidance, Cooperativeness, and Self-Transcendence because they have shown to be correlated to the presence of schizophrenia and/or psychosis (Smith et al., 2008; Fresán et al., 2015). In total there were 6 BPE variables, 5 HRV variables, and 96 QEEG variables.

Analysis in the MCMI-IV scales demonstrated that in females the Schizoid scale was predicted by 1 BPE variable; the Schizotypal scale was predicted by 1 BPE variable and 1 QEEG variable; and the Schizophrenic Spectrum was predicted by 2 BPE variables and 3 QEEG variables (Table 4.4). In males, the Schizoid scale was not predicted by any variables; the Schizotypal scale was predicted by 16 QEEG variables; and the Schizophrenic Spectrum variables were predicted by 12 QEEG variables (Table 4.4).

Table 4. 4 Biophoton emission (BPE), heart rate variability (HRV), and quantitative electroencephalography (QEEG) predictors of the Schizoid, Schizotypal, and Schizophrenic Spectrum scales of the MCMI-IV and TCI-R

Females (N=27)			
Predictor	Schizoid (rho)	Schizotypal (rho)	Schizophrenic Spectrum (rho)
BPE	Right hand mean BPE (rho=.436)	Absolute difference in hand BPE (.398)	Right hand fano factor BPE (-.415)
			Absolute difference in hand BPE (.473)
HRV	None	None	None
QEEG	None	Gamma left parietal (-.405)	Alpha2 left parietal (-.457)
			Alpha2 left temporal (-.413)
			Alpha2 right insula (-.412)
Males (N=22)			
Predictor	Schizoid (rho)	Schizotypal (rho)	Schizophrenic Spectrum (rho)
BPE	None	None	None
HRV	None	None	None
QEEG	None	Delta left temporal (-.512)	Delta left temporal (-.503)
		Delta left insula (-.552)	Delta left insula (-.556)
		Delta right insula (-.534)	Delta right insula (-.548)
		Theta left insula (-.427)	Beta1 right frontal (-.624)
		Beta1 right frontal (-.535)	Beta1 left temporal (-.709)
		Beta1 left temporal (-.665)	Beta1 left insula (-.504)
		Beta1 left insula (-.444)	Beta2 left insula (-.484)
		Beta2 left temporal (-.443)	Beta3 left limbic (.469)
		Beta2 left insula (-.465)	Gamma right parietal (.433)
		Beta3 right parietal (.423)	Gamma right frontal (-.470)
		Beta3 right temporal (.476)	Gamma left temporal (-.722)
		Beta3 left limbic (.507)	Gamma left insula (-.505)
		Beta3 right limbic (.447)	
		Beta3 right insula (.477)	
		Gamma left temporal (-.677)	
		Gamma left insula (-.459)	

Analysis of the TCI-R scales revealed that in females Harm Avoidance was predicted by 2 BPE variables; Cooperativeness was predicted by 1 HRV variable; and Self-Transcendence was predicted by 1 QEEG variable (Table 4.5). In males, Harm Avoidance was predicted by 5 QEEG

variables; Cooperativeness was predicted by 1 BPE variable and 1 QEEG variable; and Self-Transcendence was predicted by 4 QEEG variables (Table 4.5).

Table 4. 5 Biophoton emission (BPE), heart rate variability (HRV), and quantitative electroencephalography (QEEG) predictors of the Harm Avoidance, Cooperativeness, and Self-Transcendence scales of the TCI-R

Females (N=26)			
Predictor	Harm Avoidance (rho)	Cooperativeness (rho)	Self-Transcendence (rho)
BPE	Left hand mean BPE (.502) Right hand mean BPE (.455)	None	None
HRV	None	RMSSD (.394)	None
QEEG	None	None	Beta2 right occipital (-.426)
Males (N=22)			
Predictor	Harm Avoidance (rho)	Cooperativeness (rho)	Self-Transcendence (rho)
BPE	None	Mean difference between hand BPE (-.626)	None
HRV	None	None	None
QEEG	Alpha2 left parietal (-.502)	Beta1 right temporal (-.432)	Alpha2 left frontal (.481)
	Alpha2 right frontal (-.536)		Alpha2 left limbic (.522)
	Alpha2 left temporal (-.483)		Alpha2 right limbic (.544)
	Alpha2 left insula (-.479)		Beta2 left temporal (-.454)
	Gamma left temporal (-.436)		

4.4.8 Multiple regression predicting Depression/Somatic Symptom factor scores with biophoton and quantitative electroencephalographic measurements

The following analysis was complete using a regression to determine the combined predicative capacity of BPE and QEEG on mental health. This was completed on depression-

related scales instead of the psychosis-related scales because depressive symptoms are much more prevalent among the normal population. A factor analysis with varimax rotation was completed on all the MCMI-IV responses (N=57) to reduce the number of scales used to evaluate depressive symptoms. This factor analysis produced 6 components that explained 43.7%, 17.1%, 5.9%, 4.6%, 4.2%, and 3.6% of the variance, respectively. The third factor become the factor of interest as the following scales loaded onto it: **Major Depression** (0.794), **Somatic Symptom** (0.736), **Persistent Depression** (0.641), **Debasement** (0.636), **Melancholic** (0.472), and **Borderline** (0.446). This factor will be known as Depression/Somatic Symptom.

A second factor analysis was then complete on the QEEG individual Brodmann areas in the Beta1, Beta2, and Beta3 bands, as these have all shown to be related to depression (Lin et al., 2021) and depressive symptoms (Villafaina et al., 2019). This factor analysis with varimax rotation computed 10 factors that explained 60.3%, 10.6%, 8.9%, 6.2%, 5.7%, 3.0%, 1.9%, 1.2%, 0.5%, and 0.4%, respectively. The Brodmann areas that loaded onto QEEG Factor2 were all from the Beta2 band (Appendix C, Table C.1). The gyri that loaded onto the factor were from all lobes in the left and right hemispheres. This factor therefore became known as GlobalBeta2.

A regression was on the Depression/Somatic Symptom factor with all 10 QEEG factors, mean BPE for each hand, and age. The mean BPE from the left hand, QEEG Factor2 and age were significant predictors of Depression/Somatic Symptom [$F(3,52)=6.1$, $p=.001$]. These variables were able to explain 27.3% of the variance with the equation: Depression/Somatic Symptom score=**meanLeftBPE** (.009) + **GlobalBeta2** (.361) + **age** (.055) – 2.34. The meanLeftBPE, QEEG Factor2, and age had Beta values of .361, .344, and .318, respectively.

4.5 Discussion

A thorough statistical analysis of this data was completed to understand the potential of biophotons in predicting and serving as a biomarker for psychoses and mental health disturbances. In analyses that compared genders, only females and males were analyzed due to a limited or non-existent sample of non-binary and transgender individuals. We did not report this data because we did not have enough participants to accurately represent individuals of these genders.

The average scores of the MCMI-IV were within the normal range (Figure 4.5), and the ranges of scores indicated there may have been individuals who met the criteria for a disorder (Appendix A, Table A.1). However, these scores must be interpreted with caution, as this test is meant to be sensitive because it was designed to be administered to a clinical population. Therefore, administering it to a normal population could produce false positives (Butcher et al., 1998). The average scores of the TCI-R were within the normal range (Figure 4.6); however, the ranges of scores indicated there were individuals who were outside of the normal range (Appendix A, Table A.2).

There were no differences between females and male participants in age, handedness, or family history of schizophrenia or anxiety. In the psychological assessments, females scored higher in Dependent and Compulsive traits on the MCMI-IV, and higher in Harm Avoidance, Reward Dependence, Cooperativeness, and Self-Transcendence on the TCI-R. Whereas males scored higher on the Narcissism, Anti-social, Alcohol Abuse, and Drug Abuse scales of the MCMI-IV. The gender differences from the MCMI-IV scales are similar but not the exact same as previous studies (Wierzbicki & Daleiden, 1993; McCartan & Gudjonsson, 2016). However, both of these previous studies used an older version of the MCMI, and were completed with different participant demographics, a young (18-19years old) student sample (Wierzbicki & Daleidan, 1993) and individuals completing a parental competency exam (McCartan & Gudjonsson, 2016). The

gender differences found on the TCI-R are consistent with a previous study that investigating gender and age differences in TCI-R responses (Delvecchio et al., 2016).

In the heart rate variability (HRV) measures, males had a higher low frequency (LF) component than females which contributed to a higher low frequency to high frequency ratio (LF:HF), findings which are consistent with previous studies (Ramalho et al., 2017; Kunikullaya U et al., 2021). There were no gender differences in mean BPE from the hands, Fano Factor calculations of the hand BPEs, the mean difference of the hand BPE, or the absolute difference of the hand BPE.

Most of the correlations between BPE with MCMI-IV and TCI-R scales were found in females, and very few were present in males. In females, there appeared to be clusters of psychological scales that were associated with different BPE variables. First, the mean BPE from the hands were positively correlated with Schizoid, Avoidant, Dependent, Persistent Depression, Generalized Anxiety, Major Depression, and Harm Avoidance. Mean BPE from the hands was also negatively correlated to Histrionic and Turbulent in females. Mean BPE was not correlated to any HRV variables in females, but both the left and right hands were correlated positively to right parietal beta2 activity and negatively to left insular beta3 activity.

The scales that were correlated to the mean BPE from the hands were primarily related to anxiety or depression. It is possible that the BPE represented differences in blood composition that are known to be correlated with anxiety and depression, such as increased white blood cells due to systemic inflammation (Shafiee et al., 2017). Additionally, in mice high anxiety states cause oxidative stress in white blood cells (Rammal et al., 2008), and individuals with major depression have been found to have an increase in blood oxidant parameters and decreased antioxidants compared to a healthy population (Bajpai et al., 2014). Oxidative stress in cells is known to result

in an increase of BPEs (Kobayashi et al., 2009), indicating that the increased hand BPEs could have been driven by increased oxidative stress in the blood.

Additionally in females, Schizophrenic Spectrum scores and Post-Traumatic Stress scores were both correlated to right hand Fano Factor scores. It is also interesting that Schizophrenic Spectrum, Schizotypal, Paranoid, and Dependent scale scores were also correlated with the absolute difference in BPE between hands in females. The absolute difference in BPE in females was also positively correlated to the low frequency (LF) component of heart rate variability (HRV).

The idea that disparity between the left and right hand could predict disease or disorder originated from Traditional Chinese Medicine (van Wijk et al., 2010a). It is possible that disparity of hand relates to an abnormality in the lateralization of brain activity in the frontal or parietal lobes, relating to the firing of nerve or muscle fibers in the hands. Interestingly, decreased lateralization has been found in the cerebral blood dynamics of individuals with schizophrenia (Fallgatter & Strik, 2000). Similar results were found in healthy individuals who scored higher on a schizotypy questionnaire (Hori et al., 2008). Alternatively, because this variable was positively correlated with the LF component, it may be representing the sympathetic nervous system. The sympathetic nervous system regulates sweat gland activity in the skin (Laine et al., 2019). Increased sweat glad activity could alter the way the skin interacts with external light. External light applied to the skin increases the amount of biophoton emissions, a process known as delayed luminescence (Zhang et al., 2021). It's possible the disparity between the hands found here was a result of increased sensitivity of the hands to ambient lighting. The disparity would've resulted because the hands were not measured at the same time, meaning the second hand had more decay in its BPE when it was measured.

In males, the mean difference between the hands (Right hand – Left hand) was found to be negatively correlated with Novelty Seeking and Histrionic scores, and positively with Cooperativeness scores. Individuals who score high on the Histrionic subscale are dependent on others for their self-esteem and will actively seek out support and reassurance from others through manipulation. Novelty Seeking is the tendency to seek out novel stimuli, engaging in impulsive decision making, and a quick loss of temper. Cooperativeness has to do with one's acceptance of others and acting with agreeability instead of hostility towards others. The correlation directions indicate that the higher photon emissions from the right hand and lower from the left hand are associated with higher scores on the Cooperativeness scale, whereas lower photon emission from the right and higher from the left are associated with higher scores on the Novelty Seeking and Histrionic subscales. Interestingly, higher scores on Novelty Seeking have been associated with a rightward bias on a psychological task, where individuals were more likely to choose an image on the right when asked to be pick between two images side by side (Tomer, 2008).

Gender specific QEEG biomarkers have been previously found in schizophrenia (Manusheva et al., 2011), Alzheimer's cerebrospinal fluid proteins (Chino-Vilca et al., 2022), mini mental status exam scores (Choi et al., 2019), autism spectrum disorder (Neuhas et al., 2021), and autism-related behaviours in a rat model of fragile X syndrome (Wong et al, 2020). Additionally, biophoton predictions of age have also shown gender differences, with stronger predictions in males than females (Zhao et al., 2016).

Gender comparisons were made on the assumption that the wavelengths of biophotons emitted from the hands are the same for males and females. While previous of studies have indicated that the hands primarily emit in the 500 to 550nm (blue-green to green) range, these studies only measured male participants (van Wijk & van Wijk, 2005; Ortega-Ojeda et al., 2018).

The spectral range of the PMT in this was 280 to 850nm, with a peak quantum efficiency at ~460nm, indicating that the PMT can detect more photons at this wavelength compared to shorter or longer wavelengths. If females emitted biophotons at a wavelength that had a higher quantum efficiency than males, then that could explain why BPEs had more predictive power in females in this study.

Alternatively, it's possible that there were factors that introduced more noise into the measurements of the males. For example, males have higher hand temperatures (Neves et al., 2017), larger pores and sebum production (Giacomoni et al., 2007), more sweat production even when controlling for skin surface area (Giacomoni et al., 2007), and thicker skin (Sandby-Møller et al., 2003). Consistent with this idea, we did find that there was more variability within our group of male participants than in our group of female participants (Appendix D, Table D.1).

One of the goals of this research project was to determine how biophoton emissions (BPEs) compared in predictive power to more commonly used methods, heart rate variability (HRV), and quantitative electroencephalography (QEEG). In females, the BPEs were able to predict Schizoid, Schizotypal, and Schizophrenic Spectrum scores better than HRV and QEEG. HRV measures were not able to predict these scales in either males or females. QEEG was able to predict scores on the Schizotypal and Schizophrenic Spectrum scales in females and males. However, considering there were 96 QEEG variables and only 6 BPE variables, it seems like BPEs was more efficient at predicting these scales in females, despite the correlation values being similar between BPE and QEEG. In males, there were many more QEEG variables that were able to predict Schizotypal and Schizophrenic Spectrum which was the hypothesized result, as most of the correlations were found in the Delta, Beta1, Beta3, and Gamma frequencies in the left temporal lobe which has been shown

to have reduced grey matter in Schizotypal personality disorder (Dickey et al., 1999) and reduced cortical thickness in psychosis (Ziermans et al., 2012).

We also compared the predictive abilities of BPE, HRV, and QEEG in scales from the TCI-R that have been previously correlated with schizophrenia and/or psychosis (Smith et al., 2008; Fresán et al., 2015). Cooperativeness is significantly reduced in individuals with schizophrenia (Fresán et al., 2015), and Harm Avoidance and Self-Transcendence were both positively correlated with the positive symptoms of schizophrenia (Smith et al., 2008). Similar to the findings from the MCMI-IV scales, QEEG was better at predicting scores in males compared to females, and QEEG variables from the left temporal lobe were present for Harm Avoidance and Self-Transcendence.

The final analysis in this chapter evaluated the combined ability of BPE and QEEG variables to predict a factor representing Depression/Somatic Symptom scales from the MCMI-IV. In this analysis, we found that mean BPE from the left hand was the first variable to enter the regression equation, followed by GlobalBeta2 and age. GlobalBeta2 had positive factor loadings from all lobes in both the left and right hemisphere, representing whole brain Beta2 cortical activity. The Beta2 frequency band is positively correlated with the low frequency component of HRV, indicating it's related to autonomic arousal (Kuo et al., 2016). Additionally, increased global Beta2 power is associated with stronger inter-connectivity between cortical areas but decreased ability to modify its connectivity in a cognitive task, leading to poorer performance (Rogala et al., 2020). Hyper connectivity in the Beta2 band has also been found in Major Depressive Disorder (Choi et al., 2021). These findings seem to point to global Beta2 being related to arousal, decreased cognitive flexibility and depression.

The results of this study demonstrate that biophotons originating from the hands were related to personality and psychopathology with similar correlation strengths as QEEG variables.

Additionally, in our predictive model of the Depression/Somatic symptom factor we found that a BPE variable entered into the equation before the QEEG variable, indicating that biophotons were able to explain variability that the QEEG variable was not. These results provide an example of the potential that biofield physiology has (Hammerschlag et al., 2015), where multiple bioelectromagnetic measures can predict human health disorders.

Biophoton biomarkers are useful because they represent more than brain activity alone, an idea that is especially relevant as we shift our view of psychopathology to being whole body disorders as opposed to only involving the brain. The key to their future in medicine will be developing a method to determine the contribution from the different tissue types in biophoton measurements. Bioelectromagnetic based biomarkers provide clinicians an opportunity to increase the interdisciplinarity of the methods they use to screen for psychopathology, providing a more holistic measurement of the individual. Finally, biomarkers that are based in bioelectromagnetics offer novel targets for biofeedback therapy.

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Chapter 5.0: General Conclusions, Limitations, and Future Directions

5.1 General Conclusions

This thesis explored alternative methods for producing novel predictors and biomarkers for psychosis and mental health disturbances. This was done by recruiting healthy participants and administering psychological questionnaires that were sensitive to symptoms that could be present in someone without a psychotic disorder, e.g., schizotypy. We took an interdisciplinary approach to investigate electromagnetic variables, either biologic or environmental, that had not been studied in this field of research before.

As discussed in Chapter 1, interdisciplinarity in research is important because it adds diversity in knowledge in the approach to the research question. Interdisciplinary study is also important to the development of the researcher themselves. In interdisciplinary collaborations, there may be opportunities for the researcher to develop new skills, which would not only be enriching but would also increase their job prospects.

Along the lines of diversity, another important component of research is testing what are believed to be well known ideas and confirming previously found relationships. In this thesis we confirmed that the mental health and personality data collected roughly matched gender differences that have been previously found. Additionally, we decided to investigate hand biophoton measurements because previous research demonstrated its potential as a biomarker of disease and disorder. However, according to conventional Western knowledge, we should not have found any relationship between the hand measurements and mental health.

One of the historical problems in psychological research has been a lack of diversity in participants, with most published papers representing WEIRD (Western, Educated, Industrialized, Rich, and Democratic) people (Henrich et al., 2010). This is why it was important to us in the

second study to recruit a diverse sample as possible, our online methods allowed us to recruit from participants worldwide. In Chapter 3, our results demonstrated that symptoms of schizotypy showed geographical variation, not seen in depression or anxiety. Additionally, we found that the X-component of the background magnetic field was able to explain variance in symptoms of schizotypy and hypomania in females, which was not seen in depression, anxiety, or spirituality scores. There are two potential explanations that come to mind. The first is that there is a third variable that alters with the X-component, perhaps a geological variable, that females are more sensitive to. The second is less likely, but that the background magnetic field has influenced the settlement behaviour of humans according to their personalities.

In Chapter 4, we were able to demonstrate that biophoton emissions (BPEs) were more sensitive for screening for Schizoid, Schizotypal, and Schizophrenic Spectrum scores in females than measures taken with quantitative electroencephalography. Additionally, it appeared that BPEs showed some selectivity as a diagnostic in the different psychological scales that were predicted by the mean BPE of the hands, compared to the scales predicted by the absolute difference between hand BPE.

5.2 Limitations

It is important to acknowledge the limitations that were present in this thesis. The background photon measurements in Chapter 2 were susceptible to outside temperature changes in the spring and summer months. This was a result of housing the PMT in an environment that was not temperature controlled. Additionally, the results found in Chapter 2 showing the yearly variation in background temperature differed greatly from those previously found (Persinger,

2015). Based on this data, the background photon data for Chapter 3 was not included in the analysis because we were not confident in the validity of our measures.

In Chapters 3 and 4, which recruited human participants, it is important to acknowledge that the individual who decides to volunteer their time for a study does not necessarily represent the average person. In addition to the WEIRD component mentioned above, which is especially a critical component of the participants in Chapter 4. Additionally in Chapter 4, we had a fairly low sample size for correlational analysis, especially in our male group. In Chapter 3 we did have a more diverse sample; however, this was still limited to individuals who use Facebook and spent enough time on it to notice our advertisement.

5.3 Future Directions

Additional research on the geographic variation in schizophrenia needs to be completed to understand the disparity in voice hearing experiences between Western and Eastern countries (Luhrmann et al., 2015). Our results indicated that these types of experiences may be more common in females in Eastern countries. It's possible if these symptoms are more common among healthy adults then psychosis and schizophrenia may be more accepted by their communities.

The results from Chapter 4 should be replicated before any major conclusions are drawn from that study. Additionally, effort should be made to engage more non-binary and transgender individuals, because of the gender difference in the diagnostic capabilities of biophoton measurements that was found. Research can only benefit the groups that it was completed with which is why it's important to recruit participants from minority genders.

One future application of biophoton diagnostics is to identify biomarkers that indicate an individual is susceptible to developing psychoses before they have had a psychotic episode. Not

only are psychotic episodes themselves traumatic so are the subsequent hospital stays and treatment, which can discourage individuals at risk from seeking further help from the medical community (Lu et al., 2017).

A second application of this biophoton work is to work towards developing a novel technology of "photofeedback" therapy that would work similarly to neurofeedback therapy. In the case of the results of this thesis, the goal would be to reduce the absolute difference in the BPEs from the hands to determine if that had a therapeutic effect in reducing symptoms or signs of schizotypal personality disorder or psychoses.

At the beginning of this document, we reflected on the history of the approach to mental health and the differences that biological and romantic psychiatrists took. The motivation for this thesis primarily comes from themes of biological psychiatry. However, biophotons may have an aspect that would appeal to the romantic psychiatrists as well. Individuals with schizophrenia and psychosis have reported higher rating of spirituality compared to the normal population (Smith et al., 2008). While biophotons are tied to physical variables (Kobayashi et al., 1999), they still represent a more holistic measurement of the body than traditional electrophysiology measurements. It is possible that having a holistic technology would be more engaging if it appeals to their personality.

5.1 References

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Appendix A: Chapter 4 ranges of scores on MCMI-IV and TCI-R psychological questionnaires

Ranges of scores on the psychological assessments

In the responses on the MCMI-IV, the ranges of scores for each individual scale can be found in Table A.1 below.

Table A. 1 Range of scores on the scales of the Millon Clinical Multiaxial Inventory (MCMI-IV)

MCMI-IV Scale	Range of Base Rate scores
Schizoid	0 – 84
Avoidant	1 – 89
Melancholic	0 – 108
Dependence	0 – 100
Histrionic	0 – 100
Turbulent	0 – 100
Narcissistic	0 – 104
Antisocial	0 – 105
Sadistic	0 – 82
Compulsive	13 – 100
Negativistic	0 – 96
Masochistic	0 – 96
Schizotypal	0 – 79
Borderline	0 – 95
Paranoid	0 – 82
Generalized Anxiety	0 – 107
Somatic Symptom	0 – 99
Bipolar Spectrum	2 – 100
Persistent Depression	0 – 108
Alcohol Use	0 – 102
Drug Use	0 – 94
Post-Traumatic Stress	0 – 103
Schizophrenic Spectrum	0 – 83
Major Depression	0 – 108
Delusional	0 – 82

The ranges of scores for the scales of the TCI-R can be found in Table B.2 below.

Table A. 2 Range of scores on the scales of the Temperament Character Inventory (TCI-R)

TCI-R Scale	Range of Percentile scores
Novelty Seeking	2 – 99
Harm Avoidance	1 – 99
Reward Dependence	1 – 99
Persistence	1 – 99
Self-Directedness	1 – 93
Cooperativeness	1 – 96
Self-Transcendence	1 – 99

Appendix B: Chapter 4 correlations between biophoton emissions with quantitative electroencephalography and heart rate variability

Biophoton predictions of Heart Rate Variability (HRV) indices in males and females

A value that represent HRV, RMSSD, was negatively correlated with right Fano Factor hand photon emissions in males (rho=-0.502, p=0.024) but not females (rho=0.163, p=0.417). The LF component was also negatively correlated with right Fano Factor measurements in males (rho=-.502, p=.024) but not females (rho=.067, p=.739). In females, the absolute difference between the right and left hands were significant correlated with the LF component (rho=.466, p=.014) and the ratio between the LF and HF components (rho=.485, p=.010) but not in males for either (rho=-.243, p=.289) or (rho=-.426, p=.054), respectively (Table B.1).

Table B. 1 Significant correlations (Spearman's rho) between different characteristics of biophoton emissions (BPEs) and variable representing heart rate variability (HRV)

Females (N=27)						
	Mean hand BPE		Fano Factor hand BPE		Mean diff.	Absolute diff.
	Left	Right	Left	Right	(Right-Left)	| Right-Left |
MeanHR	.060	-.034	-.240	-.050	-.122	-.073
SDNN	-.064	.020	.166	.117	.057	.233
RMSSD	-.148	-.056	.098	.163	.136	-.007
LF (ms^2)	.090	.137	.010	.067	.070	.466*
HF (ms^2)	-.154	-.004	.102	.086	.186	.000
LF:HF	.177	.143	-.125	-.068	-.040	.485*
Males (N=21)						
	Mean hand BPE		Fano Factor hand BPE		Mean diff.	Absolute diff.

	Left	Right	Left	Right	(Right-Left)	| Right-Left |
MeanHR	-.297	-.221	.144	.285	.103	-.284
SDNN	.068	.013	-.040	-.423	-.079	-.153
RMSSD	.144	.064	.014	-.452*	-.130	-.016
LF (ms^2)	.012	-.121	-.014	-.502*	-.155	-.243
HF (ms^2)	.212	.149	-.012	-.347	-.022	.010
LF:HF	-.323	-.425	-.140	-.283	-.275	-.426

Whole sample (N=49)

	Mean hand BPE		Fano Factor hand BPE		Mean diff.	Absolute diff.
	Left	Right	Left	Right	(Right-Left)	| Right-Left |
MeanHR	-.054	-.107	-.126	.026	-.020	-.119
SDNN	.072	.116	.038	-.065	.077	.140
RMSSD	.006	.049	.018	-.131	.048	.031
LF (ms^2)	.104	.117	.004	-.129	.069	.242
HF (ms^2)	.030	.087	.053	-.127	.110	.029
LF:HF	-.028	-.062	-.088	-.096	-.022	.193

*p<.05; MeanHR, mean heart rate; SDNN, standard deviation of interbeat intervals; RMSSD, root mean square of successive interbeat intervals; LF, low frequency; HF, high frequency

Correlations between QEEG and mean biophoton emissions (BPEs) from the hands in males and females

Presented below (Table B.2) are Spearman correlation coefficients of the biophoton variables of interest with QEEG variables representing activity of the different lobes for the classical frequency bands. For mean biophotons, there were gender differences in the pattern of correlations between mean biophoton emissions (BPE) of the hands and QEEG variables. In females, there were global correlations between the right hand and theta activity (rho's=.398 to .474, p<.05) and beta3 activity (rho's= -.432 to -.588, p<.05). This was not found for the left hand BPE in females. Whereas in males, there were global correlations between delta activity with the BPE from the left (rho's= -.414 to -.555, p<.05) and right hands (rho's= -.456 to -.676, p<.05).

Another pattern that emerged from this analysis was in the left hand BPE of females, which showed a positive correlations to Beta2 activity in the left limbic lobe (rho=.407, $p<.05$), right insula (rho=.383, $p<.05$), right temporal lobe (rho=.416, $p<.05$), right parietal lobe (rho=.449, $p<.05$), and bilateral occipital lobe (left: rho=.396, $p<.05$; right: rho=.480, $p<.05$). This same pattern was also observed in gamma activity in the right occipital lobe (rho=.393, $p<.05$).

Table B. 2 Spearman rho values representing bivariate relationships between mean hand biophoton emissions (BPEs) from the hands with brain activity for females and males.

Females, left hand BPE (N=27)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	.006	-.033	-.067	-.076	-.012	.146	.132	.198	.108	-.049	.253	.223
Theta	.046	.084	.176	.136	.024	.192	.181	.263	.183	.144	.335	.220
Alpha1	-.104	-.212	-.302	-.336	-.277	-.210	-.232	-.135	-.190	-.206	.147	.063
Alpha2	-.070	-.111	-.180	-.160	-.086	-.100	-.065	-.062	-.063	-.087	.161	.107
Beta1	-.002	-.070	.184	-.005	-.186	-.072	-.002	.123	.156	.203	.194	.295
Beta2	.267	.283	.407*	.380	.283	.383*	.342	.416*	.346	.449*	.396*	.480*
Beta3	-.333	-.280	-.300	-.338	-.413*	-.330	-.322	-.321	-.214	-.142	-.099	-.020
Gamma	-.163	-.325	.065	-.098	-.212	-.021	-.101	.209	.176	.255	.346	.393*
Females, right hand BPE (N=27)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	.285	.276	.122	.137	.132	.283	.285	.312	.366	.240	.371	.423*
Theta	.328	.337	.426*	.413*	.302	.328	.398*	.467*	.441*	.426*	.474*	.418*
Alpha1	.115	.027	-.148	-.142	-.125	-.098	-.088	-.091	.013	.029	.126	.155
Alpha2	.043	.001	-.089	-.067	-.030	-.068	-.062	-.033	.025	.053	.131	.162
Beta1	.026	-.047	.027	-.040	-.125	-.056	-.148	-.063	.079	.128	-.007	.131
Beta2	.324	.322	.338	.341	.414*	.407*	.337	.357	.264	.410*	.217	.358
Beta3	-.548*	-.493*	-.515*	-.562*	-.488*	-.516*	-.545*	-.588*	-.432*	-.333	-.360	-.229
Gamma	.026	-.136	.026	.068	-.117	-.013	-.189	.058	.092	.223	.109	.309
Males, left hand BPE (N=23)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	

Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	-.501*	-.489*	-.457*	-.451*	-.209	-.355	-.414*	-.542*	-.476*	-.463*	-.555*	-.521*
Theta	-.339	-.308	-.156	-.153	.030	.010	-.082	-.050	-.219	-.156	-.271	-.337
Alpha1	-.499*	-.427*	-.354	-.356	-.222	-.180	-.175	-.172	-.334	-.359	-.309	-.446*
Alpha2	-.386	-.319	-.249	-.248	-.225	-.155	-.212	-.186	-.187	-.293	-.273	-.299
Beta1	-.078	.198	.112	.256	.116	.186	.399	.373	.333	.167	.167	-.024
Beta2	.135	.219	.148	.136	.017	.142	.174	.227	.268	.235	.281	.160
Beta3	.103	.212	.017	-.008	-.089	-.096	.110	.111	.224	.253	.266	.119
Gamma	-.310	-.065	-.250	-.335	-.070	-.129	-.044	.098	.178	.133	.169	-.040

Males, Right hand BPE (N=23)

	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	-.505*	-.543*	-.535*	-.546*	-.275	-.474*	-.480*	-.676*	-.499*	-.456*	-.471*	-.458*
Theta	-.270	-.277	-.238	-.248	.028	-.046	-.076	-.146	-.163	-.169	-.222	-.263
Alpha1	-.329	-.295	-.170	-.189	-.051	-.096	-.050	-.095	-.205	-.158	-.210	-.339
Alpha2	-.478*	-.375	-.257	-.273	-.230	-.124	-.206	-.205	-.157	-.232	-.239	-.265
Beta1	-.127	.163	.004	.228	.184	.208	.309	.136	.273	.157	.055	-.074
Beta2	.098	.181	.043	.093	.059	.142	.115	.087	.198	.108	.110	-.006
Beta3	.163	.316	.022	.020	.030	.046	.172	.034	.278	.233	.209	.007
Gamma	-.269	-.023	-.380	-.424*	-.037	-.127	-.111	-.115	.201	.140	.071	-.126

* $p<.05$

Correlations between QEEG and mean biophoton emissions (BPEs) from the hands in males and females

In females there were only significant correlations between the right hand Fano Factor values with QEEG variables, the left hand Fano Factor values were not significantly correlated to any of the QEEG variables ($p>.05$) (Table B.3). The right hand Fano Factor variables were correlated with alpha1 activity in the right frontal (rho=-.476, $p<.05$), bilateral limbic lobes (left: rho=-.480, $p<.05$; right: rho=-.497, $p<.05$), bilateral insular lobes (left: rho=-.445, $p<.05$; right: rho=-.497, $p<.05$), bilateral temporal lobes (left: rho=-.529, $p<.05$; right: rho=-.445, $p<.05$), and left parietal lobe (rho=-.397, $p<.05$). The right Fano Factor values in females were also correlated with: beta2 in the right parietal lobe (rho=.383, $p<.05$) and left occipital lobe (rho=.415, $p<.05$), as well as gamma activity in the right temporal activity (rho=.395, $p<.05$).

In males, the left Fano Factor values were correlated with: alpha1 activity in the bilateral limbic lobes (left: rho=-.434, $p<.05$; right: rho=-.432, $p<.05$), and the right parietal lobe (rho=-.535, $p<.05$), alpha2 activity in the bilateral limbic lobes (left: rho=-.439, $p<.05$; right: rho=-.433, $p<.05$), and the right parietal lobe (rho=-.469, $p<.05$), and beta1 activity in the right frontal (rho=.434, $p<.05$) and bilateral temporal lobes (left: rho=.543, $p<.05$; right: rho=.452, $p<.05$) (Table B.3).

Table B. 3 Spearman rho values representing bivariate relationships between the Fano Factor calculations of mean hand biophoton emissions (BPEs) from the hands with brain activity for females and males.

Females, left hand Fano Factor of BPE (N=27)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	-.181	-.139	-.295	-.264	-.233	-.091	-.113	-.228	-.019	-.272	.141	.071
Theta	-.020	.143	.124	.051	.047	.329	.203	.241	.187	.014	.309	.125
Alpha1	.015	.072	.012	-.016	.190	.103	.160	-.020	.077	-.127	.219	.091
Alpha2	-.151	.077	-.081	-.044	.024	.076	.072	-.094	-.039	-.205	.017	-.047
Beta1	-.129	-.043	-.179	-.203	.230	-.077	.032	-.284	-.209	-.309	-.172	-.190
Beta2	.195	.242	.171	.193	.234	.182	.205	.030	.066	.079	.123	.111
Beta3	-.010	-.021	-.142	-.115	-.061	-.116	-.093	-.193	-.122	-.112	-.041	-.191
Gamma	-.072	.134	-.132	-.178	-.042	.019	.107	-.225	-.004	-.215	.037	.046
Females, right hand Fano Factor of BPE (N=27)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	-.080	.010	.155	.122	-.035	.247	.148	.268	.068	.048	-.022	-.140
Theta	-.188	-.095	-.054	-.045	.047	.074	.018	.013	-.095	-.177	-.181	-.295
Alpha1	-.371	-.476*	-.480*	-.497*	-.445*	-.418*	-.529*	-.445*	-.397*	-.376	-.246	-.373
Alpha2	-.220	-.140	-.153	-.154	.016	.152	-.005	-.024	-.136	-.219	-.211	-.408*
Beta1	-.119	-.027	-.062	-.074	-.032	.081	.123	.015	.004	-.022	-.041	-.062
Beta2	.084	.162	.234	.215	-.036	.248	.170	.359	.325	.383*	.415*	.309
Beta3	-.127	.057	.100	.091	.040	.120	.142	.190	.036	.061	.029	.044
Gamma	-.275	-.070	.115	.011	-.072	.153	.148	.395*	.147	.085	.159	.020
Males, left hand Fano Factor of BPE (N=22)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	

Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	-.190	-.067	-.110	-.130	.107	.206	.093	.003	-.319	-.377	-.134	-.136
Theta	-.098	.001	-.020	-.042	.217	.255	.208	.115	-.203	-.293	-.195	-.173
Alpha1	-.216	-.182	-.434*	-.432*	-.155	-.044	-.134	-.090	-.422	-.535*	-.194	-.121
Alpha2	-.323	-.266	-.439*	-.433*	-.149	-.202	-.180	-.407	-.417	-.469*	-.177	-.205
Beta1	.308	.434*	.122	.129	.036	.116	.543*	.452*	.067	-.034	.199	.152
Beta2	.306	.210	.129	.164	.238	.094	.261	.120	.073	.006	.171	.143
Beta3	.078	.072	-.227	-.171	.190	-.134	.042	-.090	-.286	-.160	-.140	-.024
Gamma	.076	.045	-.345	-.374	.090	.170	.325	.166	-.331	-.143	.048	.014

Males, Right hand Fano Factor of BPE (N=22)

	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	-.030	-.089	-.062	-.044	.129	-.041	.067	-.241	-.354	-.144	-.331	-.261
Theta	-.015	-.026	-.192	-.221	.072	-.071	.002	-.222	-.338	-.326	-.338	-.260
Alpha1	.193	.209	.121	.162	.309	.107	.136	-.038	-.054	-.057	-.305	-.236
Alpha2	-.147	-.071	-.183	-.139	.112	-.066	.021	-.180	-.215	-.203	-.218	-.230
Beta1	.114	.121	-.101	.073	.331	.072	.085	-.225	-.157	-.140	-.228	-.246
Beta2	-.117	-.047	-.266	-.109	.057	-.108	-.129	-.250	-.333	-.283	-.313	-.308
Beta3	.305	.308	.077	.176	.465*	.261	.197	-.067	-.099	-.103	-.068	-.140
Gamma	.228	.228	-.185	.020	.210	.151	.100	-.327	-.341	-.222	-.286	-.335

* $p<.05$

Correlations between QEEG with mean and absolute differences between biophoton emissions (BPEs) from the hands in males and females

In females, the mean difference between hand BPEs (Right hand – Left hand) was positively correlated with: Delta activity in the bilateral frontal lobes (left: rho=.465, p<.05; right: rho=.501, p<.05), bilateral limbic lobe (left: rho=.399, p<.05; right: rho=.423, p<.05), and bilateral parietal lobe (left: rho=.382, p<.05; right: rho=.483, p<.05). Theta activity in the left frontal lobe (rho=.465, p<.05), right limbic (rho=.419, p<.05), and left insular lobe (rho=.406, p<.05). Alpha1 activity in the bilateral frontal lobes (left: rho=.387, p<.05; right: rho=.404, p<.05), right limbic lobe (rho=.422, p<.05), and bilateral parietal lobes (left: rho=.398, p<.05; right: rho=.479, p<.05). Mean difference between the hands in females was negatively correlated to the left occipital lobe in beta1 activity (rho=-.391, p<.05) and gamma activity (rho=-.449, p<.05). In males, the mean difference between hand BPEs (Right hand – Left hand) was positively correlated with alpha1 activity in the right parietal lobe (rho=.485, p<.05). Additionally in females, the values representing the absolute difference between mean BPE of the hands was positively correlated to gamma activity in the right occipital lobe (rho=.425, p<.05) (Table B.4).

In males, the absolute difference was negatively correlated with: delta activity in the right insula (rho=-.442, p<.05), theta activity in the right frontal (rho=-.483, p<.05), bilateral limbic cortex (left: rho=-.470, p<.05; right: rho=-.473, p<.05), right insula (rho=-.597, p<.05), and bilateral temporal (left: rho=-.416, p<.05; right: rho=-.458, p<.05). Beta2 activity in the bilateral frontal lobes (left: rho=-.468, p<.05; right: rho=-.508, p<.05), bilateral limbic lobes (left: rho=-.478, p<.05; right: rho=-.480, p<.05), bilateral insular lobes (left: rho=-.500, p<.05; right: rho=-.546, p<.05), and bilateral temporal lobes (left: rho=-.498, p<.05; right: rho=-.420, p<.05). Absolute difference between the hands in males was also positively correlated to beta3 in the left

frontal (rho=.542, p<.05), bilateral limbic lobes (left: rho=.494, p<.05; right: rho=.492, p<.05), left temporal lobe (rho=.477, p<.05), right parietal lobe (rho=.470, p<.05), and bilateral occipital lobes (left: rho=.447, p<.05; right: rho=.438, p<.05) (Table B.4).

Table B. 4 Spearman rho values representing bivariate relationships between mean and absolute hand biophoton emissions (BPEs) from the hands with brain activity for females and males.

Females, mean difference, Right hand BPE – Left hand BPE (N=27)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	.465*	.501*	.399*	.423*	.230	.120	.186	.095	.382*	.483*	.110	.224
Theta	.465*	.379	.353	.419*	.406*	.091	.271	.184	.330	.372	.090	.231
Alpha1	.387*	.404*	.351	.422*	.234	.156	.243	.093	.398*	.479*	.046	.206
Alpha2	.275	.240	.227	.217	.137	.046	.045	.024	.201	.238	-.109	.070
Beta1	.049	-.016	-.330	-.118	.114	-.031	-.273	-.374	-.200	-.205	-.391*	-.332
Beta2	-.012	-.076	-.197	-.160	.032	-.134	-.151	-.212	-.208	-.181	-.376	-.323
Beta3	-.173	-.231	-.193	-.200	-.007	-.161	-.247	-.251	-.244	-.241	-.357	-.286
Gamma	.356	.361	.031	.365	.197	-.062	-.119	-.265	-.212	-.082	-.449*	-.253
Males, mean difference, Right hand BPE – Left hand BPE (N=23)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	.010	-.082	-.138	-.143	-.116	-.191	-.075	-.153	-.008	.052	.124	.168
Theta	.049	-.005	-.161	-.193	-.105	-.161	-.090	-.191	.083	-.052	.035	.113
Alpha1	.374	.318	.348	.304	.318	.167	.274	.204	.352	.485*	.306	.305
Alpha2	-.056	.006	.069	.057	.083	.144	.089	.074	.125	.182	.116	.108
Beta1	-.124	-.125	-.236	-.137	.128	-.020	-.180	-.312	-.129	-.023	-.186	-.083
Beta2	-.191	-.194	-.264	-.178	.006	-.054	-.188	-.292	-.204	-.300	-.343	-.321
Beta3	.101	.166	.039	.059	.243	.281	.170	-.069	.096	-.014	-.057	-.109
Gamma	.050	.053	-.257	-.188	.041	-.033	-.107	-.329	.018	.010	-.196	-.111
Females, absolute difference, |Right hand BPE – Left hand BPE| (N=27)												
	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	

Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	.153	.035	-.028	.011	.104	-.156	.037	-.023	.005	.134	-.027	.214
Theta	.077	-.007	-.012	-.002	-.044	-.193	-.074	-.093	.013	.140	.033	.163
Alpha1	.286	.203	.214	.231	.231	-.053	.207	.087	-.001	.085	-.121	.186
Alpha2	.062	-.066	-.020	.020	-.029	-.139	-.046	.005	-.048	.134	.095	.185
Beta1	.089	-.109	.192	.246	-.085	-.227	-.111	.061	.095	.237	.172	.250
Beta2	-.007	-.084	.074	.049	.005	-.048	.053	.076	-.065	-.013	-.024	.139
Beta3	-.035	-.228	-.046	-.091	-.107	-.366	-.111	-.077	-.111	.013	.059	.198
Gamma	.210	-.253	.206	.208	.007	-.340	.015	.023	-.081	.198	.121	.425*

Males, absolute difference, |Right hand BPE – Left hand BPE| (N=23)

	Frontal		Limbic		Insula		Temporal		Parietal		Occipital	
Hemisphere	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Delta	-.213	-.318	-.315	-.319	-.192	-.442*	-.257	-.412	-.357	-.324	-.229	-.019
Theta	-.342	-.483*	-.470*	-.473*	-.368	-.597*	-.416*	-.458*	-.403	-.306	-.186	-.021
Alpha1	.203	.125	.241	.288	.403	.071	.321	.173	.036	.162	.012	.115
Alpha2	.035	-.069	.218	.187	.109	.055	.226	.223	.134	.197	.282	.223
Beta1	-.122	-.216	-.145	-.038	.009	-.228	-.043	-.024	-.111	.002	-.045	.027
Beta2	-.468*	-.508*	-.478*	-.480*	-.500*	-.546*	-.498*	-.420*	-.338	-.319	-.283	-.243
Beta3	.542*	.366	.494*	.492*	.241	.093	.477*	.362	.339	.470*	.447*	.438*
Gamma	-.020	-.217	-.252	-.266	-.162	-.405	-.174	-.074	-.111	.054	.205	.159

* $p<.05$

Appendix C: Brodmann areas from the Quantitative electroencephalographic measurements that loaded onto a factor of interest

Table C. 1 Brodmann areas from the Beta2 band that significantly loaded onto QEEG Factor2

Frequency	Hemisphere	Lobe	Brodmann area	Gyrus	Factor score
Beta2	L	Frontal	BA4	Precentral gyrus	0.850
Beta2	L	Frontal	BA6	Middle frontal gyrus	0.881
Beta2	L	Frontal	BA8	Superior frontal gyrus	0.868
Beta2	L	Frontal	BA9	Middle frontal gyrus	0.939
Beta2	L	Frontal	BA10	Superior frontal gyrus	0.768
Beta2	L	Frontal	BA11	Middle frontal gyrus	0.808
Beta2	L	Frontal	BA25	Medial frontal gyrus	0.857
Beta2	L	Frontal	BA45	inferior frontal gyrus	0.923
Beta2	L	Frontal	BA44	Precentral gyrus	0.923
Beta2	L	Frontal	BA46	Middle frontal gyrus	0.868
Beta2	L	Frontal	BA47	inferior frontal gyrus	0.889
Beta2	R	Frontal	BA6	Middle frontal gyrus	0.770
Beta2	R	Frontal	BA8	Superior frontal gyrus	0.819
Beta2	R	Frontal	BA9	Middle frontal gyrus	0.821
Beta2	R	Frontal	BA10	Superior frontal gyrus	0.845
Beta2	R	Frontal	BA11	Superior frontal gyrus	0.842
Beta2	R	Frontal	BA44	Precentral gyrus	0.731
Beta2	R	Frontal	BA45	inferior frontal gyrus	0.785
Beta2	R	Frontal	BA46	Middle frontal gyrus	0.845
Beta2	R	Frontal	BA47	inferior frontal gyrus	0.827
Beta2	L	Temporal	BA20	Fusiform gyrus	0.840
Beta2	L	Temporal	BA21	Middle temporal gyrus	0.857
Beta2	L	Temporal	BA27	Parahippocampal gyrus	0.762
Beta2	L	Temporal	BA28	Parahippocampal gyrus	0.856
Beta2	L	Temporal	BA34	Parahippocampal gyrus	0.839
Beta2	L	Temporal	BA35	Parahippocampal gyrus	0.795
Beta2	L	Temporal	BA36	Parahippocampal gyrus	0.777
Beta2	L	Temporal	BA37	Fusiform gyrus	0.812
Beta2	L	Temporal	BA38	Superior temporal gyrus	0.894
Beta2	L	Temporal	BA39	Middle temporal gyrus	0.850
Beta2	L	Temporal	BA42	Transverse temporal gyrus	0.847
Beta2	L	Temporal	BA41	Transverse temporal gyrus	0.775
Beta2	R	Temporal	BA20	Fusiform gyrus	0.759

Beta2	R	Temporal	BA21	Middle temporal gyrus	0.729
Beta2	R	Temporal	BA27	Parahippocampal gyrus	0.695
Beta2	R	Temporal	BA28	Parahippocampal gyrus	0.782
Beta2	R	Temporal	BA34	Parahippocampal gyrus	0.794
Beta2	R	Temporal	BA35	Parahippocampal gyrus	0.739
Beta2	R	Temporal	BA37	Fusiform gyrus	0.771
Beta2	R	Temporal	BA38	superior temporal gyrus	0.798
Beta2	R	Temporal	BA39	Middle temporal gyrus	0.785
Beta2	R	Temporal	BA41	Transverse temporal gyrus	0.716
Beta2	R	Temporal	BA42	Transverse temporal gyrus	0.710
Beta2	R	Temporal	BA35	Parahippocampal gyrus	0.709
Beta2	L	Insula	BA13	Insula	0.850
Beta2	R	Insula	BA13	Insula	0.724
Beta2	L	Cingulate	BA23	Posterior cingulate	0.744
Beta2	L	Cingulate	BA24	Cingulate gyrus	0.831
Beta2	L	Cingulate	BA24	Anterior cingulate	0.824
Beta2	L	Cingulate	BA29	Posterior cingulate	0.791
Beta2	L	Cingulate	BA30	Posterior cingulate	0.838
Beta2	L	Cingulate	BA33	Anterior cingulate	0.778
Beta2	R	Cingulate	BA23	Posterior cingulate	0.743
Beta2	R	Cingulate	BA24	Cingulate gyrus	0.798
Beta2	R	Cingulate	BA24	Anterior cingulate	0.780
Beta2	R	Cingulate	BA25	Subcallosal gyrus	0.782
Beta2	R	Cingulate	BA29	Posterior cingulate	0.784
Beta2	R	Cingulate	BA33	Anterior cingulate	0.756
Beta2	L	Parietal	BA2	Postcentral gyrus	0.815
Beta2	L	Parietal	BA5	Paracentral lobule	0.779
Beta2	L	Parietal	BA7	Precuneus	0.791
Beta2	L	Parietal	BA31	Precuneus	0.757
Beta2	L	Parietal	BA40	Inferior parietal lobule	0.823
Beta2	R	Parietal	BA2	Postcentral gyrus	0.835
Beta2	R	Parietal	BA3	Postcentral gyrus	0.770
Beta2	R	Parietal	BA5	Paracentral lobule	0.709
Beta2	R	Parietal	BA7	Precuneus	0.729
Beta2	R	Parietal	BA31	Precuneus	0.730
Beta2	R	Parietal	BA40	Inferior parietal lobule	0.706
Beta2	L	Occipital	BA17	Lingual gyrus	0.841
Beta2	L	Occipital	BA17	Lingual gyrus	0.839
Beta2	L	Occipital	BA30	Cuneus	0.811
Beta2	R	Occipital	BA17	Lingual gyrus	0.809
Beta2	R	Occipital	BA17	Lingual gyrus	0.802
Beta2	R	Occipital	BA30	Cuneus	0.812

Appendix D: Variability of biophoton emission (BPE) variables within male and female participant groups.

Table D. 1 Standard deviation of the mean hand biophoton emission (BPE) and Fano Factor (FF) scores for the hands in males and females

	Female	**Male**
Mean Left BPE	39.9	46.5
Mean Right BPE	32.8	44.6
FF Left	0.032	0.050
FF Right	0.036	0.041