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Electroencephalograph (EEG) study of mental fatigue in learning the Physics at Senior High School's students

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Abstract
The result of national examination in Senior High School students of Indonesia fluctuated for the last 3 years particularly in Yogyakarta. This examination is one of the national indicators for the achievement in the knowledge comprehension among the student on a certain subjects. Physics is a subject tested producing digression on the average score for last 3 years; 2015-2017. Some factors that contributes are learning process method, environment, subject, teacher, and student's cognitive manner. However, latest factor has a high effect on accomplishing a success. The objective of this study is to investigate the mental fatigue of students in taking a part of teaching-learning process of Physics by analyzing the brain activity at cognitive system in 4 sessions. It is the combination of learning methods (autodidact and non-autodidact) and conditions (late morning and afternoon). An experimental study was conducted at laboratory to record beta, alpha and theta wave of brain's recorded by electroencephalograph (EEG). Four students of Senior High School were participated in this study to attend a learning process of Physics for 90 minutes in each session. Non-parametric statistical analysis was done to test the hypothesis. The result of this study showed that the autodidact learning method in the late morning for 54.25 minutes had a better performance in learning the Physic subject.
Keywords: Electroencephalograph, Mental fatigue, Student, Senior high school, Physics

1 Introduction

Education becomes a responsibility for people to improve the knowledge so as to become a virtuous personality spiritually and physically. Therefore, it is significant to the endless learning and supported by the government by accommodating place for studying in the form of formal education. Formal education is a structured education consisting of elementary school, junior high school, and senior high school. Wherein, there is a national test as the indicators for achievement in the knowledge comprehension at the end of every level school called National Examination.

Unfortunately, based on record by Ministry of Education and Culture (2017), the result of National Examination in Indonesia fluctuated for the last 3 years especially in D.I. Yogyakarta where Physics is a subject tested experiencing the declining on the average score at Senior High School.

Based on Kinantie et al., (2012), students in senior high school especially in 3rd grade are stressful in upcoming of national examination. On the result of research, 4.15% of students were categorized as normal, 15.2% of students were categorized as light stress, 49.74% of students were categorized as medium stress, 30.05% of students were categorized as heavy stress, and 0.52% of students were categorized as very strong in stress.

Meanwhile, based on Djemari & Kartowagiran (2009), in the upcoming of national examination, it was recorded that 81% of students in school categorized as good school and 65% students in school categorized as low school added more time for studying. Moreover, 41% students felt fatigue in the upcoming of national examination.

In fact, students of senior high school in Yogyakarta are asked to learn the Physics for 90 minutes continuously in a day which is done for 3 times in a week. Meanwhile, the periods of prolonged cognitive activity has led to mental fatigue and Wascher et al., (2014) found that 1 hour cognitive task had already led to mental fatigue. Mental fatigue refers to a physiological state in which the cognitive performance declines. It can reduce the working memory performance and an ability to focus attention. When a person in in a state of mental fatigue, he or she would find difficulties in obtaining and processing information in a fast and efficient way (Charbonnier et al., 2016).

Mental fatigue is able to be analyzed by assessing an electric activity in brain that can be seen by Electroencephalograph (EEG). Spectral EEG measure has been proposed to be valid and reliable indicators of mental fatigue (Wascher et al., 2014). A shift of EEG amplitude toward Theta, Alpha, and Beta might be related to a decrease in the level of arousal one core aspect of mental fatigue. Theta waves lie in the range of 4-8 Hz appearing as the consciousness slips toward drowsiness. Alpha waves lie within 8-13 Hz that indicates both a relaxed awareness without any attention or concentration. Beta waves meanwhile lie within 14-30 Hz stated as active thinking, active attention, focus on outside world, or solving concrete problems (Sanei & Chambers, 2007).

A number of previous researches used EEG to measure a mental fatigue. It used EEG to measuring the mental fatigue caused by mobile 3D and correlated with the natural sound (Mun et al., 2014), measuring mental fatigue focused on fatigue level after watching 3DTV (Chen et al., 2013, 2014), measuring mental fatigue related attentional process by conducting a fictitious experiment (Boksem et al., 2005; Charbonnier et al., 2016; Käthner et al., 2014), and measuring mental fatigue in different group of age (Arnau et al., 2017).

Based on the existing study, the measurement of mental fatigue using EEG assessment has been conducted by some researchers. However, the mental fatigue measurement for high school student has not been conducted while students are on the Physics learning process in class.

The objective of this study is to investigate the mental fatigue of students in taking a part of teaching-learning process of Physics by analyzing the brain activity at cognitive system.

2 Theoretical Review

2.1 Mental Fatigue

Mental fatigue is included as a psychological state that arises when someone do a continuous task for a long time or when someone do a task requiring focus and attention. Mental fatigue is a decline of cognitive performance that is able to reduce working memory performance and decrease focus attention ability (Wascher et al., 2014). When someone reaches mental fatigue state, the consequence is a difficulty to get and process the information in a fast and efficient way (Charbonnier et al., 2016).

There are 4 factors influencing mental fatigue, which are:

a. Circadian Rhythm Factor

Body has natural cycle that will continue to recur for 24 hours called as circadian rhythm. Circadian rhythms are physical, mental, and behavioural changes that follow a daily cycle as one of factor influencing mental fatigue (Taphoorn et al., 1993). Circadian rhythms are important in determining the sleeping and feeding patterns of all animals, including human being. It organizes pattern of sleep, body temperature, digestion function, etc. it responds primarily to light and darkness in an organism's environment. Sleeping at night and being awake during the day is an example of a light-related circadian rhythm. According to Kim & Duffy (2018), changes of sleeping and being awake cycle can result in an inability to fall asleep at the desired time, difficulty remaining asleep, or difficulty remaining awake throughout the desired wake episode. That mismatch called circadian rhythm sleep-wake disorders that affect to sleep disruption.

b. Sleep Quality Factor

The average time to sleep in a day is between 6-8 hours for adult. They who do not sleep for less and more than 6-8 hours will lead to sleepiness. For 6-8 hours, human need to have good sleep quality. Good sleep quality is beneficial in positive outcomes such as better health, less daytime sleepiness, and better psychological function.

c. Health Factor

Health is a prosperous state of body, soul, and social that enables for every human to live productively. Health maintenance is needed to overcome and prevent health problems that require examination or treatment. The example of health problem that lead to fatigue is such as anemia, diabetes, thyroid hormone problem, rheumatism, etc. Beside those medical problems, fatigue can also occur in overweight or lack of weight human body. Being overweight can make body to work harder in doing some activities, while being lack of weight means weak muscle strength that leads to feel fatigue faster.

d. Work Factor

Rodahl (1989) stated that work factor was divided into external and internal factors.

- External Factors

  It is influenced by factors from the external body of workers which are task demand, work organization, and work environment.

  - Task. It is divided to physical and mental task. Physical task is task from work stations, layout in workplace, equipment and tools, condition in the workplace, lifting and manual handling, supporting equipment, display control work procedures, etc. Meanwhile, mental task are complexity, difficulty of job that influence the worker's emotion, responsibility, etc.
  - Work organization. It includes work hour, break time, shift work, and salary system.
  - Work environment. It includes physical work environment, chemical environment, biological work environment, and psychological work environment.

- Internal Factors

  It is factors from the internal by of human which are somatic and psychology factors.

  - Somatic factors; gender, age, body size, body fitness, nutrition.
  - Psychology factors; motivation, perception, self-confident, willingness, satisfaction, etc.

2.2 Electroencephalograph

Electroencephalography (EEG) is the neurophysiologic measurement of the electrical activity of the brain by recording from electrodes placed on the scalp. Electrode placement is accomplished by measuring the scalp. Electrode locations and names are specified by the International 10–20 system (Cheng & Hsu, 2011).

The International 10-20 system is an internationally recognized method to describe the location of scalp electrodes. Jasper (1958) in Herwig et al., (2003) stated that the International 10-20 system is commonly used for EEG electrode placement and for correlating external scalp location to underlying cortical areas. The numbers '10' and '20' refer to the fact that the distances between nearest electrodes are either 10% or 20% of the total front-back or right-left distance of the scalp. The location of scalp electrodes based on International 10-20 system is shown in Figure 1 below.

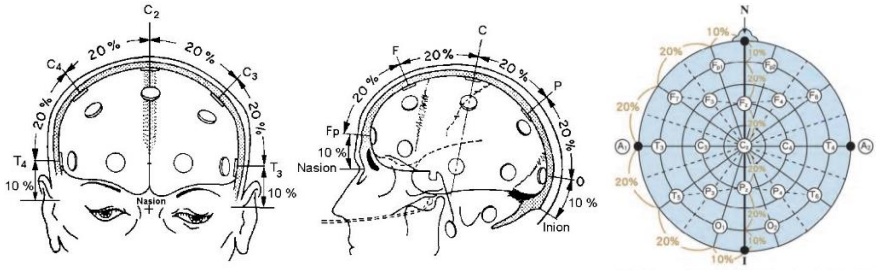

Figure 1. International 10-20 System, Electrode Position
(Source: Cheng & Hsu, 2011)

Each site has a letter to identify the lobe and a number to identify the hemisphere location. The letter 'F' means frontal lobe, 'T' means temporal lobe, 'P' means parietal lobe, and 'O' means occipital lobe. Meanwhile, there is no central lobe exists, the 'C' letter is used for identification central of scalp only. The 'z' means zero that refers to an electrode placed on the middle line. Even numbers (2, 4, 6, and 8) refer to electrode positions on the right hemisphere. Odd numbers (1, 3, 5, and 7) refer to electrode positions on the left hemisphere.

Four anatomical landmarks are used for the essential positioning of the electrodes; first, the 'N' letter refers to nasion which is the point between the forehead and the nose; second, the 'I' letter refers to inion which is the lowest point of the scalp from the back of the head and is normally indicated by a prominent bump; then, the 'A' letter refer to pre auricular points anterior to the ear.

3 Research Methods

3.1 Participants

Four healthy students (2 females and 2 males) of the final grade senior high school were participated in this experiment. They were in the age of 17-18 years old, had similar interest in Physics, and got in range 80 to 84 for physics score in school represent good Physics knowledge comprehension. None of participants had a shoddy habit in their life.

3.2 Apparatus

The main equipment used in this study was Electroencephalograph type Open BCI Ganglion Board (4-channels) as a reference electrode for measuring the brain activity. A set of personal computer was used to present the raw EEG signal using Open BCI GUI 2.1.1. Meanwhile, the experiment was carried out using some learning tools in the form of book and video.

3.3 Experiment Design

Experiment was conducted in Laboratory where each participant sat in a comfortable position on the seat provided. The temperature and lighting of experiment place will be set similar with classroom in school. The experiment used two different learning tools: Physics book as an autodidact learning method and watching video as a non-autodidact learning method. Autodidact learning type is a type of learning where students personally initiate and direct their effort to perform the learning activity without relying on teachers, parents, or other agents of instruction (Simons, 1989). Elsewhere, non-autodidact learning type is the presence of teacher on learning activities as an important role in learning process for developing and stimulating students (Van Beek et al., 2014).

Each learning method was also performed in different time whereas Dunn et al., (2002) revealed that 47 percent of high school students were late morning and afternoon learners, 40 percent were early morning learners, and remain was early night owls learners. Then, this study took the late morning and afternoon as the time variable.

Thus, the experiment consisted of 4 sessions, each of which had 1 trial, including autodidact learning in the late morning, autodidact learning in the afternoon, non-autodidact learning in the late morning, and non-autodidact learning in the afternoon.

Four electrodes of Sn was placed at frontal (F3 and F4) and Parietal (P3 and P4) as shown in Figure 2 according to the 10-20 system. Those electrodes have been commonly validated to analyze the mental fatigue (Babiloni, 2012; Yin & Zhang, 2017). Frontal lobe is an area in the brain of mammals located at the front of each cerebral hemisphere. It had a function as a part in impulse control, language production, working memory, problem

solving. It also assist in planning, organizing, actuating, and controlling behavior. Meanwhile, parietal lobe is located just behind the frontal lobe. It integrates sensory information that also has a function for comprehending numbers and the manipulations of objects. Damage to this lobe can cause eyesight problems, left and right hemisphere confusion, inability to perform mathematical solutions, reading and writing problems, and symbol comprehension (Cheng & Hsu, 2011).

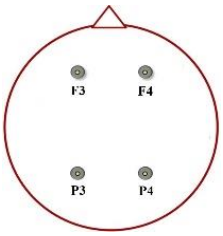

Figure 2. Head plot

3.4 Task

Respondent were instructed to learn the sub chapter of Physics subject that is Electromagnetic Induction. This chapter is the most difficult chapter among others (personal communication, August 28, 2017). Babiloni (2012) expressed that the more demanding task meant the higher mental fatigue. Thus, this is reasonable to take this subchapter as task in this experiment.

3.5 Procedure

The experiment was conducted for 2 days for each respondent and 2 sessions per day. The total time for each session was 125 minutes. They contained 5 minutes for briefing and getting used to being in a class, 90 minutes for studying, and 30 minutes later for answering 10 question as an assignment with the questions related to subchapter that has been studied before. The recording of brain activity was done only when the respondents studied in both two methods. In the first day, at 9.00 in the late morning, the respondent conducted the first session by learning Physics using random learning method either autodidact or non-autodidact. It finished until 11.00 and continued at 13.00 in the afternoon for the second session. Respondent rests for 2 hours between late morning and afternoon session where mental fatigue has recovered (Nishihara et al., 2014). In afternoon session, the respondent learnt using a different learning method compared to the previous one. In the next day, respondent did the third and fourth session on the same order as the previous day.

3.6 Data Processing

EEG raw signal was filtered by Notch and Band Pass Filter (Chen et al., 2013, 2014; Mun et al., 2014; Zhao, Zhao, Liu, & Zheng, 2012). Notch filter is used to reject the narrow frequency at 49-51 Hz for rejecting noise due to electrical problems and leaves the rest frequency. Band pass filter is used to select frequency from EEG data that will be used which is Theta (4-8 Hz), Alpha (8-13 Hz), and Beta (13-30 Hz). They were processed using Matlab R2016a.

3.7 Data Analysis

Data analysis was done using a signal analysis and non-parametric statistical analysis. Signal analysis is an analysis by calculation RMS (Root Mean Square) of Theta, Alpha, and Beta amplitude for each minute in order to see the shift of wave each frequencies (Soewardi et al., 2015). The formula of RMS is shown in (1) below, where N represent amount of data and x represent the amplitude.

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} {x_i}^2} \quad (1)$$

Beside it, Wilcoxon Signed-Rank Test (significant $P<0.05$) was done for identifying the difference between the variable both learning method and condition.

4 Result and Findings

4.1 Analysis of Mental Fatigue

Table 1: Result of Experiment on Early Time for Getting Mental Fatigue

	Autodidact		**Non-autodidact (Video)**	
	Late morning (minute)	***Afternoon (minute)***	***Late morning (minute)***	***Afternoon (minute)***
Average	54.25^{th}	29.25^{th}	65.75^{th}	28.5^{th}
Range	48^{th} - 61^{st}	25^{th} – 34^{th}	57^{th} - 82^{nd}	21^{st} - 39^{th}

Table 1 shows average of early time for getting mental fatigue at students. By autodidact method in the late morning, early time for declining the concentration of students started in range between 48th to 61st minutes or at average 54.25th minutes. In the afternoon, students started to decline of the concentration in range between 25th to 34th minutes or at average 29.25th minutes. By non-autodidact method in the late morning, early time for declining the concentration of students started in range between 57th to 82nd minutes or at average 65.75th minutes. In the afternoon, students started to decline of the concentration in range between 21st to 42nd minutes or at average 29.25th minutes. The declining of concentration meant that students started to get mental fatigue.

Wilcoxon Signed-Rank Test was done to compare the result of early time of participant for getting mental fatigue. It revealed that average early time for getting mental fatigue by autodidact learning type in the late morning was not significantly longer time for getting mental fatigue than afternoon condition (P=0.068>0.05), by non-autodidact learning type in the afternoon was not significantly longer time for getting mental fatigue than afternoon condition (P=0.066>0.05), by autodidact in the late morning was not significantly shorter time for getting mental fatigue than non-autodidact in the late morning (P=0.109>0.05), then by autodidact in the afternoon was no difference in time for getting mental fatigue with by non-autodidact in the afternoon (P=1.000>0.05).

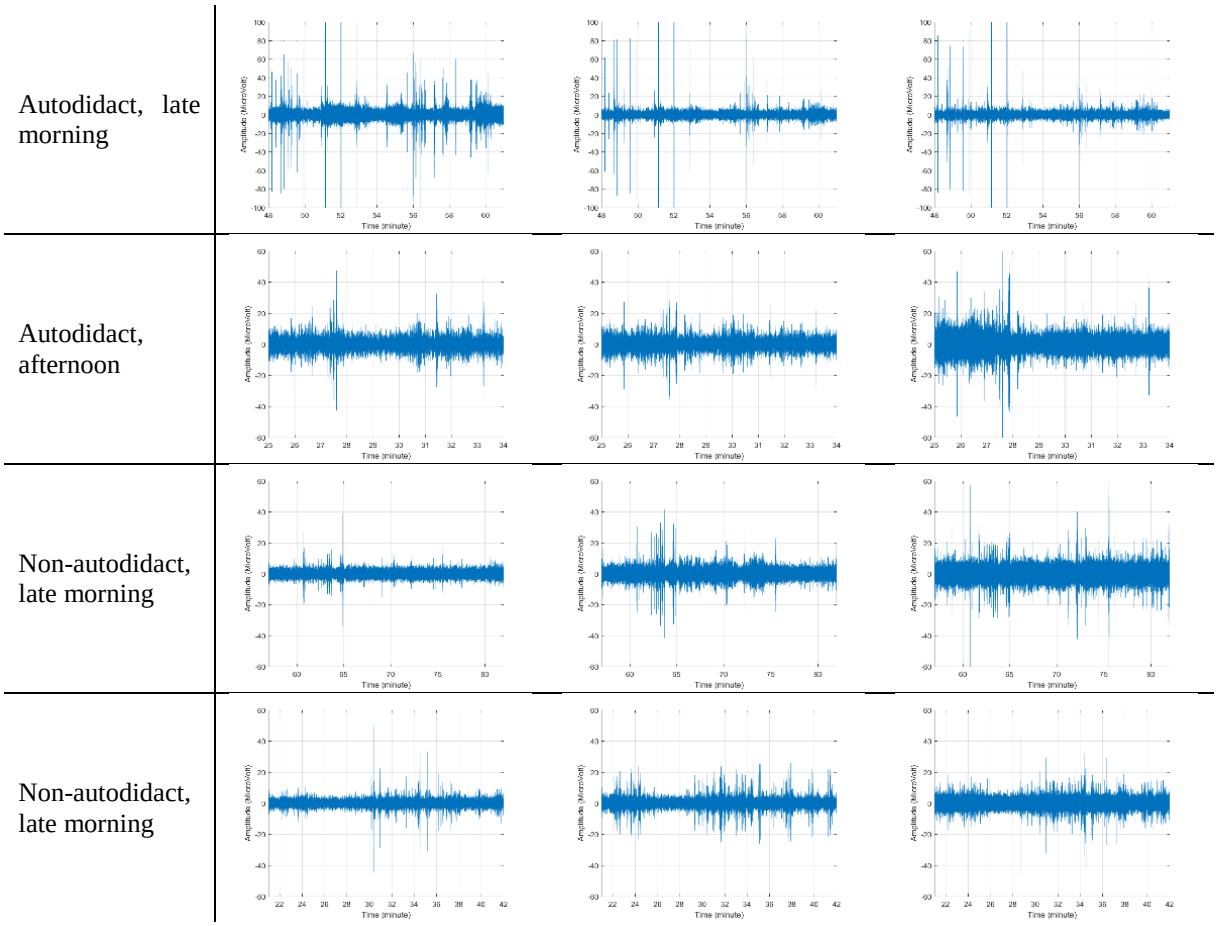

Figure 3. Comparison of EEG signal on each range of early time for participant getting mental fatigue based on frequency: (a) Theta (4-8 Hz), (b) Alpha (8-13 Hz), and (c) Beta (13-30 Hz)

Early time for student getting mental fatigue was supported with a shift of EEG amplitude toward Theta, Alpha, and Beta on each range of early time that is showed at Figure 3. In order to see the shift of amplitude easier, the RMS was calculated. Figure 4 shows the graphic of RMS at EEG amplitude on those each range time.

Figure 4 showed that, on the autodidact in the late morning, amplitude of Beta was greater than Theta and Alpha until at 47th minute but, the amplitude of Theta was increased at 48th minute and greater than amplitude of Beta and Alpha. On the autodidact in the afternoon, amplitude of Beta was greater than Theta and Alpha until at 29th minute, but then, the amplitude of Theta was increased at 30th minute and greater than amplitude of Beta and Alpha, and the amplitude of Alpha was increased at 36th minute and greater than amplitude of Beta and Theta. On the non-autodidact in the late morning, amplitude of Beta was greater than Theta and Alpha until at 61st minute, but then, the amplitude of Alpha was increased and greater than amplitude of Beta at 62nd minute. On the non-autodidact in the afternoon, amplitude of Beta was greater than Theta and Alpha until at 29th minute, but then, the

amplitude of Alpha and Theta was increased at 30th minute and Alpha was greater than amplitude of Beta and Theta at 31st minute.

Based on EEG signal, amplitude of Theta and/or Alpha was continues increased whereas in line with the decreasing of Beta on certain time. Based on Charbonnier et al., (2016), those conditions stated that the subject feels mental fatigue.

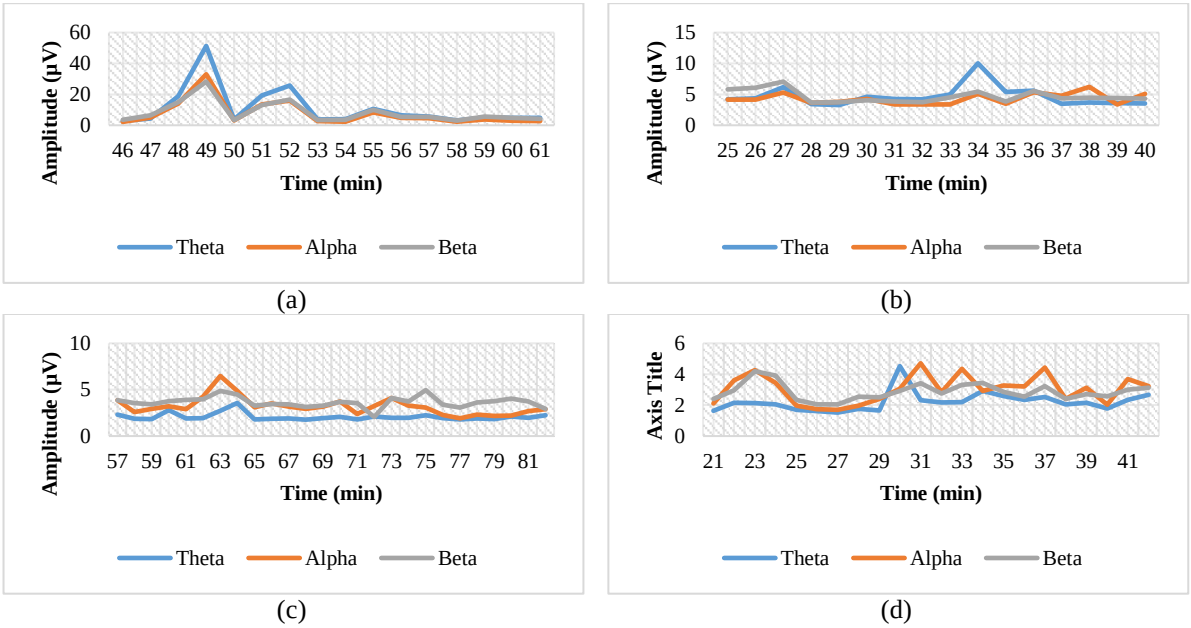

Figure 3. Graphic of RMS at EEG amplitude on each range of early time for participant getting mental fatigue: (a) Autodidact in late morning, (b) Autodidact in afternoon, (c) Non-autodidact in late morning, and (d) Non-autodidact in afternoon

4.2 Statistical Analysis for Final Score of Study

Table 2 shows the final score of Physic subject especially on Electromagnetic Induction subchapter by using two methods and different conditions in teaching learning process. By autodidact method in the late morning, the result of final score (67.5 of 100) was the highest among others. In the afternoon, the result of final score (52.5 of 100) was lower than the result of final score in the late morning condition. By non-autodidact method in the late morning, the result of final score (52.5 of 100) was higher than the result of final score in the afternoon (50 of 100).

Table 2: Result of Final Score

	Autodidact		**Non-autodidact**	
	Late morning	***Afternoon***	***Late morning***	***Afternoon***
Average	67.5	52.5	52.5	50

Wilcoxon Signed-Rank Test was done to compare the final score result between both learning method and condition variables. It revealed that final score by autodidact learning type in the late morning was not significantly higher than afternoon condition (P=0.059>0.05), by non-autodidact learning type in the afternoon was not significantly higher than afternoon condition (P=0.102>0.05), by autodidact in the late morning was not significantly higher than non-autodidact in the late morning (P=0.109>0.05), then by autodidact in the afternoon was not significantly higher than non-autodidact in the afternoon (P=0.180>0.05).

4.2 Late Morning vs. Afternoon Analysis

It can be seen that participant in the late morning condition had longer time for getting mental fatigue and higher final score compare with afternoon condition. Vollmer et al., (2013) expressed that student had fresher mind and a better physical condition in earlier day compared to the student's condition in the afternoon. It is stated that a student will find it more difficult in receiving information in the afternoon due to the exhausted body condition. Vollmer et al., (2013) also stated that morning method person in learning style gets both better grading and higher attention.

Moreover, it was noted that the experiment performed in the late morning showed 26.7˚C as the room temperature, and 31.9 ˚C in the afternoon experiment. Kulve et al., (2017) mentioned that the sleepiness of a person is significantly higher while reaction time is slower in warm exposure. Romeijn et al., (2012) expressed that

alertness will reduce when room temperatures increases; while Lan et al., (2011) stated that a high ambient temperature could reduce the performance on reaction time tasks. Thus, based on room temperature, previous study was in line with the experiment result, where the room temperature of afternoon experiment was warmer than the one in the late morning experiment and went along with the fastest time in starting mental fatigue.

In addition, the lighting level of late morning experiment (79 Lux) was brighter than afternoon experiment (70 Lux) resulting in a longer time in starting mental fatigue in the late morning. It was approved by Romeijn et al., (2012) that bright light could improve body performance and reduce the sleepiness. So that, learning process in the late morning had better performance based on score of study and early time for getting mental fatigue result.

4.2 Autodidact vs. Non-autodidact Analysis

In the late morning, autodidact learning type had shorter early time for getting mental fatigue than non-autodidact learning type. On the contrary, autodidact learning type had higher result final score then non-autodidact learning type.

Based on Van Oers (1987) in Simons (1989), there are two aspects of student activities during learning, which are quality and quantity of learning activities. Quality of learning activities is quality of information that students got while quantity of learning activities is an effort to get the information during studying. Quality of learning activities in the late morning can be seen by the result score of study gotten where autodidact learning type had higher result final score interpret as better quality of learning activities then non-autodidact learning type with significant difference as much as P=0.109. Moreover, Based on Simons (1989), a student who decided to learn by autodidact learning type have to exert more effort. Meanwhile, based on Babiloni (2012), the more demanding task that needed more effort result higher mental fatigue. It was in line with the result of early time for getting mental fatigue in the late morning, where autodidact learning type needed more effort resulted more earlier time for getting mental fatigue than non-autodidact learning type with significant difference as much as P=0.109 for early time mental fatigue comparison.

Meanwhile, in the afternoon, that autodidact learning type has longer early time for getting mental fatigue and higher result score of study than non-autodidact learning type in the afternoon with significant difference as much as P=1.000 for both early time mental fatigue and P=0.108 for result score of study comparison.

Furthermore, based on Lodewijks (1982), science student in autodidact learning type is performed better than student in a learning sequence predetermined by teachers and Van der Sanden (1986) in Simons (1989) stated that some students performed better without instruction on a practical construction than with explicit and detailed advice from a teacher. So that, autodidact learning type had better performance based on early time mental fatigue and score of study result**.**

5 Conclusion

Based on the analysis, it can be concluded that the proper duration for learning Physic on autodidact learning method in the late morning was before 54.25 minutes, autodidact learning method in the afternoon was before 29.25 minutes, non-autodidact learning method in the late morning was before 65.75 minutes, and non-autodidact learning method in the afternoon was before 28.5 minutes. Meanwhile, the autodidact learning method in the late morning had the highest result of final score obtained after learning Physic rather than others. Thus, the autodidact learning method in the late morning is better in learning the Physics subject.

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