An Approach of Brain-Computer Interface Electroencephalography for Measuring Visual Height Intolerance

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Abstract – The environment is one factor that influences the quality of life, including a high environment for people with the fear of height (Visual Height Intolerance, VHI). Currently, VHI is measured by using the Visual Height Intolerance Severity Scale (VHISS). The lack of evidence-based testing makes these measurements feel weak and less meaningful. The use of Virtual Reality (VR) and Electroencephalography (EEG) based on the Brain-Computer Interface (BCI) deserves to be tested. The test is done by reading the human brain's electrical activity using a BCI-based EEG when given VR exposure. The analysis process uses a simple wave concept. Furthermore, the correlation study was carried out using the Spearman-rho method with a consideration of the normality test, which produced non-parametric data. The correlation test results show that the BCI-based EEG biometric data in the form of the amount of waves per time and magnitude has a strong relationship with the VHISS scale. The higher the number of waves per time, the higher the amplitude, the higher the VHISS scale. The evaluation was carried out by examining the correlation based on the demographics of age and gender. Finally, EEG based on BCI and VR can be an alternative and concrete evidence to review the level of visual height intolerance other than VHISS.

Keyword: brain-computer interface, electroensephalography, visual height intolerance, virtual reality.

I. INTRODUCTION

Fear at high altitudes is normal, but the fear becomes unnatural if it is disturbing and hindering activities. According to Huppert, of a total of 1,960 people recruited in Germany, the prevalence of lifetime Visual Height Intolerance (VHI) was 32.7%. As many as 12% of these people met the psychiatric criteria to suffer from acrophobia [1]. In the Netherlands, 530,000 suffer from phobias. Every year 75,000 new cases are detected. Acrophobia is the most common, but access to evidence-based therapy is currently limited due to the high cost of care, long waiting lists, and a general reluctance to seek treatment. These inhibitions can make the disorder chronic and increase the risk of developing other mental disorders, such as anxiety and depression, especially for women if left untreated [2]. The fear of heights reduces body stability, the possibility of shock or stress, physical health, mental health, and Quality of Life. The correlation of the above problems with fear of heights has been studied previously [3].

The next problem arises when examining the level of fear. Testing directly at high altitudes is a difficult challenge due to the considerable risk of falls, difficult places to reach, and difficulty maintaining long-term exposure to altitude, and unsatisfactory evidence-based measurements. Moreover, when the test is carried out simultaneously for high school students, which is the period when the disturbance begins to be felt and not too difficult to cure.

VHI can be measured by the Visual Height Intolerance Severity Scale (VHISS) [1]. However, VHISS can only be applied to patients who have experienced exposure to altitude. For patients who have never been exposed to or avoided altitude, VHISS cannot be used, because it measures based on their experience. Patients also need concrete evidence of the results of the examination. The proposed alternative solution that can be used is to use height exposure through Virtual Reality [2], [4-5].

An alternative to VHISS that can be considered is electroencephalography (EEG), based on the Brain-Computer Interface (BCI), because the brain's electrical waves change when the senses are stimulated. BCI-based EEG with VR has been applied to neurorehabilitation [6]. The importance of this research is to ensure the use of BCI-based EEG with VR can be an alternative to VHISS.

Research related to height anxiety with visual exposure has been carried out using various measuring instruments, namely the electrocardiogram and the Skin Conductance Level. From this measuring instrument, the heart rate and skin conduction rate show a significant correlation [7]. Another measuring tool specifically used for the fear domain at height is Acrophobia Questionary (AQ) [8]. In 2017, the Visual Height Intolerance Severity Scale (VHISS) was proposed to replace Acrophobia Questionary (AQ) [1].

Biometric measures such as the EEG hold promise as a viable alternative to subjective questionnaires in evaluating the psychophysical effects associated with visual exposure [9]. The use of complex EEG is undoubtedly challenging to reach commercially. The use of BCI-based EEG is interesting to be further investigated in providing alternative concrete evidence for detecting the level of anxiety towards the altitude.

Visual Height Intolerance Severity Scale (VHISS) is a measuring tool that measures anxiety about height. The measuring instrument was formulated by Huppert and his friends in 2017 in Germany [1]. VHISS is structured with several questions and includes a subjective questionnaire. The results of the measuring instrument are presented in the form of a scale. Patients fill it out based on their experience, so this measurement tends to be subjective. VHISS was developed to replace the Acrophobia Questionary. The advantage of VHISS is that it can find out the level of anxiety on a scale without having to be diagnosed with acrophobia. Acrophobia Questionary is purely used to measure heights' phobia and does not measure a patient's anxiety level.

Virtual Reality (VR) is a way of manipulating visual exposure so that the user appears to be in a virtual world so that what the patient sees is unreal. VR can be an alternative to facilitate access, reduce costs, and improve the reception of stimulation than traditional exposure. The use of VR has been proven in many studies [2], [4-5], [10] and fulfilled the research protocol in the Randomized Controlled Trial (RCT). Moreover, VR in height phobia (acrophobia) gives disturbing signs of anxiety [11]. The use of BCI and VR-based EEG will undoubtedly produce a different response to the patient's condition.

Electroencephalogram (EEG) is a non-invasive test that aims to detect electrical wave activity in the brain using electrodes embedded in an EEG device [12]. EEG signals can predict psychological indicators and measure alertness [13-14]. The recording of this bioelectric signal originated form the experiments of Italian scientists Luigi Galvani (1737-1798) and Alessandro Volta (1755-1832). British scientists Georg Ohm (1787-1854) and Michael Faraday (1791-1867) managed to prove biological tissue, especially muscle tissue, has sufficient electrical properties. EEG is an indispensable method for studying the brain's functional status from a clinical perspective and still maintains laboratory characteristics with a relatively simple, non-invasive, and reproducible test. Outside of its clinically established field, EEG is also of interest in trials in other areas. The EEG origin is based on the flow of ionic currents generated by neurons in the extracellular space. To understand the extracellular potential's postsynaptic origins, we can imagine ionic currents flowing inward towards the cell through the synaptic membrane and out through the extracellular membrane's large surface [15].

Brain-Computer Interface (BCI) is an EEG adaptation in technological developments. It is designed as a high-magnitude and low-number of waves per time EEG response to external stimulation of time [16]. Biometric measures, such as the electroencephalogram (EEG), are promising to be a viable alternative in subjective questionnaire assessments to evaluate psychophysical effects associated with Virtual Reality (VR), which can provide a continuous objective measurement without damaging the exposure [9]. BCI works by capturing the tiny electrical impulses released when neurons fire in the brain using the sensor's tip/arm placed on the forehead as the main electrodes. The Ear Clip that is installed functions as a reference electrode or a comparison electrode of the main electrode, which maintain a stable and detectable electrode potential [17].

Another study used heart rate and skin moisture to determine anxiety about height [7]. Together with the use of VR, BCI-based EEG has often been used in the field of neurorehabilitation [18]. However, its use is limited to the rehabilitation process. The high cost of using the EEG makes BCI a cheaper option. The combination of VR and EEG based on BCI is expected to contribute to the measurement of height anxiety as an alternative to VHISS based on the small electrical jumps that occur in the brain.

II. METHOD

The method used in the research that has been carried out consists of four stages and is depicted in Fig. 1: data collection stage, data validation stage, data analysis stage, and evaluation stage.

Fig. 1 Diagram of the Research Method

A. Data Acquisition

Data collection is divided into two stages. The first stage is to fill in the Visual Height Intolerance Severity Scale (VHISS). The results obtained by VHISS are in the form of a scale. The second stage uses Virtual Reality as a stimulus and Brain-Computer Interface (BCI) as an EEG with the MILA framework [19]. The results obtained from these tools are in the form of the number of waves per time and magnitude. Each sample has three data, data from EEG based on BCI in the form of the number of waves per time, magnitude, and scale from VHISS.

Fig. 2 shows the visual exposure of the VR used. The exposure uses 360-degree video flown by a drone vertically reaching 700 feet above the surface. Participants will still be able to see the altitude from the front and back for one minute. The video runs in a VR Player embedded in a VR box and used in conjunction with the BCI-based EEG.

The BCI-based EEG used is shown in Fig. 3. This device is a product of MindWave Headset made by Neurosky as MW001 model. This tool has been involved in various studies, such as detecting eye blinks based on biometrics [13], controlling a robot [20] until it is used to identify stress [17]. Neurosky Mindwave was selected as BCI to obtain biometric data from the brain at a lower cost without losing its ability to capture EEG-like neuronal activity when given visual exposure via VR. Awangga's use of MILA reinforced the work as a Low-cost BCI framework for acquiring EEG data [19].

Fig. 2 Visual exposure of virtual reality used

Fig. 3 BCI-based EEG used

B. Data Validation

The used VHISS uses a different language from the original VHISS. Hence, data validation is required. This step aims to ensure that the VHISS measuring instrument used is reliable even though it uses a different language from the actual language. In this study, the BCI-based EEG was not validated considering that the measuring instrument used was the same as the MILA framework [19]. VHISS validation was carried out using the Alpha Cronbach method to determine the consistency of a series of measurements against the VHISS measuring instrument. This method measures each correlation coefficient between items and resulting r count. r count is then compared with the r value in the r table according to the desired confidence as a statistical agreement standard according to the number of participants.

C. Data Analysis

There are two main kinds of captured data, the data from VHISS and the data from the BCI-based EEG. The data obtained from the VHISS has a scale between 1-9. The data obtained from the BCI-based EEG is a series of 4000 lines of data in mV (millivolts) units. Furthermore, a simple algorithm is used to determine the number of waves per time and magnitude from the EEG data.

Wave (λ) is composed of hills and valleys of the waves that pass through the equilibrium point, as shown in Fig. 4. The series of data from the EEG-based BCI consists of positive and negative values. Positive values represent hills, and negative values represent valleys with zero equilibrium. The number of waves in a spesific time is also known as frequency. The number of waves per time is known from the wave density as in equation 1. The denser the wave, the greater the number of waves per time obtained. The number of waves per time shows the intensity of the neuron when it creates ion currents.

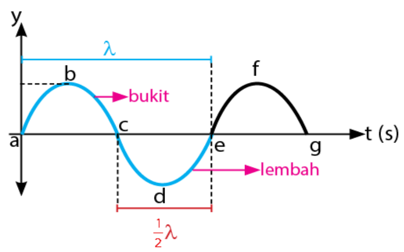

Fig. 4 Wave concept

Magnitude is the largest ion current captured by the electrode obtained from the farthest point to the point of equilibrium. The magnitude is always an absolute value and can be obtained either from the hills of wave or the wave valleys (1).

$$f = \frac{n}{t} \tag{1}$$

f = number of waves per time (hertz)
n = the number of wave
t = time (second)

The next analysis stage is to determine the appropriate correlation method. The first step that can be done is to test normality data by using the Shapiro method. The test aims to determine whether the data used has a parametric scale (normally distributed) or non-parametric (not normally distributed). Some of the parametric methods for correlation tests are Pearson and Regression. The Spearman method includes a correlation test for non-parametric methods, where the assumption of population distribution is no longer a limitation.

Considering the magnitude data is in the form of intervals, and VHISS data is ordinal, the correlation method used can use the Spearman-rho method. This consideration is also supported by the distribution of the data population, which tends to be non-parametric. Unlike the Pearson method, which is more suitable for parametric data or normally distributed data [21].

The Spearman correlation calculates two variables divided by the product of their standard deviation to collect a ranking based on the two variables. This method is often used for ordinal data or interval and ratio data that are not normally distributed. Interval and ratio data that are not normally distributed are usually referred to as ordinal data, which are natural order [22], [23]. The rho value (as a unit of measure for the Spearman method) is obtained by calculating the total distance between two variable ratings (VHISS scale rank with the number of waves per time rating or VHISS scale rating with magnitude rating) and divided by the standard deviation of the number of participants. The correlation method is shown in (2).

$$r_s = \frac{6\sum {d_i}^2}{n(n^2-1)} \tag{2}$$

r_s = the spearman-rho correlation value
d_i = the ranking distance between the variable rank x and the variable rank y
n = number of participants

D. Evaluation

Evaluation is carried out by conducting further analysis of the correlation measurement results. Some things that might be done are understanding the participant demographics, such as gender and age of participants, by relating them to BCI-based EEG data and VHISS data. The degree of correlation that can be studied becomes more variable.

III. RESULTS AND DISCUSSION

A. Data Acquisition

The data were collected at the Sekolah Menengah Atas Negeri (Public Senior High School) 1 Karangjati, Karangjati District, Ngawi Regency (SMAN 1 Karangjati). SMAN 1 Karangjati is located in a flat lowland area with an altitude of about 70 meters above sea level. Judging by the school zoning policy in East Java, most participants live in the eastern region of Ngawi Regency. The area's topography is classified as lowland, with an altitude of about 70 meters to 170 meters above sea level. In contrast to the southern part of Ngawi Regency, which tends to be higher on the mountain's slope, to reach the highlands, the participants need to cover about 30 km, which is quite far, as shown in Fig. 5.

SMAN 1 Karangjati is one of the schools with the best sports achievements in the area. One of the obstacles faced by students during exercise is anxiety when in high places. Some who have the ambition to work in high places and environments such as flight attendants, air force, and civil engineering must learn to eliminate heights' anxiety. The school was pleased to be involved in this research.

The number of participants involved was 107 people with a range of age around 16 years to 17 years. There are 74 persons on their 16s and 33 persons on their 17s. They are 67 male participants and 40 female participants. Measurements using BCI-based VHISS and EEG and the given VR exposure were carried out regardless of age or gender. All of them are students at the school.

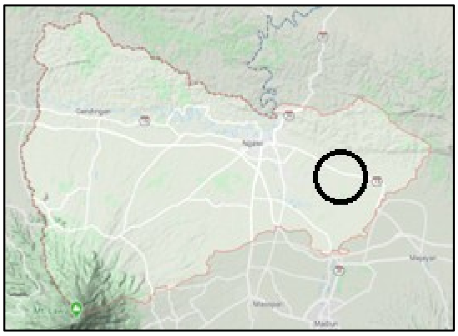

Fig. 5 Participants environmental topography

Fig. 6 shows one of the processes when data collection was carried out. First, each participant is invited to fill out the VHISS questionnaire compiled by Huppert [1]. The larger the scale obtained, the stronger the anxiety it has. The next step is to measure using EEG based on BCI and VR. The BCI-based EEG connects to the computer wirelessly using the MILA system model [19].

Each participant obtained the VHISS results as in Table I. The scale was calculated from the VHISS questionnaire consisting of eight questions with an answer score from 0 to 2 according to Huppert rules [1]. All scores for each participant are then added up to obtain the VHISS Scale. The ninth and tenth questions are specific and serve to ascertain whether the participant has acrophobia with a score of 1 or does not have acrophobia with a score of 0. Other information obtained is the participant's demographics, gender, and age.

BCI based EEG model using MILA framework [19] produce biometric data as shown in Fig. 7. The model is built using the Python programming language with a console display. The final product obtained is the number of waves per time and magnitude. The number of waves per time is obtained from the number of waves divided by time. The number of waves per time is calculated simply without a method like Fourier Transform. The magnitude is obtained from the highest amplitude at the time of data collection.

Based on all participants, the number of waves per time obtained was in the range of 8 hertz to 15 hertz, while the obtained magnitudes were in the range of 400 mV to 1800 mV. The author tries to directly draw the number of waves per time and magnitude relationship with each question on the VHISS, and the results are not interrelated. Each question has its weight. For example, in the first question, the majority have the same answer, which is one. In contrast, each participant has various waves per time and magnitudes, which creates the assumption that what the participants feel is different from one another. Measurements when composing VHISS questions by Huppert [1] already under careful consideration, so the VHISS scale is ready to be correlated directly with BCI-based EGG.

B. Data Validation

The reliability coefficient (raw_alpha) VHISS is 0.66, which shows that the measuring instrument used has fairly good resistance to repeated data collection based on the standard reliability coefficient of 0.5. The mean value of r as "r count" obtained is 0.20. The value of "r count" > "r table" (0.20 > 0.19), with a significance level of 5%, then the average item on VHISS can be said to be valid. [24]. We can conclude and show that the VHISS measuring instrument's accuracy and precision are good to use with 95% confidence.

TABLE I
EXAMPLE OF OBTAINED VHISS DATA

Participant	VHISS Questions								VHISS Scala	Acrophobia Question		Gender	Age
	1	2	3	4	5	6	7	8		9	10		
1	1	2	1	1	1	1	1	1	9	0	0	P	16
2	1	2	1	1	1	1	0	0	7	0	0	P	16
3	1	0	1	1	0	0	0	0	3	0	0	L	17

Fig. 6 Data acquired process

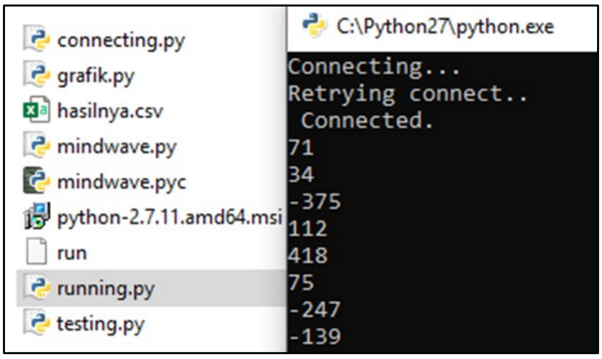

Fig. 7 Example of BCI-based EEG data obtained

C. Data Analysis

Correlation studies were conducted twice with different BCI-based EEG data. The data used for the analysis consisted of waves per time data from the BCI-based EEG with the VHISS scale and magnitude data from the BCI-based EEG with the VHISS scale. These data resulted in two correlation studies of waves per time with the VHISS scale and magnitudes with the VHISS scale.

The first step to take is the normality test. This testing step is carried out to determine which correlation method is more appropriate. The normality test result for waves per time data are shown in left side of Fig. 8 with p-value 0.005572. Using a significance value of 0.05 means that the p-value is smaller than the significance value, so the number of waves per time data can be declared not normally distributed. The farther data are distributed from the normal line, the more the data are declared to be not normally distributed.

The results of the normality test for the magnitude data are shown in right side of Fig. 8. The p-value obtained was 1,727 x 10^{-10}. The data is declared not normally distributed based on the p-value obtained, which is much smaller than 0.05. It can be interpreted that the magnitude data are not normally distributed at the 95% confidence level.

The Spearman-rho method is used if the data requirements used are ordinal and not normally distributed have been met. VHISS shaped ordinal scale, while the number of waves per time data shaped interval can then be known as the ordinal natural order. This is based on the form of number of waves per time data, which is also sequential like ordinal even though it has a wider range.

The rho value obtained was 0.7035187, which shows a fairly strong and harmonious correlation (shown in left side of Fig. 9). The p-value obtained is 2.2 x 10^{-16} and is smaller than 0.05 significance value. Therefore, the relationship between the number of waves per time and VHISS is accepted with a confidence level of 95%. From these data, the higher VHISS scale, the higher number of waves per time obtained.

The correlation test result between the magnitude data and the VHISS scale are shown in right side of Fig. 9. The p-value obtained was 2.2 x 10^{-16}. By comparing the 0.05 significance value, the result indicated a relationship between the magnitude data and the VHISS scale with a 95% confidence level. The rho value obtained was 0.7269371, meaning that the correlation between the magnitude data and the VHISS scale was considered strong and consistent. The higher the VHISS scale, the higher the magnitude obtained. The number that is often used as a reference is the rho value of 0.6. The rho value above 0.5 is considered to have a relationship, while a rho value below 0.5 can be considered as having no relationship. Uncertain standards give the researcher the freedom to measure it according to research conditions and findings with consideration. The greater the rho value, the stronger the relationship between the two juxtaposed data.

Overall, the tests carried out have sufficiently correlated results. The distribution of a number of waves per time data tends to be in line with the VHISS scale. Likewise, the magnitude data tends to be in line with the VHISS scale. From these data it can be concluded that the denser the distribution of number of waves per time and magnitude data with the VHISS scale, the stronger the correlation obtained.

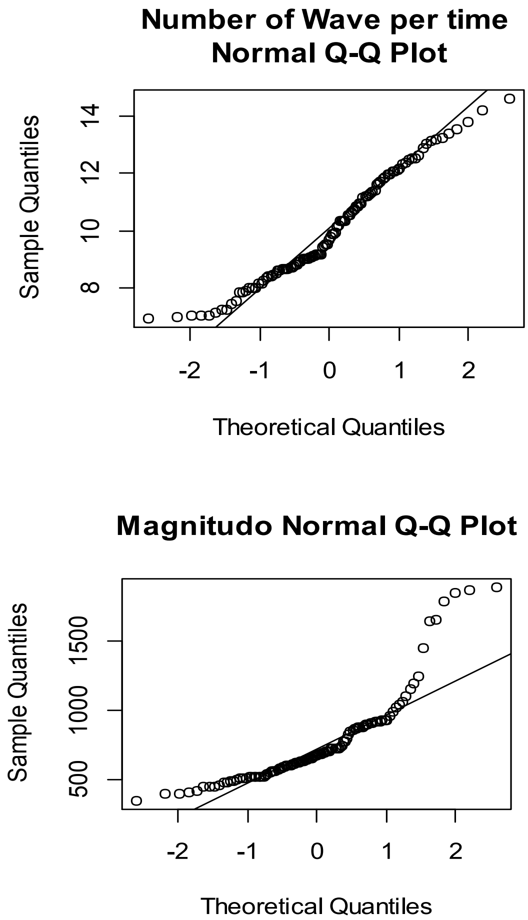

Fig. 8 Result of normality test

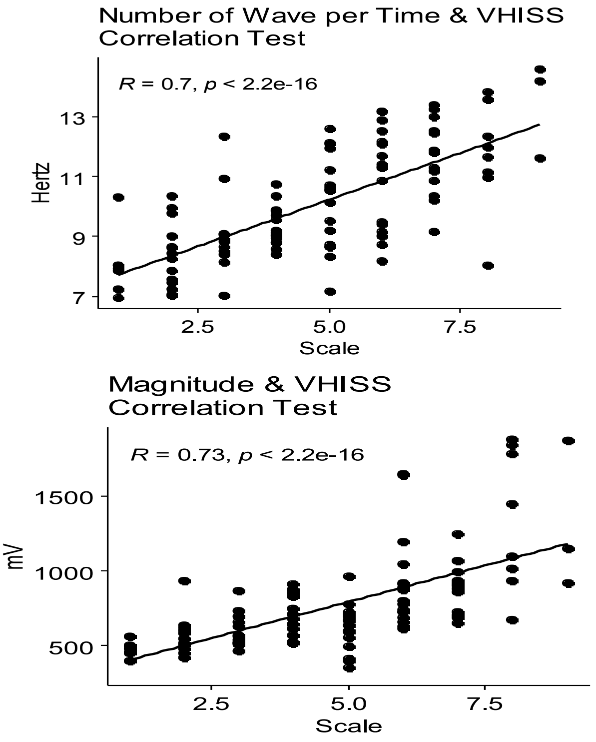

Fig. 9 Result of correlation test

D. Evaluation

An experiment that can be done to ensure correlation studies have stronger confidence is splitting the data and comparing them by demographics. The experiment is also test how appropriate the relationship between VHISS and the number of waves per time and magnitude of the BCI-based EEG under various data conditions.

The demographic information obtained is age and gender. Therefore, during the experiment, the data is separated by age (16 and 17), and gender (male and female). The data that had been separated were analyzed similarly from the previous one. The results is shown in Table II.

Based on the correlation testing result for participants aged 16 years, there was no significant difference in the correlation between VHISS data and BCI-based EEG data with the overall correlation test. The number of waves per time with the VHISS scale and magnitudes with the VHISS scale can be correlated with evidence of a p-value smaller than 0.05 at the 95% confidence level. The relatively strong rho value indicates the strength of the correlation. Moreover, it also applies to other correlation testing, age 16 years, age 17 years, male gender, and female gender are all correlated. However, the strength of the correlation obtained are varies. On average, it can be concluded that VHISS and EEG based on BCI and VR have a harmonious relationship.

TABLE II
CORRELATION AND EVALUATION RESULT

Correlation Test	*p-value*	*rho*
Overall		
Number of waves per time and VHISS	2.2×10^{-16}	0.7035187
Magnitude and VHISS	2.2×10^{-16}	0.7269371
Age 16 years		
Number of waves per time and VHISS	5.355×10^{-11}	0.6794946
Magnitude and VHISS	5.088×10^{-16}	0.7773845
Age 17 years		
Number of waves per time and VHISS	1.258×10^{-7}	0.7741227
Magnitude and VHISS	4.826×10^{-4}	0.5736708
Male Gender		
Number of waves per time and VHISS	2.642×10^{-9}	0.6592421
Magnitude and VHISS	6.28×10^{-11}	0.697416
Female Gender		
Number of waves per time and VHISS	3.161×10^{-9}	0.7792349
Magnitude and VHISS	1.008×10^{-10}	0.8194791

IV. CONCLUSION

One of the tools to measure the level of anxiety of heights is VHISS. However, VHISS measurement is sometimes unsatisfactory without concrete evidence. By utilizing biometric measurements of ion changes in the brain, EEG-based BCI and VR are interesting to try. The study of 107 participants aged 16-17 years showed that the results of biometric readings in the form of the number of waves per time and magnitude had a relationship with VHISS. The higher the number of waves per time, the higher the magnitude, the higher the VHISS scale. In other words, the more electrical activity between neurons in the brain when given exposure, the higher the data value is obtained from EEG-based BCI and VHISS. The relationship was tested using the Spearman correlation method, considering that the form of the data is an interval, and the distribution of data is non-parametric or not normally distributed. The evaluation was carried out by separating the demographics of the participants. Overall, based on both age and gender, the correlation test result show their suitability. Therefore, it can be concluded that the BCI-based EEG is quite capable of being one of the cheap alternatives that can be offered to measure the level of anxiety towards height apart of VHISS. It is hoped that the correlation study between BCI-based EEG and VHISS can provides an alternative measurement of the level of anxiety towards height visually, so that several problems such as rehabilitation due to stroke, unbalanced body stability, the possibility of shock and stress, mental disorders, physical disorders, and quality of life can be handled. The test gives faster and more precise early detection. The improvement to this research is broad. For example, the use of Fourier Transform and the use of complex EEG may provide stronger accuracy.

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