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Article

The Relationship Between Brain Wave Power Value Of Pain Perception And Empathy Using The Electroencephalogram (EEG)

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***Abstract*— Pain is said to be influenced by many psychological factors such as emotional state that manipulated the level of empathy. However, there are limited studies exploring the neuro-correlation connecting all these aspects. The current study aims to assess the dominant brain wave power value of pain perception and empathy by determining the area activated associated with the imaginary pain under three different categories which are stranger, one-self and loved-one. The study utilized a tool of brain signal detector (electroencephalography (EEG) device) which is Emotiv Insight focusing the relevant area of the brain (AF3, AF4, T7, T8 and Pz) to record the electrical signal of healthy subjects during the pain-visual-stimuli presentations. Images showing the pain condition were used as stimulus material during the EEG brain scanning session. The analysis was performed using Emotive Launcher and Brain Vision Analyzer version 2.2. Findings indicates the imaginary pain has activated the prefrontal area of the brain, specifically the medial frontal gyrus (MFG), superior frontal gyrus (SFG), orbital gyrus, subcallosal gyrus, and rectal gyrus; and revealing theta power band as the most dominant brain wave in this research. These power values also relate with the pain perception that influenced by the empathy level of individuals as observed, individual with high empathy do feel more pain for others. This outcome will help in understanding the mechanism of empathy and pain perception especially when imagining their loved one in pain that could enhance the research development in examining psychological processes.**

***Keywords*— EEG; Imaginary Pain; Empathy; Brain Wave; Power Value**

I. INTRODUCTION

Empathy is derived from the Greek term 'empathia', which consists of the prefix em-, which means inside, and the Greek word 'pathos', which means feeling; etymologically, empathy means "inside feeling" [23]. Empathy is defined as representing others' pain within one's own pain systems and is one of the most important abilities for appropriate social communication. Empathy is also defined as the ability to understand and enter another person's feelings and emotions, or to experience things from the other person's point of view [23]. This kind of emotion is actually an ability to emotionally understand of others' situation where they will try to put themselves in someone else's position. Empathy is different from sympathy or pity emotions. When a person is sympathetic, he "feels sorry" for a person in trouble and sees that person with a sense of separation. However, empathy is gets on the same level as the person in trouble and in a sense feels what the person is going through.

Empathy is also an interpersonal communication mechanism that elicits responses from others, helps figure out priorities within relationships, and brings people together in social groups [9]. In fact, the ability to infer another person's mental state requires the ability to inhibit the egocentric bias, that leads us to attribute our own intentions, beliefs or emotions to others [21].

Empathy can be categorized into two types: affective (emotional) empathy and cognitive empathy. Emotional empathy is the observer's affective response to the observation, inference or imagination of another person's feelings as a consequence of emotional sharing [21]. Affective empathy also linked to emotional responses and is often associated with anxiety and stress in social context [16]. Cognitive Empathy is the ability to adopt another person's perspective [21]. This aspect focuses on understanding emotions and is correlated with lower levels of depression [16]. It involves distinct neural networks and is crucial for moral decision-making [13].

In research that used real painful stimuli, females were found to have a higher sensitivity to painful faces or a higher pain rating while observing another person's pain than males. [2]. Across multiple contexts and measurement approaches, men show substantially lower levels of empathy than women [4]. According to [14], women consistently achieve higher scores on self-report measures of empathy.

Human brain is one of the most complicated, complex and mesmerising elements of the universe. Neuroscience of empathic-pain processing can be investigate using various techniques of brain imaging including functional Magnetic Resonance Imaging (fMRI) and electroencephalogram (EEG). Considered this research context, the EEG is one of the versatile techniques of brain imaging and an electrophysiological monitoring method to record electrical activity of the brain [1]. The measurement of electrical activity from the brain is useful because it reflects how the various neurons in the brain network communicate with each other via electrical impulses. EEG is a brilliant tool for studying the neurocognitive processes a fundamental of human behaviour. EEG has successfully showed good performance as fMRI instead it diminished the issues of claustrophobic. In fact, EEG offers several strong qualities as a tool for examining brain activity because it directly measures the brain's electrical activity, unlike the other methods record changes in blood flow (fMRI) or metabolic activity (PET), which are indirect markers of brain electrical activity [8, 11]. However, it is difficult to map the empathy mechanism in brain due to many considerations. For instants, the painful situations and certain emotion could induce strong empathic responses. While pain is influenced by many psychological factors that manipulated the level of empathy. Similarly, the emotion for example love that could manipulated the pain perception thus affected the empathy levels. Electroencephalography is used to study the neurocognitive processes like an examination of the correlation between brain electrical mechanism and changes in emotion. This work aims to evaluate the brain wave power value of pain threshold by event-related potentials measured using electroencephalogram and the relationship between pain threshold, perception and the empathy modulated by imagining others including their loved ones in pain.

II. MATERIAL AND METHODS

A. *Participant*

This experiment involved 18 healthy human volunteers (10 males and 8 females student). The participants were recruited among students in Universiti Sains Islam Malaysia (USIM) with age ranging between 18-25 years old. The participants were recruited through the advertisement and word of mouth method. The inclusion criteria are; has normal colour vision, healthy, and provides written informed consent. Participants with a history of a medical condition that may interfere with brain function, a history of a psychiatric disorder requiring current psychotropic medication or previous inpatient psychiatric hospitalization, or who are taking drugs that may affect the central nervous system, such as antidepressants, antiepileptic medication, sleeping pills, substance abuse, pregnancy, and so on, are excluded. This research has been approved by Research Ethics Committee of USIM (USIM/JKEP/2020-110).

B. *Materials*

Visual-pain stimulation was utilized in this study. The stimuli consist of unfortunate events that caused pain was used and it is intended to replace the actual pain stimulus. Three images showing mild (Figure 1), moderate (Figure 2) and severe (Figure 3) levels of pain were used during the EEG brain scanning session. All the images were obtained from the open access source and ensured not to have any copyright issues.

Figure 1. Stimuli representing mild level of pain.

Figure 2. Stimuli representing moderate level of pain.

Figure 3. Stimuli representing severe level of pain.

C. Procedure

The participant was seated comfortably on chair and table provided facing a blank wall after wearing the headset (as shown in Figure 4). Before the task begin, the instructions on how to respond to the tasks was given. Participant was allowed to practice this task several times before the actual task was carried out. A sheet of paper and a pen are provided on the table for rating purposes. Prior to visual stimulation, the empathy level of participant needed to be assessed by answering an empathy questionnaire. After viewing each image, the participant is required to rate the pain they might feel by imagining their self, loved one or stranger in the same unfortunate event. All the images were arranged and presented in pseudorandom order. These images were presented on a 12-inch tablet in front of the participant. Participant was asked to do their rating (write on paper) from no pain to worst possible pain (scale of 0 to 5) as shown in Figure 5. The participant undergoes an EEG brain scanning during the empathic-pain visual stimuli is exposed to them. During the stimulation, the EEG records their brain activities.

Figure 4. Participant sat comfortably facing a tablet and blank wall.

Figure 5. Participant do the rating by writing on paper.

Throughout the session, participant was advised to minimize their movement and eye blinking in order to reduce the motion artefacts. Along with the experimental procedure (pain images rating), the electroencephalogram (EEG) data was recorded. The brain electrical activities were captured from five (5) points electrodes placed on the scalp (AF3, AF4, T7, T8 and Pz). Besides, no hair care products such as gel, wax, hairspray and more was allowed to be applied to lower the electrodes impedances since wet hair will only contributes to higher impedances. The colour indicator on the software was used to graphically monitor the impedance of each electrode, with green (Figure 6) denoting low impedances and good recording quality and red (Figure 7) denoting high impedances and poor recording quality.

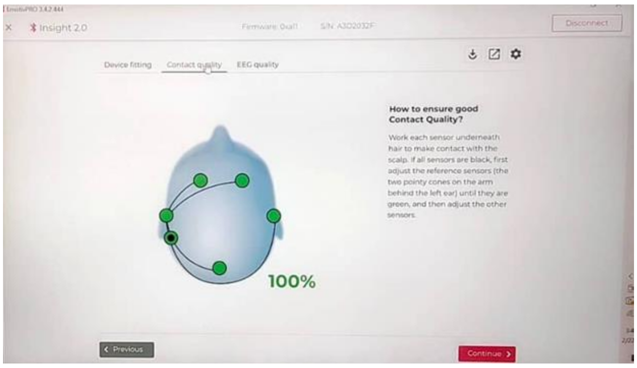

Figure 6. The green indicators on the software showing the low impedance of electrodes and good recording quality.

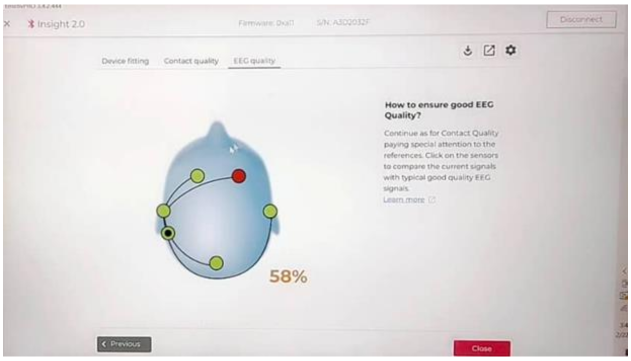

Figure 7. The red indicators on the software showing the high impedance of electrodes and poor recording quality.

D. Empathy Test (Questionnaire)

Participants were asked to answer a questionnaire of Empathy for Pain Scale (EPS), which characterizes the phenomenology of empathy for pain, including the vicarious experience of pain when seeing others in pain [6]. The EPS questionnaires are in English language. This questionnaire consists of four sections, in which it aims to find out the participant's feeling when looking at (1) A person undergoing a surgical procedure, (2) A person who has recently had a surgical procedure in real life, (3) A person being physically assaulted and (4) A person being accidentally injured.

This is a psychometrically sound new scale that characterizes empathy for pain and vicarious pain, where it offers valuable insight to the phenomenological profile of the affective, empathic and sensory dimensions of empathy for pain [6].

E. EEG Recording and Analysis

A lightweight and user-friendly design equipment named EMOTIV Insight 5 Channel Mobile Brainwear was used. The EEG sensors have five channels (AF3 – Left Frontal, AF4 – Right Frontal, T7 – Left Temporal, T8 Right Temporal, Pz – Mid Brain) and two references: CMS/DRL references on left mastoid process. The raw EEG data was recorded using EmotivPRO software while the neurophysiological data was analysed using EEG analysis software, BrainVision Analyzer 2.1. The pre-processing steps were applied to all raw EEG data to reduce artefacts from body movement and eye blinking.

Figure 8. EMOTIV Insight 5 Channel Mobile Brainwear – Stealth black-2.0.

III. RESULT AND DISCUSSION

A. Empathy and Pain Rating Assessment

TABLE I. EMPATHY AND PAIN RATING SCORES OF EACH PARTICIPANTS

Subject	Empathy Score	Empathy Result	Pain Rating		
			ST	OS	LO
SF8	3.46	Moderate	3.00	3.00	3.33
SM9	3.17	Moderate	4.00	4.33	4.67
SM10	2.56	Low	3.00	3.00	3.33
SM12	3.79	Moderate	4.00	4.00	4.67
SF13	3.85	Moderate	4.00	4.67	4.67
SF15	4.00	High	3.67	3.33	4.67
SM17	3.10	Moderate	3.00	3.67	3.67
SM18	3.04	Moderate	2.33	2.33	3.33
SM19	3.15	Moderate	3.00	2.67	4.00
SM20	3.10	Moderate	2.00	3.00	4.00
SF21	2.48	Low	2.67	3.00	3.00
SF22	3.75	Moderate	2.33	3.00	3.67
SF23	4.00	High	4.00	4.33	4.67
SF24	3.06	Moderate	3.00	2.67	3.33
SM25	3.79	Moderate	4.00	4.67	5.00
SF26	2.63	Low	4.00	3.67	4.67
SM28	3.38	Moderate	3.33	4.00	4.33
SM30	2.50	Low	4.33	3.67	4.33

*ST = stranger, OS = one-self, LO = loved one

There is a trend can be observed among the participants who were undergone for empathy questionnaires and pain rating after visual-pain stimulation. Participant who has scored high in empathy, demonstrated a high pain rating towards strangers, self and loved one. This result is the evidence that the participants do feel like they are in that persons' situation and feel like they were experienced the pain illustrated in the stimuli. There also participants did lower score in empathy thus provide them to rate lower in pain rating as well. This finding can be concluded as empathy do affect the pain perception in either role as they produced significant response for stranger, self or loved one.

B. Power Spectral Density (PSD)

The power spectral density (PSD) of EEG is a basic approach to assess the activity of cortical cells grouped in parallel and space averaged over cortex physiologically, therefore inferring information about brain activity in different cortical areas [24]. This study focused to further analysed on the frontal region of the brain since it is the area that processing pain. The brain wave acquired from all channels was analysed which depicted AF3 and AF4 at the frontal region has higher PSD compared to T7, T8 and Pz as shown in Figure 9(a), 9(b) and 9(c).

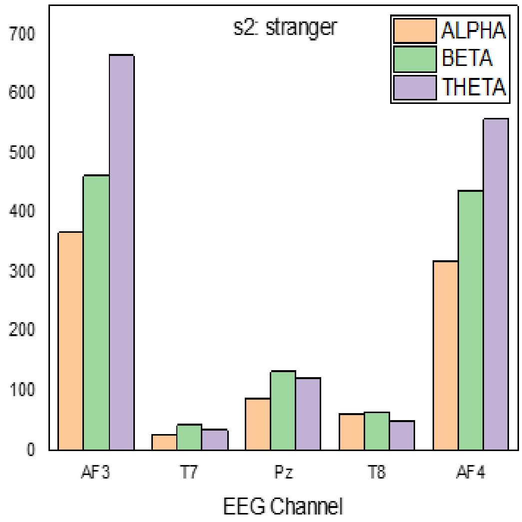

Figure 9. (a) The graph of brain wave when participant imagining a stranger in a painful situation.

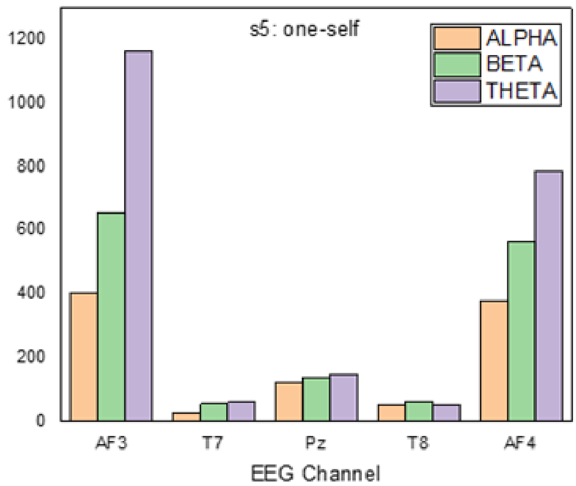

Figure 9. (b) The graph of brain wave when participant imagining him/herself in a painful situation.

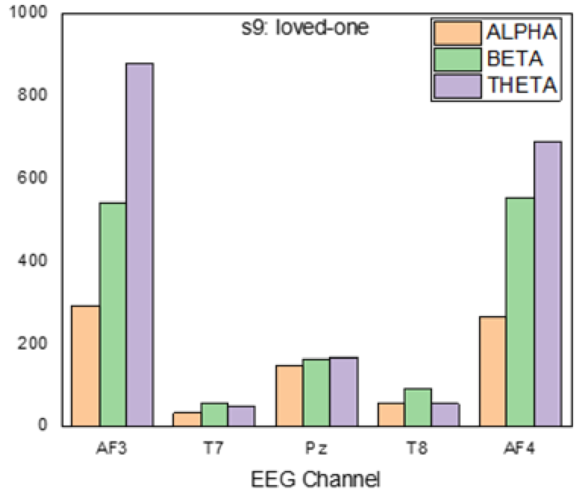

Figure 9. (c) The graph of brain wave when participant imagining a loved-one in a painful situation.

Each intercepted EEG channel has been divided into three segments of interest which are; theta (4-8Hz), alpha (8-13Hz), and beta (13-30Hz). Increasing PSD of a certain frequency in a certain scalp electrode indicates a dominant EEG frequency on the underlying brain region [26]. Alterations in power density of these bands are believed to be associated with various brain activities, such as sleep stage, mental task, and even the severity of neuropsychiatric problem, such as epilepsy, Parkinson's disease, brain death, and so on [15]. The PSD showed the highest at the electrodes located at the frontal lobe (AF3 and AF4) concluded that the subjects were in the activity of thinking, arranging, problem solving, and decision making [18].

C. Brain Area Activation

The prefrontal area plays a significant role in the empathy-pain process, integrating cognitive and emotional responses to others' pain. Most researcher claimed that the frontal lobe functions in planning, attention, decision making, problem solving, and inhibition of behaviour [18]. According to [12], empathy for pain is not only a cognitive process, but also closely connected with emotional responses, highlighting the function of the prefrontal cortex in integrating these components. Moreover, the prefrontal region exhibits different activation patterns depending on the perspective (self vs. other) and type of information (visual or contextual) that are provided [7].

The imaginary pain has activated the prefrontal area of the brain specifically the medial frontal gyrus (MFG), superior frontal gyrus (SFG), orbital gyrus, subcallosal gyrus and rectal gyrus. Along with the insula and anterior cingulate cortex (ACC), this activation is modulated by visual cues, such as body parts or facial expressions, which can distinctly activate sensorimotor processing areas indicating that empathy involves both emotional and sensory processing [7, 25].

MFG contributes to emotional and cognitive processes by integrating the information, allowing for a nuanced empathic response [17]. Whereas, the SFG is linked to the emotional sharing of pain, engaging in vicarious experiences that allow individuals to resonate with others' suffering and it also supports cognitive processes, such as understanding another's perspective, which is essential for effective social interactions [20, 22].

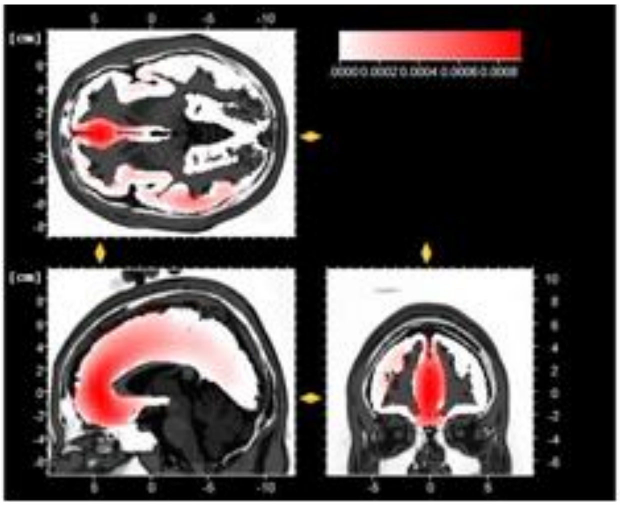

Figure 10. Low Resolution Electromagnetic Tomography (LORETA) within the Montreal Neurological Institute (MNI-Colin-PD) space was computed from 5-Channel EEG activity showing brain area activated during experiment which are medial frontal gyrus (MFG), superior frontal gyrus (SFG), orbital gyrus, subcallosal gyrus, and rectal gyrus.

TABLE II. COORDINATES OF ACTIVATED AREA ASSOCIATED WITH IMAGINARY PAIN PROCESSING UNDER INFLUENCE OF EMPATHY (OR EMOTION)

Areas of activation	**Coordinates**		
	x	**y**	**z**
Medial frontal gyrus	-3	47	-6
	-1	51	-6
	0	45	21
Superior frontal gyrus	-3	64	-6
	-6	60	-6
	-11	45	23
Orbital gyrus	-3	41	-21
	-1	45	-20
Subcallosal gyrus	-3	23	-11
Rectal gyrus	-3	40	-28
	-1	45	-23

D. . Dominant Brainwave

Various research exploring brain oscillations during empathic responses have found that theta wave activity has a major influence on empathy for pain. High theta wave activity (4-8 Hz) is linked with emotional sharing in empathy, whereas alpha waves (8-13 Hz) are associated with emotional regulation. The research reveals that the theta power band presented as the most dominant brain wave. As can be seen in Figure 3, nine stimulus was given to participants which represent three different categories which are S1-S3 for strangers, S4-S6 for oneself and S7-S9 for loved-one. It can be said that when participant view painful stimuli, the theta event-related synchronization (ERS) increases, implying that it plays a role in emotional sharing during empathy for pain [mu].

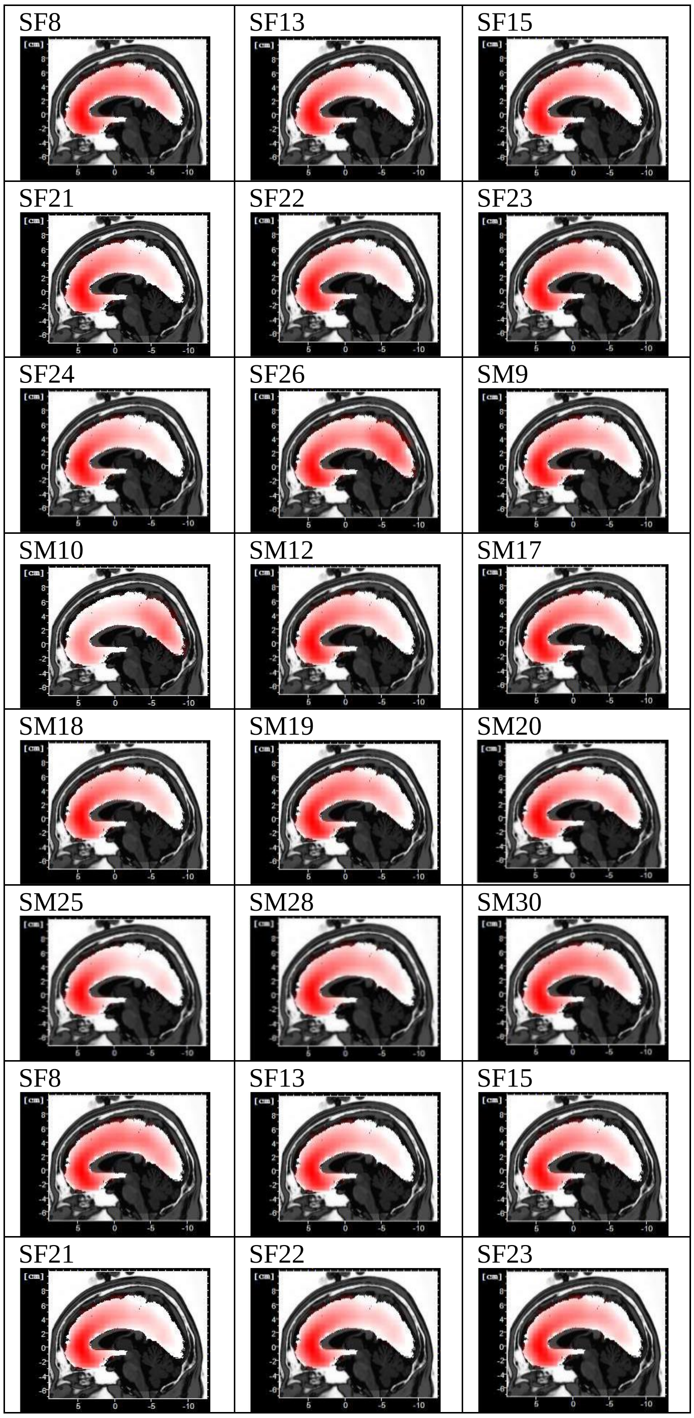

Figure 11. Low Resolution Electromagnetic Tomography (LORETA) within the Montreal Neurological Institute (MNI-Colin-PD) space was computed from 5-Channel EEG activity showing brain area activated during experiment for all participants.

Although having a high theta power band may enhance empathetic responses, it may also result in maladaptive altruism, in which being overly sympathetic causes mental distress or burnout [3]. This emphasizes why maintaining mental health requires a balance in empathetic engagement. While theta waves play an important part in empathetic responses, it is important to note that personal traits could influence these brain mechanisms, potentially affecting the overall empathic experience [5, 10].

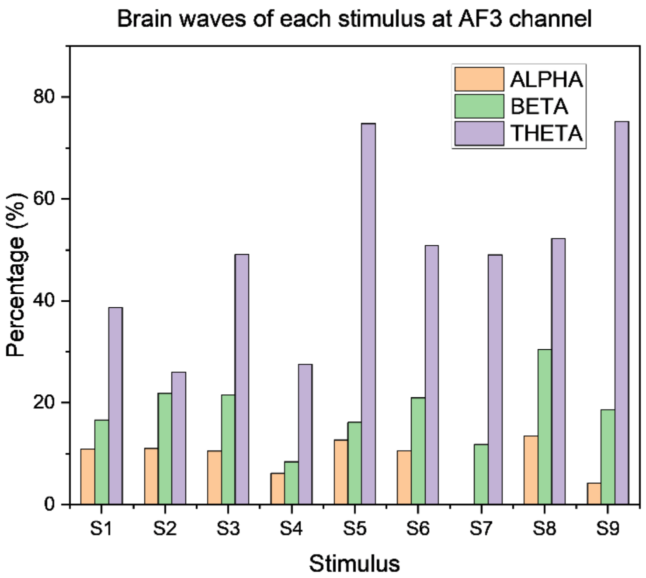

Figure 12. An example of graph showing theta wave at AF3 channel as the highest brainwave in this experiment. S1-S3 represents the participant's brainwave during the pain rating towards stranger while S4-S6 towards oneself and S7-S9 towards loved-one.

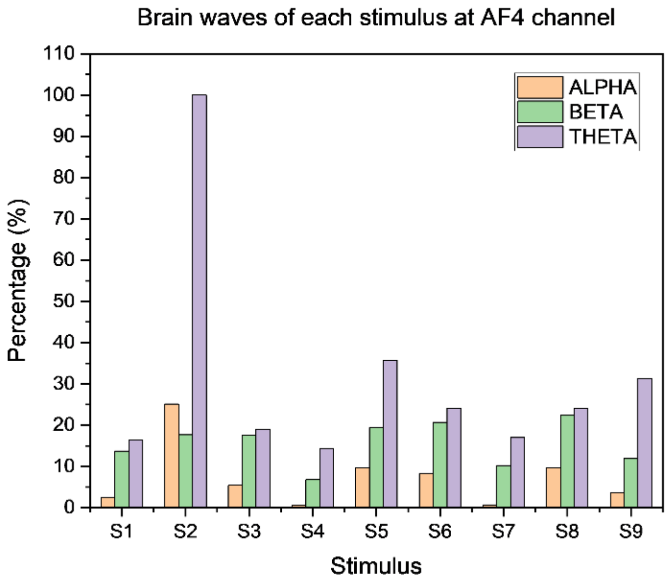

Figure 13. An example of graph showing theta wave at AF4 channel as the highest brainwave in this experiment. S1-S3 represents the participant's brainwave during the pain rating towards stranger while S4-S6 towards oneself and S7-S9 towards loved-one.

TABLE III. THE DOMINANT BRAINWAVE FOR DIFFERENT STIMULUS TYPES OF EACH PARTICIPANTS

Subject	**ST**		**OS**		**LO**	
	AF3	**AF4**	**AF3**	**AF4**	**AF3**	**AF4**
SF8	Theta	Theta	Theta	Theta	Beta	Theta
SM9	Theta	Theta	Theta	Theta	Theta	Theta
SM10	Theta	Beta	Theta	Theta	Theta	Theta
SM12	Theta	Theta	Theta	Theta	Theta	Theta
SF13	Theta	Beta	Theta	Theta	Theta	Theta
SF15	Theta	Theta	Theta	Theta	Theta	Theta
SM17	Beta	Beta	Beta	Beta	Beta	Beta
SM18	Theta	Theta	Theta	Theta	Theta	Theta
SM19	Theta	Theta	Theta	Theta	Theta	Theta
SM20	Theta	Theta	Theta	Alpha	Alpha	Alpha
SF21	Beta	Beta	Theta	Beta	Beta	Beta
SF22	Alpha	Alpha	Theta	Alpha	Theta	Alpha
SF23	Theta	Theta	Theta	Theta	Theta	Alpha
SF24	Theta	Theta	Theta	Theta	Theta	Theta
SM25	Theta	Theta	Theta	Theta	Theta	Theta
SF26	Theta	Theta	Theta	Theta	Theta	Theta
SM28	Theta	Theta	Theta	Theta	Theta	Beta
SM30	Theta	Theta	Theta	Theta	Theta	Alpha

*ST = stranger, OS = one-self, LO = loved one, AF3 & AF4=channel

IV. CONCLUSIONS

This study reveals that brain power value is crucial to be determined to analyse the neurocognitive process related to empathy and pain perception in human. The imaginary pain has activated medial frontal gyrus (MFG), superior frontal gyrus (SFG), orbital gyrus, subcallosal gyrus, and rectal gyrus, and revealing theta power band as the most dominant brain wave. These power values also relate with the pain perception that influenced by the empathy level of individual as observed, individual with high empathy do feel more pain for others. This outcome will help in understanding the mechanism of empathy and pain perception especially when imagining their loved one in pain that could enhance the research development in examining psychological processes. Indirectly, it helps to enhance the personality of new generation to develop good profile and will be improving the quality and productivity of community in strengthening healthcare, society and economic for sustainable nation.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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