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Study on Empathetic-Pain Perception in Brain Induced by Three Levels of Empathetic-Pain Perception Stimuli

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ABSTRACT

Empathetic-pain perception is a divergence from empathy which is a pain perceived as a reflection of perception from others. The study of empathetic-pain perception and empathy were always related with a psychological disorder affecting social and humanity values. The process involved in empathetic-pain perception formations in brain were believed to be different if induced by different level of empathetic-pain perception stimuli. Therefore, this paper was aimed to study the processes involved in empathetic-pain perception formation by revealing the activation-time intervals and source location of the highest empathetic-pain perception intensity. This study conducted an experiment to induce empathetic-pain perception on 16 participants using still pictures as visual-stimuli. Electroencephalograph (EEG) recorded brain signal of the participants during the visual-stimuli presentations while the EEG signal was analysed using MATLAB® toolbox, EEGLAB. Time/frequency decomposition in EEGLAB produces ERSP images which determine the activation-time intervals for empathetic-pain perception and, by performing source localization within the activation-time intervals using sLORETA, the source locations for most active processes in empathetic-pain perception were determined. The processes involved in empathetic-pain perception formation in every level were 'stimuli-learning' and 'memory-reconstructions' by Posterior Cingulate BA 30, pain-regulation by either Postcentral Gyrus BA 2, Cingulate Gyrus BA 24 or both, and visual-stimuli and visual-memory processing by Lingual Gyrus at almost similar time intervals. However, the processes were also performed by various brain areas to either perform attention-sustain process while managed working memory and self-control regulation by Middle Frontal Gyrus BA 46, mirror-neurons activation while processed attention information and emotions by Inferior Parietal Lobule BA 40, multisensory integration by Superior Temporal Gyrus BA 22, or motor-neurons activation to control the skeletal system respectively in every level by Paracentral Lobule BA 6 and Precentral Gyrus BA44. In conclusion, the empathetic-pain perception formation process discovery was necessary to differentiate every affectional level of the empathetic-pain perception.

INTRODUCTION

Empathy perception, the social-emotional response that is induced by the perception of another person's affective state, is a fundamental component of emotional experience and plays a vital role in social interaction (Avenanti, Bueti, Galati, & Aglioti, 2005; Eisenberg & Strayer, 1990; Goldstein & Michaels, 1985). In other words, empathy allows interactions within a community by perceiving emotion which similar with the other person and react to the situation together with them.

Empathy perception deficiencies are the factor of many psychological illness and mental problems. Some example for the psychological illness and mental problems due to lack of empathy perception are autism, sociopath and psychopath (Baron-Cohen & Wheelwright, 2004; Jones, Happé, Gilbert, Burnett, & Viding, 2010). Empathy perception is very important to human life especially towards infants and children. The reason a person should have empathy perception is because empathy perception prevents a person from becoming 'animal-like' cold-heartless human being (de Waal, 2008; Lynam, Whiteside, & Jones, 1999). Other than that, failure of perceiving empathy also means that the person either fails to learn or have problems with their memory (Benedek & Schetky, 1987; Bloise & Johnson, 2007; Goldstein & Goedhart, 1973). Empathy perception has been studied before by some psychologists and neuroscientists considering that empathy perception falls into cognitive perception category

MATERIALS AND METHOD

Participants

In this study, there were two independent groups of participants which a group is involved in the selection of empathetic-pain perception stimuli while the other group were involved in empathetic-pain perception experiment.

The participant group for selection of empathetic-pain perception stimuli is labelled as Group A and is consisted of 50 students from UTM, aged from 19 to 25 years old. The students' agreement to help screening the empathetic-pain inductive pictures were obtained. The gender distribution is 25 females (F) to 25 males (M) (25F:25M). On the other hand, the participants that involved in empathetic-pain perception experiment belongs to Group B. Group B consisted of 16 healthy students with age ranged from 19-25 years old (MEAN = 22.31 years, SD = 2.15) with the ratio of eight males to eight female students (8M:8F). The Group B participants were also involved in electroencephalogram (EEG) recording during the experiment. Prior to the non-invasive measurement involved, the participants were

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advised to read an informed consent to learn about experiment procedure and psychological risks that they may face after participating in this experiment. Other than that, the experiment possesses an ethical endorsement to carry out non-invasive study on brain signals of healthy humans regarding psychophysics stimulation which approved by Research Management Centre of Universiti Teknologi Malaysia. All the participants from both groups are free from any sort of psychological complexes or mental illnesses.

Selection of empathetic-pain perception stimuli

In this study, the stimuli are obtained from International Affective Picture System (IAPS) provided by The National Institute of Mental Health (NIMH) for the Study of Emotion and Attention from University of Florida (Lang, Bradley, & Cuthbert, 2005). Still pictures, when used as inducing stimuli in an experiment are called visual-stimuli. In this study, the pictures were screened through two selection processes to finalize visual stimuli with potential to induce empathetic-pain perception

In the first screening process, members of Neuroscience Team from Faculty of Biosciences and Medical Engineering (FBME) in Universiti Teknologi Malaysia (UTM) have discussions to select potential empathetic-pain perception visual-stimuli pictures as many as possible. At the end of the selection process, 157 still pictures that contained unfortunate events like deaths, injuries, illnesses, crimes, surgeries, and sadness were chosen; the team members believed that by watching these unfortunate events will lead the perception of empathetic-pain in most participants.

In second screening process, the 157 pictures were presented to Group A participants. They were briefed about empathetic-pain perceptions to help them differentiate empathetic-pain perception from another kind of perceptions. When ready, the selection process begins by scoring the presented pictures in the range of 1 to 5 with 1 for the least and 5 for the most effective empathetic-pain perception inducer pictures. At the end of the screening process, the scores for every picture were averaged so that each picture has a final empathetic-pain perception score. The pictures were then divided into six stimuli groups which are Group 1, Group 2, Group 3, Group 4, Group 5, and Baseline Group. The division of the pictures is as shown in Table 1.

Table 1 Assignation of empathetic-pain perception scores for each empathetic-pain perception stimulus-picture group/ level

Final empathetic-pain perception scores	Pictures of empathetic-pain perception group / level
0	Baseline
0.1 - 0.4	Exempted
0.5 - 1.4	1
1.5 - 2.4	2
2.5 - 3.4	3
3.5 - 4.4	4
4.5 - 5.0l	5

Through the assignation as in Table 1, the different levels of empathetic-pain perception stimuli were created; Group 5 contained the highest level of empathetic-pain perception pictures while Group 1 contained the lowest level of empathetic-pain perception pictures. The total number of pictures per one group/level is ten pictures; the groups were filled started with pictures that have largest median score and stopped when a group is fully occupied. However, the number of visual-stimuli to be presented in the experiment are five pictures from each group. Therefore, the visual-stimuli were selected randomly using MATLAB® randomizer.

Tools and equipment

During the empathetic-pain perception experiment, the visual-stimuli are presented and graphically designed using MATLAB add-in extension called Psychtoolbox. Psychtoolbox has function to visualize any desired task presentation from MATLAB coding on laptop screen (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Thus, the design of the task for this study is written as MATLAB coding and ran using psychtoolbox. Psychtoolbox read the stimuli pictures by IAPS that loaded into it and projected them to become visual-stimuli as designed.

On the other hand, the brain activities of the participants were recorded using NeuroConn from NEURO PRAX® electroencephalograph (EEG) device. NeuroConn EEG consisted of Full-band DC-EEG and BIOSIGNAL AMPLIFIER (amplifier) with input impedance larger than 10GΩ, and a PANEL-PC (therapist). In the experiment, 27 electrode-cables were connected to the 'electrode input box' of the amplifier while the other end of the electrode-cables were attached on NeuroConn EEG cap. The 27 electrodes are positioned on participants' scalp based on extended 10-20 system electrode placement. The EEG 10-20 system electrode placement is referring to the distance between adjacent electrodes that were 10% or 20% of the distance from anterior to posterior or of the half diameter of the head distance (Chatrian, Lettich, & Nelson, 1985; Committee, 1994; Jasper, 1958).

Other than that, Hare's Psychopathy Checklist-Revised (PCL-R) is given to each of the participants to assess their psychopathy tendency which directly tells the participants' level of empathy perception. The maximum score of the checklist is 40 where the different total scores inversely define subjective empathetic-pain perceptions of the participants from psychopathy tendency. The high score determines that there is high tendency of psychopathy and that the level of empathy perception is low (Decety, Chen, Harenski, & Kiehl, 2013). The same case goes when the score for psychopathy tendency is low. Thus, we selected only participants with low PCL-R value ($0 \leq$ PCL-R ≤ 20) for further data collection because it means their empathy perception level is high and because participants with low PCL-R score are presumed to have capability in perceive empathetic-pain. The division of the scores for level of empathy perception are as follows: **1)** high level of psychopathy tendency or low level of empathy perception ($31 \leq$ PCL-R ≤ 40), **2)** intermediate level of psychopathy tendency or intermediate level of empathy perception ($21 \leq$ PCL-R ≤ 30), and **3)** low level of psychopathy tendency or high level of empathy perception ($0 \leq$ PCL-R ≤ 20) (Hare, Clark, Grann, & Thornton, 2000).

Lastly, the analysis was performed using EEGLAB while the source localisation of the ERP files was performed using sLORETA.

Design of empathetic-pain perception experiment

The experiment is designed as 'blocks of runs', 'runs of sets', and 'sets of pictures' while conducting EEG recording along the presentations of 'baseline-set' and the 'stimuli-set'. The experiment consisted of four 'blocks of runs' while one 'block' consisted of five 'runs' of picture 'sets' which makes the total number of runs in one experiment are 20 runs. One 'run' consisted of one 'set' of 'baseline-pictures' which is called 'baseline-set' and six sets of 'stimuli-pictures' which is called 'stimuli-sets. Therefore, this makes the total number of baseline-sets and stimuli-sets in one experiment are 20 sets and 120 sets respectively. Every 'baseline-set' consisted of a fixation cross picture and five non-affective-inducer pictures. Baseline-sets were neutraliser in the experiment to induce participants to have neutral-perceptions while watching the non-affective-inducer pictures.

While, every stimuli-set consisted of a fixation cross picture as well as five empathetic-pain perception pictures which make the total number of 'baseline-pictures' and 'stimuli-pictures' excluding fixation crosses are 100 and 600 pictures respectively.

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Participants ranked empathetic-pain perception scores only on empathetic-pain-perception pictures of 'stimuli-sets' at after the presentations of every 'stimuli-set'. The total number of EEG recordings for one 'run' is two times, ten times in one 'block', and 40 times in the whole experiments.

Determination of empathetic-pain perception activation-time

The wavelet transform analysis is conducted in this study to determine the activation-time of empathetic-pain perception by plotting time/frequency decomposition of EEG data in EEGLAB. The empathetic-pain perception EEG data (LL, LM, and LH) were averaged separately and were subtracted with neutral-perception ERP data (baseline-sets) to let the time/frequency decomposition determine the activation-time on empathetic-pain perceptions over neutral-perceptions. Plotting of time/frequency decomposition produced event-related spectral perturbation (ERSP) image which depicts activation-time based on changes or perturbations in the spectral content of the data. The changes or perturbations should be due to empathetic-pain perception activity over neutral-perception activity, which could be positively or negatively triggered.

There are series of colour marks in the ERSP image which represent positive and negative activity of empathetic-pain perception. The colour scale on the right represents positive activity with yellow-to-red colour while negative activity with blueish-to-blue colour while zero activity or neutral activity with green colour. Positive activities mean that empathetic-pain perception was higher than neutral-perception while, negative activities of empathetic-pain perception mean that the empathetic-pain perception activities were suppressed to become lesser than neutral-perception activity. The empathetic-pain might be suppressed by other affection that comes along the empathetic-pain perception presentation such as fear, disgust, and anger (Martin et al., 2015). Whereas, neutral activity indicates that empathetic-pain perception has same activity with neutral-perception.

Source localisation of brain activities using sLORETA

sLORETA is a source localization tool which it applies an instantaneous, distributed, discrete linear solution to extract and depicts information on the time course and source location of EEG brain signal (Pascual-Marqui, 2002). Source localization is performed on ERP files during the activation-times which were following the time frames for colour marks in the ERSP images. The ERP data for empathetic-pain perception is transformed into sLORETA format and were statistically analysed in comparison with ERP data for perceptions towards baseline pictures using Log of ratio of averages (log of F-ratio). The statistical analysis produces a generated sLORETA (*.slor) file which contains the test result of significance difference between empathetic-pain perception and neutral perception. The test result files were dragged into sLORETA Viewer and generating voxel values to represent empathetic-pain perception intensities for voxels that appeared on MRI template. The highest empathetic-pain perception intensities were identified by finding the highest voxel values to investigate the formation of empathetic-pain perception.

RESULTS AND DISCUSSION

Activation-time of empathetic-pain perception in brain

Activation-time of empathetic-pain perception were determined by performing time/frequency decomposition. The ERSP images produced for LL, LM, and LH of empathetic-pain perception are shown in Fig. 1, Fig. 2, and Fig. 3 respectively.

Fig.1 ERSP image with significant differences between empathetic-pain perception and neutral-perception are the activation-time frames for empathetic-pain perception activity of Level-Low (LL).

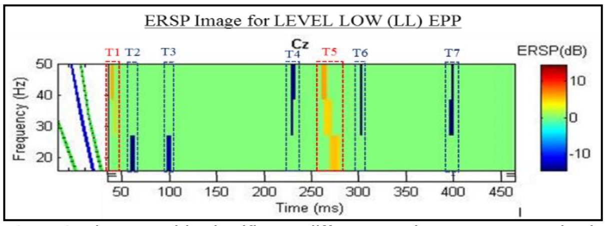
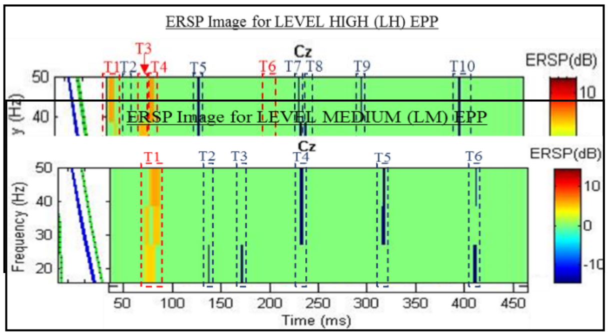


Fig. 2 ERSP image with significant differences between empathetic-pain perception and neutral-perception are the activation-time frames



for empathetic-pain perception activity of Level-Medium (LM).

Fig. 3 ERSP image with significant differences between empathetic-pain perception and neutral-perception are the activation-time frames for empathetic-pain perception activity of Level-High (LH).

Overall, the ERSP images concluded that perturbations in the spectral content of the subtracted empathetic-pain perception ERP over neutral-perception ERP were recognised as the significant difference between empathetic pain perception and neutral-perception activity in the brain. In this study, the time interval for the significant difference to take place are activation-time frame for empathetic-pain perception. The empathetic-pain perception activation-time frame was recorded and was essential in comparing empathetic-pain perception process corresponding to different levels of empathetic-pain perception stimuli.

Process of empathetic-pain perception formation in brain

Following the activation-time intervals of empathetic-pain perception, there were source location of empathetic-pain perception that could describing the formation of empathetic-pain perception in brain to be compared among every level. Graphs contained time transitions and source location of the most active brain signal while watching the empathetic-pain perception stimuli of every level can be found in Fig. 4, Fig. 5, and Fig. 6 respectively.

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Fig. 4 Graph of empathetic-pain perception formation with the source location of the highest empathetic-pain perception intensity for LL at every activation-time.

Fig. 5 Graph of empathetic-pain perception formation with the source location of the highest empathetic-pain perception intensity for LM at every activation-time.

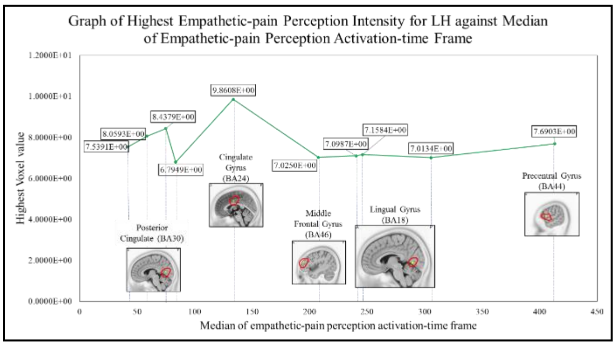


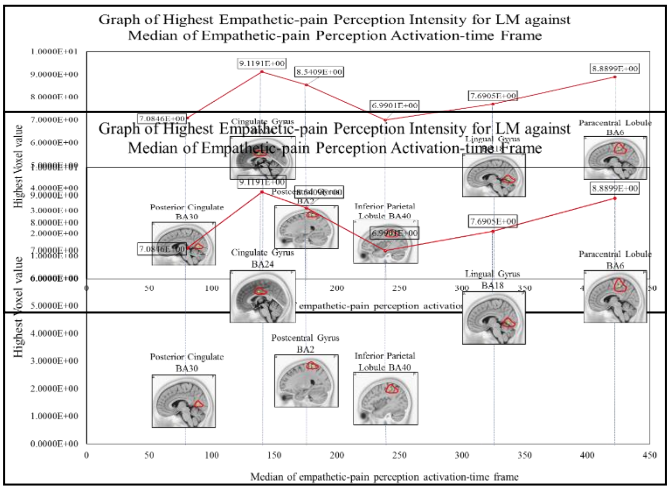
Fig. 6 Graph of empathetic-pain perception formation with the source location of the highest empathetic-pain perception intensity for LH at every activation-time.

The formation of empathetic-pain perception as induced by LL, LM, and LH of empathetic-pain perception stimuli shows that the processes of the highest empathetic-pain perception intensity involved are different in every level as every brain area possesses different brain function which can be found in Table 2 follows.

Table 2 Brain function for the brain areas involved in formation of empathetic-pain perception

Source location	Process executed during empathetic-pain perception
Lingual gyrus BA 18	Processing visual stimuli and visual memory.
Paracentral lobule BA 6	Premotor cortex; controls motor activity.
Posterior Cingulate BA 30	Involved in emotion, activated by emotional memory recalling (learning) and pain.
Precentral gyrus BA 44	Controls voluntary movements of skeletal muscles, visual inspection.
Postcentral gyrus BA 2	Sensory receptive area for sense of touch and pain, a part of somatosensory cortex.
Middle Frontal Gyrus BA 46	Sustaining attention, managing working memory, regulate self-control.
Superior temporal gyrus BA 22	Regulate emotions due to facial stimuli, analyses social information received visually, multisensory integration,
Inferior parietal lobule BA 40	Mirror system, processing information from attention, emotional processing.
Cingulate Gyrus BA 24	Participate in limbic system by producing anatomic effects associated with emotions
Inferior Frontal Gyrus BA 46	Mirror neurons firing, active during motor preparation

Referring to Table 2 above, Postcentral Cingulate BA 30 is a brain area that involved in memory recall and learning. In empathetic-pain perception formation of every level, the empathetic-pain perception pain stimuli were learned and identified within the first 100ms by the Postcentral Cingulate BA 30. In previous studies on empathetic-pain



perception, Limbic System and Primary Somatosensory Cortex are found to be activated during empathetic-pain perception stimulation and were known as sensory receptive area pertaining to pain which responses emotionally. Among the brain areas listed in Table 2, Postcentral Gyrus BA 2 is one of the Primary Somatosensory Cortex while, Cingulate Gyrus BA 24 is one of the Limbic System. After the regulation by either the Limbic System area or the Primary Somatosensory area, LL and LH of empathetic-pain perception formation performed attention sustaining, working memory management, and self-control regulation by Middle Frontal Gyrus BA 46. On the other hand, LM processed information from attention by Inferior Parietal Lobule BA 40 which also hosted the mirror system and emotional processing process. In every level of empathetic-pain perception formation, there is Lingual Gyrus BA 18 as the second-last activated brain area which processed visual stimuli and visual memory. However, the processed information from the Lingual Gyrus BA 18 was transferred to Superior Temporal Gyrus BA 22 for LL, Paracentral Lobule BA 6 for LM, and Precentral Gyrus BA 44 for LH which, all the three brain areas completed the formation using multiple integration of auditory and visual information, motor neurons to control the movements of the skeletal muscles.

CONCLUSION

In conclusion, the results in this study have discovered the activation time, source location, and intensity of empathetic-pain perception activity are not uniform among the levels of empathetic-pain perception. Therefore, the proposed hypothesis which suggest that studying the process of empathetic-pain perception formation induced by different empathetic-pain perception are essential for empathy detection, were supported.

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