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The Effect of Emotional Distraction on Declarative Memory and an Exploration of its Physiological Marker: An Affective Computing Perspective

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Abstract. This study aimed to investigate the effects of emotional distraction (ED) on declarative memory performance. The study was conducted using the within-subject experiment paradigm on 38 students aged 18–21 years (20 males). Declarative memory was measured using a word-pair association (WPA) task. Emotional distraction (ED) is induced using the International Affective Pictures System (IAPS) and International Affective Digitized Sounds (IADS) grouped based on their valence (neutral, positive, or negative). Measurement of physiological responses was undertaken by measuring Galvanic Skin Responses (GSR) and Electroencephalography (EEG) with Frontal Alpha Asymmetry (FAA) index. The result show a significant difference in the WPA score where the positive is lower than the neutral condition ($p = 0.011$), but only in the group in which the positive block was presented first. From the GSR data, the significant main effect of the order of experimental block regardless of the ED valence was ($p < 0.001$; $F = 16.045$), finding that the first block elicits significantly higher GSR amplitude compared to the second ($p < 0.001$; $t = 4.94$) and the third ($p = 0.001$; $t = 3.90$). Meanwhile, the FAA index showed no significant difference ($p = 0.654$; $F = 0.433$). In conclusion, we found an indication of the after-effect of positive emotional stimuli on declarative memory performance; however, looking at the habituation pattern of the GSR data, it could also be explained using the ED interference effect and the intertwined balance of cognitive and affective processes.

Keywords: affective computing; declarative memory; electroencephalography; emotional distraction; Galvanic Skin Responses

One of the advantages of the e-learning method compared to more traditional methods, apart from the flexibility of embedding additional audiovisual materials, is the potential to integrate it with intelligent adaptive systems. This approach is a potential new paradigm to addressing the limitations of the traditional e-learning method (e.g., no personalization of learning content based on the user's state), and evaluating its effectiveness is an emerging research field (Alghabban & Hendley, 2022; Cidral et al., 2018; Yakin & Linden, 2021; Younes, 2021). This new mode opens up the tremendous potential for integrating affective computing (Egger et al., 2019; Tao & Tan, 2005; Vijaya & Shivakumar, 2013) with the extant learning system. The implementation of affective computing involves measuring the user's emotional state and behavior and using that information to provide automated an adaptive and personalized intervention to optimize the learning outcome. In this perspective, some considerations

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*Address for correspondence: zul.fikri.kh@gmail.com need to be investigated, such as what kind of stimulus has the facilitating effect on the learner's performance, what should be avoided, and what physiological markers could potentially be useful in this context. The present study attempts to address those questions and provide some discussion points based on the data of this research. To address these questions, first, we must decide which cognitive processes are involved and are thought crucial in this context. In this study, declarative memory will be used as the benchmark for learning performance. Subsequently, the effect of emotional stimuli would be tested as the basis of further considerations as to whether these stimuli would facilitate or hinder performance.

Declarative memory is a type of memory related to conscious knowledge that can be remembered verbally and non-verbally, including ideas, concepts, sounds, images, sensations, and words (Kihlstrom et al., 2017; Squire & Dede, 2015; Suzuki, 2003). Declarative memory forms the basis of those systems involved in learning, consolidating, storing, and using the various types of knowledge: facts (semantic knowledge), events (episodic knowledge) and words (lexical knowledge) (Squire & Dede, 2015). This type of memory could be expressed using language because it is assumed to be encoded symbolically. Declarative memory serves a specific purpose in terms of processing and learning, and declarative memory is adaptable in learning situations. Knowledge stored in declarative memory can be accessed flexibly by consciousness and used in different contexts because it can be compared with others (Squire & Dede, 2015). Declarative memory plays a central role in coding information about the relationship between memory items (Eichenbaum et al., 1991). Eichenbaum et al. (1991) added that declarative memory is supported by relational representations that allow for the comparison of memory items in different contexts. Testing on the concept of the relationship divulges whether the relationship between one item and another has been established.

Several studies have investigated the impact of emotion on memory. While research on the effect of emotion on the ability to remember events (episodic) has achieved relatively uniform results (Knight & Mather, 2009), the effect on non-episodic declarative memory still shows mixed results. Some studies have found that emotion strengthens memory (Adelman & Estes, 2013; Buchanan & Lovallo, 2001) while other studies have found the opposite, (Luethi, 2008; Rice et al., 2007) as well as interactive effects. (Knight & Mather, 2009; Meng et al., 2017; Schaefer et al., 2009). Affect or emotion refers to a mental state that can be described as pleasant or unpleasant (valence) and has a degree of arousal (Barrett & Bliss-Moreau, 2009; Barrett et al., 2016) and consists of the combination of physiological arousal with the cognitive interpretation to interpret stimuli subjectively. Arousal can be viewed as the intensity of the emotion which can be indicated by measuring physiological and psychological responses. Meanwhile, valence refers to the polarization of the emotion, which is positive or negative.

In most of the studies that found a facilitating effect of emotion on memory, the recall or recognition tasks are typically targeted at the emotional stimulus itself, especially in previous research undertaken by Adelman and Estes (2013); Buchanan and Lovallo (2001); Meng et al. (2017); and Schaefer et al. (2009). Emotional stimuli have a more salient distinctiveness and relevance to the condition of the subject in that they benefit memory by becoming a mnemonic (Bennion et al., 2013). While this condition is ideal, in reality, designing the learning materials to be inherently emotional (see for example Plass et al. (2014); Plass and Kaplan (2016) poses an additional challenge. Hence, a different focus of investigation is needed, in which the emotional stimuli are goal-irrelevant, that is, not directly related to the main materials.

Within this framework, the physical characteristics of the stimuli are, ideally, no longer a limitation. Any kind of audio or visual, as long as it is possessed of the same abstract characteristics (e.g., the valence charge of the stimulus) should produce the same effect conceptually. However, another issue emerges, which is whether these goal-irrelevant stimuli would distract the users instead and hinder their performance. Knight and Mather (2009) argue that emotions can weaken memory performance when the nature of the emotion has high arousal so that it distracts the subject and interferes with attention. Furthermore, Knight and Mather (2009) argue that attention has more of a role in determining the effect of emotions on memory. In this view, Emotional Distraction (ED) might interfere with the facilitating effect of emotion on memory. Investigations into ED have revealed that goal-irrelevant emotional stimuli impair executive function performance (Cohen et al., 2012; Dolcos, 2006; Tavares et al., 2016; Verbruggen & Houwer, 2007). Emotional stimuli are strong sources of distraction, capturing attention and reallocating processing resources, thereby impairing cognitive function (Straub et al., 2019).

In line with the purpose of the study, physiological data were gathered to explore some of the known markers of emotional activation as the basis for affective computing. It is established that emotional states would reflect on the physiological response e.g., electro-dermal level, heart rate variability, and the brain's activity, hence this information is becoming studied more widely to develop an emotion recognition system, see review by Egger et al. (2019). The advances in wearable sensor technology (Sawangjai et al., 2020) that allow one to record these data more easily and flexibly also open up research opportunities in this field (Egger et al., 2019). These objective physiological signals could be used to infer the user's state almost instantaneously and continuously.

The present study aimed to investigate the effects of ED on declarative memory performance. Participants are instructed to undergo a declarative memory task, while at the same time emotional stimuli that are goal-irrelevant to the task are presented. Through this design, we control the mnemonic effect of the emotional stimuli and explore whether ED interferes with declarative memory performance. As the secondary goal of this research, a measurement of physiological reactions is carried out to obtain data on the patterns of physiological responses toward emotional stimuli while carrying out a cognitive task. This study will explore physiological measurements using two methods: electro-dermal responses using the Galvanic Skin Response (GSR), and brain electrophysiology using Electroencephalography (EEG). The results of this exploration are aimed to give recommendations for further research programs in designing e-learning materials in affective computing research.

Methods

Participants

The participants were 40 (20 males) students of the Faculty of Psychology Universitas Gadjah Mada and Faculty of Industrial Technology Universitas Atma Jaya (Yogyakarta), aged 18–21 years (mean = 19, *SD* = 1.0). They had normal or corrected-to-normal vision, were right-handed and with no neurological conditions based on self-reporting. Data from two participants were eliminated due to a technical error during data collection (a software bug meant the data were not recorded completely), leaving 38 participants. The GSR data that can be analyzed are 33 datasets by eliminating 5 datasets considering the noise to the data due to movement artifacts. The EEG data that can be used were 13 datasets, eliminating 25 datasets due to noise and artifacts. Participants received a monetary reward (IDR 50.000) for being part of the experiment regardless of the completion.

Declarative Memory Measurement

Declarative memory is measured through WPA which has been used in several studies with various adaptations (Bramao & Johansson, 2017; Holz et al., 2012; Squire, 2017). In general, this task consists of two unrelated words that are paired by the researcher, e.g., "*kucing–botol*"(cat–bottle), the subject is asked to remember the pair and given a recognition or cued recall of the word pair. This study will use the WPA protocol which is adapted from Bramao and Johansson (2017) in the form of 24 unrelated word pairs. The WPA protocol focuses on verbal and relational semantic memory but has the flexibility to combine these elements with additional context. This task was compiled by the researcher by first selecting 72 words with the highest word frequency appearing in the Indonesian Language Dictionary (*Kamus Bahasa Indonesia; Pusat Bahasa Departemen Pendidikan Nasional*, 2008) which were calculated using a web-based application (writewords.org.uk/wordcount.asp). It has been established that word frequency has a substantial effect on the memory of the word (Lohnas & Kahana, 2013); but see also (Goette et al., 2022), in this experiment we choose to use the higher frequency words to avoid the confounding factor of an unrecognized word impacting the participants. The word-pairing process is done by assigning a random number to each word. The word list consists of 36 pairs of unrelated nouns of 3–8 characters. Item selection was carried out by judgment from 5 non-subject students who have similar general characteristics to the target subjects (students of each faculty, aged 18–21) to choose pairs of words that were considered to be related. The final result is a list of 24 word pairs.

Emotional Distraction Stimuli

Emotional stimuli were presented as distractors by providing a stimulus in the form of images using the IAPS (Lang, 1995) and sound using IADS (Bradley & Lang, 1999). The IAPS and IADS have been tested on various population groups and each stimulus has its valence and arousal norms. The mean of valence and arousal for both stimuli is presented in Table 1. The IADS sounds were presented while the participants memorized the word pair, while IAPS pictures were presented before the word pair (see the design of the experiment in Figure 1) The combination of the two methods can also strengthen its effectiveness empirically in inducing emotions (Lynn et al., 2012). The picture and sound stimuli were selected in the high arousal category, as categorized by Yusainy (2017).

Table 1
Mean of Valence and Arousal of IAPS' and IADS' Stimulus Used in This Study

Stimulus	Parameter	Neutral	Positive	Negative
IAPS	Valence	5.14	7.52	2.75
	Arousal	4.63	6.64	6.55
IADS	Valence	5.11	7.17	2.20
	Arousal	4.84	5.71	6.90

Physiological Response Measurement

GSR or Electro-dermal Activity is an electrical conduction in the skin that can be measured through sensors on the skin (Boucsein, 2012). The conductivity of individuals' skin varies and changes as the skin is moistened by sweat. The GSR can reveal physiological changes in the sympathetic nervous system (Boucsein, 2012; Figner & Murphy, 2011). The GSR has been widely used in various studies to detect emotions, arousal (Figner & Murphy, 2011), stress conditions (Setz et al., 2010), and cognitive load (Nourbakhsh et al., 2012). The GSR is more sensitive and specific in measuring the level of arousal of emotions (Boucsein, 2012). This study will use GSR as a basis for observing physiological responses that are influenced by ED treatment, especially in terms of arousal. The study used a GSR sensor from Shimmer type Shimmer3 GSR+ with a measuring capacity of 0.2–100 µS (micro Siemens) and a 104 Hz sampling rate. The sensor is connected to a computer via Bluetooth and data are recorded using iMotions software.

Electroencephalography (EEG) is a method for recording the electrical activity of the brain on the surface of the scalp (Luck, 2012, 2014). Data inference from EEG associated with emotions is addressed by various methods. This study will perform inference measurement of emotions using the FAA index which is the result of measuring the difference in activity between the right and left front hemispheres. The measurement is carried out by comparing the alpha wave power with EEG (Coan & Allen, 2004; Davidson, 1993; Quaedflieg et al., 2015).

Activity in the left frontal hemisphere is associated with an active approach system when individuals experience positive emotions. Meanwhile, activity in the right frontal hemisphere reflects a withdrawal system that is active when the individual looks to avoid a potentially dangerous condition, which is thus associated with negative emotions (Davidson, 2004; Quaedflieg et al., 2015). The FAA index is estimated by subtracting the alpha power on the right side from the alpha power on the left (right minus left) (Allen et al., 2004). The alpha power is interpreted inversely with the brain's activity of its respective region, i.e., more alpha power in the left means less brain activity in this area. This assumption means that the higher the FAA index, the higher the alpha power in the right hemisphere, which means higher activity in the left hemisphere. Several studies related to the FAA have shown that left frontal hemisphere activity can predict emotional flexibility (Papousek et al., 2011) and emotion regulation (Jackson et al., 2003). Meanwhile, activity in the right frontal hemisphere is associated with affective disorders, such as depression (Thibodeau et al., 2006) and social anxiety disorder (Moscovitch et al., 2011). In this study, the FAA index will be used as a differentiator of emotional valence, in the form of positive and negative or neutral. Left frontal hemisphere activity, which is characterized by higher right alpha power as well as the FAA index, shows more positive emotions.

The FAA was selected because this measurement is relatively simple and could potentially be done online for further research (such as in affective computing research program) or in a practical setting. We also have to consider the quality of the EEG device used in this research (Emotiv Epoch+) which is not ideal for use in a research study involving strict timing, such as event-related potentials; ERP and latent features measurement, for the performance test of the device, see (Hairston, 2012; Kotowski et al., 2018; Taylor & Schmidt, 2012). The EEG used in this study is Emotiv Epoch+ which consists of 14 channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF42) +2 reference channels with CMS/ DRL noise cancellation at locations P3 and P4. The Emotiv Epoch+ has a sampling rate of 128 SPS (samples per second) with a measuring capacity of up to 8400 μV (microvolt) and digital notch filtration at frequencies of 50 and 60 Hz.

The acquisition of physiological data from the GSR sensor was recorded with the iMotions version 6.2 program (imotions.com). Data from the EEG sensor was recorded using the Emotiv TestBench SDK program, and both sensors were connected to the computer via Bluetooth connection.

Design of the Experiment

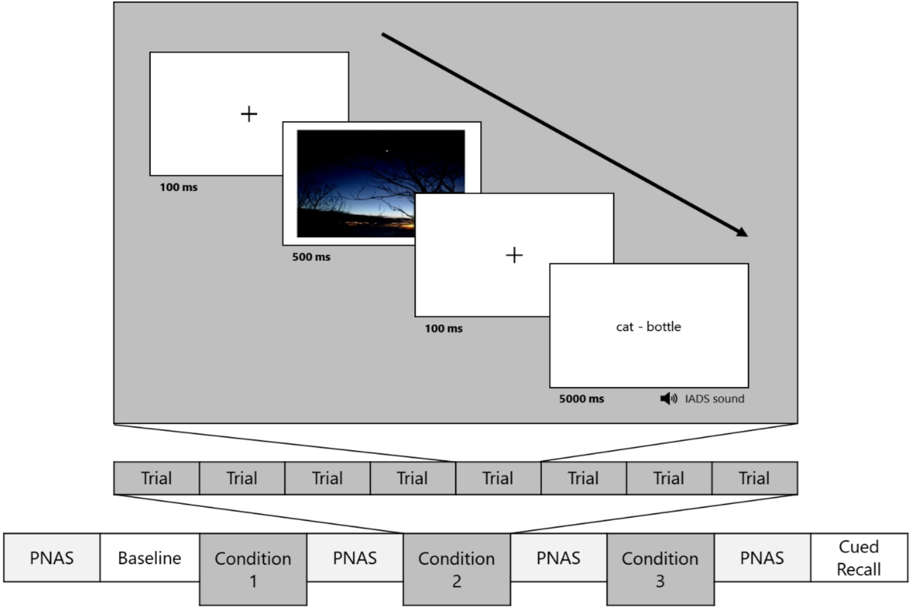
The experiment was designed with the same-subject experimental design. Each subject received three types of conditions, namely positive-, negative-, and neutral-emotional distraction. Each subject underwent three experimental blocks, with each block containing eight WPA word pairs, and audiovisually induced ED stimuli grouped by their valence. Counterbalance was applied to the block order: for half of the subjects, the positive condition was presented first (group 1), followed by neutral and negative, while in the other half the negative condition was presented first (group 2). Note that the neutral condition was presented in the second block for all subjects; we use this block to serve as the baseline for the subjects' relative performance in this task and as a condition break between two emotional valences since the duration of the emotion induced by this experiment is still unknown.

All instructions were presented via computer which also recorded sensor data, timing, response, and subjects' behavior via the webcam. Each block began with instructions as to what the subject's next assignment would be. The Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988) questionnaire was administered at the beginning of the experiment and after each block, aiming to provide a time buffer between blocks to further avoid overlapping physiological effects between the blocks. Data from the PANAS scale would not be included in the actual statistical analysis. The baseline physiological data were recorded for 3 minutes, while the subject was instructed to wait. After 3 minutes, an instruction would appear to memorize unrelated word pairs and ignore the images and sounds that appeared, followed by the actual task.

The WPA task consists of 24 word pairs divided into 3 blocks with 8 trials in each block.

Each trial consisted of a fixation cross for 100 milliseconds, followed by an IAPS image displayed for 500 milliseconds (the brief administration of IAPS can still induce emotion) see (Schupp et al., 2004), followed by another fixation, and ended with a word-pair task that was displayed for 5000 milliseconds, following the duration of the study phase as in Bramao and Johansson (2017). The IADS sound was given when the subject saw and memorized the word pairs. The flow of the experimental protocol is illustrated in Figure 1. Each occurrence of IAPS and IADS was chosen randomly on a per trial basis in the same valence polarity, with the condition that no single stimulus is presented repeatedly. In this way, we control the characteristics of the stimuli by distributing their random variability.

Figure 1
The Design of The Experiment



A cued recall task was given at the end of the task by displaying one cue word, e.g., *kucing*–.. and four possible answer choices. The format and the order of the task followed the order of presentation of the WPA in the learning phase so no subject received the question in the same order. However, all subjects received the same order of questions as the order of word pairs obtained from the learning phase. The distractor answer choices are always taken randomly from all possible answers with random positions.

The stimulus was presented and randomized with a system built using the JAVA Netbeans IDE 7.3.1 platform. The experimental protocol was run on a computer with an Intel(R) Core(TM) i5-4460 (3.2 GHz) processor, with an NVIDIA GeForce GTX 960 graphics card, and 8 GB of Random Access Memory running on the Windows 7 x64 operating system. The subject sat approximately a 30 cm distance in front of the Dell S2740L with a 27-inch screen and full HD resolution (1920x1080 pixels) at a refresh rate of 60Hz. The audio was delivered through consumer-grade speakers (Okaya).

Experiment Procedure

The subjects were given consent followed by an additional explanation from the experimenter to ensure that they understood the experimental procedure. The experimenter explained that the subjects would wear GSR and EEG during the experiment which might cause discomfort if used for a long period. Subjects were also asked to minimize head and hand movements. The experimenter asked the subjects a few questions before the experiment as the basic screening processes, such as their caffeine consumption, sleeping hours, drug consumption, and any specific phobias they might have. The participants then signed an informed consent if they agreed to the experimental procedure; participants would still receive the reward regardless of the completion of the task.

The participants were asked to take the most comfortable position in front of the computer. The experimenter then paired the prepared device and made sure each sensor had good contact. The experimenter then instructed the subjects to follow the instructions on the screen and again asked them to minimize movement. Participants wore the EEG and the GSR sensor for the duration of the task. The experimenter then left the subjects in the experiment room. The experimenter then removed the GSR and EEG after the completion of the experiment. The whole experiment task took approximately 15–20 minutes for a single participant. The experimenter then rewarded the subject after they had signed the attendance list. Preparation and inspection of experimental instruments were carried out before the next subject entered the experiment room. These preparations included cleaning the GSR sensor, applying conductive gel to the EEG sensor, charging the sensor, and confirming the computer settings.

Data Analysis

Preprocessing data from the sensor is first carried out to extract features which are then used in the statistical tests. Repeated-measures ANOVA was used to compare the WPA performance, mean amplitude of the GSR, and FAA index separately, by taking into account its between-subjects effect on the experimental group. Statistical analysis was done using Jamovi 1.6.23 (jamovi.org) for Windows.

WPA Data

A reliability estimation using Cronbach's Alpha method on the WPA score shows a coefficient of 0.789 which means this task is quite reliable and can be used to research standards (Howitt & Cramer, 2017). The WPA score is then weighted based on the item's difficulty level. The difficulty level is calculated based on the average correct answer for each item on the norm for all subjects. The weighting is done by reducing the score to 1 with the average correct answer for each item on the norm for all subjects. For example, an item which shows the correct answer norm of 0.711 is weighted as a score of 0.289 (from the results of 1–0.711).

GSR Data Preprocessing

Extraction of GSR data on each subject was performed at 3 minutes during baseline and 24 epochs of data within the time window of 5600 milliseconds per trial relative to the onset of the stimulus. Baseline removal of the GSR was done by subtracting the trial data from the mean of the baseline data. This process aimed to reduce the variability of sweat activity which consists of tonic and non-specific Skin Conductance Resistance. Aggregation on GSR data was done to reduce high-frequency noise by first taking the average data every 100 milliseconds (downsampling to 10 Hz). Then the mean amplitude in the 8 trials based on the treatment conditions was calculated and used in the statistical tests.

EEG Data Preprocess and FAA Calculation

Data were processed using EEGLAB (Calderon & Luck, 2014) 14.0.0b running in MATLAB 2011b. Basic filtering was done by performing a notch filter at a frequency of 50 Hz. The correction of artifacts in this study was carried out using the Blind Source Separation method using the Independent Component Analysis (ICA) method (Jung et al., 2000) with the 'runica' algorithm in the EEGLAB. The elimination of components was carried out visually by the researcher based on certain characteristics, namely, those determined by Jung et al. (2000): ICA components originating from the frontal area have a narrow temporal resolution and tend to be scattered and appear systematically. The next step is to extract the EEG data based on the events that have been determined in the experimental design. This study produces baseline physiological data for 3 minutes, as well as data during experimental conditions for 5600 milliseconds (5.6 seconds) per trial relative to the onset of the stimulus.

We performed a Fast Fourier Transformation to obtain the alpha power for the FAA index calculation (Allen et al., 2004). This study focused on alpha waves at a frequency of 8–13 Hz. The amplitude of the alpha wave (alpha power) is calculated on the frontal electrodes, namely F3, F4, F7, and F8. Alpha power is used to measure the relative asymmetry of alpha waves in the frontal area. Alpha power was also subtracted from the baseline condition data to measure only the FAA activation associated with the stimulus. The FAA is calculated on the natural log of the alpha wave amplitude. The FAA index estimation follows the following formula.

$$FAAindex = mean\left(\ln\left(powR\right) - \ln\left(powL\right)\right)$$

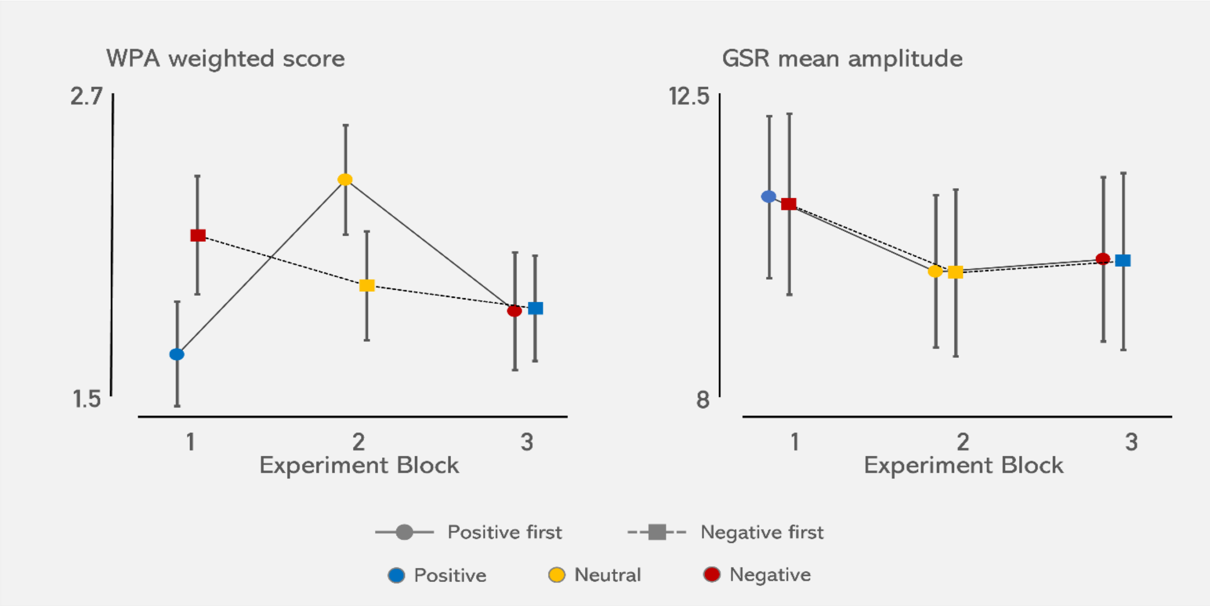
The calculation of the power spectrum is calculated within the epoch time window of 1500 milliseconds with an overlap (Hamming window) of 50% (Allen et al., 2004).

Results

WPA Performance

The results of the RM ANOVA comparison on the weighted WPA score with Group as the between-subjects factor showed a significant main effect of the ED (p = 0.029; F = 3.714). While there were no significant differences between-subjects from the Group factor (p = 0.933; F = 0.007), a significant interaction of the EDxGroup was observed (p = 0.035; F = 3.53), indicating that the order of the experimental block, hence the valence of the stimuli, interacted with the WPA score. A post hoc test (Tukey) showed a significant difference in the positive with neutral condition (p = 0.011; t = -3.599), but only in group 1 in which the positive block was presented first followed by neutral and negative. Figure 2 (left) illustrates the WPA performance as a function of the experimental block order on both groups.

Figure 2
WPA Weighted Score (Left) and GSR Mean Amplitude (Right) as a Function of The Experimental Block Order



Note. Solid line represents group 1 (positive-neutral-negative), and the dashed line represents group 2 (negative-neutral-positive); the blue marker is the positive ED condition, yellow is the neutral ED, and red represents the negative ED condition

Physiological Responses

The results of the comparison test for GSR mean amplitude data showed the significant main effect of the ED ($p = 0.003$; $F = 6.292$). No significant difference from the Group factor ($p = 0.977$, $F = 0.0001$), but significant interaction of the EDxGroup ($p < 0.001$, $F = 9.78$) was found. Meanwhile, the FAA index of the EEG data showed no significant difference ($p = 0.654$; $F = 0.433$).

A subsequent post hoc test (Tukey) was done on the GSR mean amplitude data. For group 1 (positive first), a positive ED elicited higher amplitude compared to neutral ($p = 0.002$; $t = 4.23$) and negative ($p = 0.054$; 2.99). Meanwhile, for group 2 (negative-first), a significant difference was observed only on the negative ED compared to neutral ($p = 0.007$; $t = -3.856$). These results indicate that the first block always elicits higher GSR than the rest, a subsequent analysis was done by eliminating the ED factors and investigating only the block order effect. Indeed, a significant main effect was found ($p < 0.001$; $F = 16.045$), and a post hoc test reveals significantly higher GSR amplitude of the first block (regardless of the ED valence) compared to the second block ($p < 0.001$; $t = 4.94$) and the third block ($p = 0.001$; $t = 3.90$). See Figure 2 (right).

Discussion

This study aimed to investigate the effects of ED induced by emotionally charged audiovisual stimuli on the performance of declarative memory. The declarative performance was measured using a WPA in which participants were instructed to memorize pairs of unrelated words (e.g., *kucing–botol*; cat–bottle). In the learning phase, audio and visual stimuli were presented to the participants as the distractors. The stimuli were grouped into three valence categories: neutral, positive, and negative.

The result of our study was quite unexpected; we found a facilitating after-effect of the positive stimuli to the declarative memory performance, but the stimuli themselves impaired the encoding at the time of the presentation. In other words, when positive stimuli were presented in the first block, participants showed impaired performance in the cued recall of that block. The next experimental block, however, (neutral condition), showed better performance. This pattern was not observed for the group for which the negative valence ED was presented first. In this group, the performance was generally unaffected by the experimental manipulations.

These data suggest that positive emotion has a lingering after-effect on the participants, affecting their cognitive processing in the next block. The indirect effect of emotion on subsequent cognitive performance was found in Knorzer et al. (2016), however, in their study they found that a negative emotion induced before the learning task facilitated their learning outcomes, while a positive emotion suppressed it. Knorzer et al. (2016) argue that positive emotion consumes more cognitive capacity, thereby reducing the individual's ability to process information more deeply. Meanwhile, negative emotion increases the subject's attention so that it allows individuals to process information more deeply. Pratto and John (1991) argue that two types of emotional information (positive and negative) are evaluated differently, from the assumption that negative stimuli have more influence on survival, so humans evolved to be more sensitive in detecting these stimuli. The subsequent improvement in performance after the positive ED block contradicts this suggestion.

Another possibility is that at the first condition when the positive ED distracted participants' attention from the task, participants then tried to correct this behavior by devoting more cognitive resources to the subsequent block. This would explain the overcorrection pattern of the performance (compared to the linear pattern of the negative-first group); however, the data of this study could not clarify this assumption. This pattern could be viewed in different ways; either the positive ED impairs the memory performance and/or it facilitates the subsequent block. To confirm the first view, there should be significant differences between the two groups for the first block, which there were not. To confirm the second view, there should be significant differences between groups for the second block, and the neutral-after-positive should be higher than the neutral-after-negative, which again was not the case. This might also be because of the design of the experiment where we could not directly compare the after-effect of the ED within individual participants. Adding one additional neutral ED block at the end of the experiment might clarify this assumption, e.g., whether the neutral block after the positive block in the negative-first group would also shows performance improvement.

A study by Gupta et al. (2016) that investigated the ED interference effect under different conditions of cognitive load might also help in explaining this finding. In their experiment, they found a consistent pattern of interaction between the loads of the task with the valence of ED in capturing participants' attention. On the one hand, when the task requires low cognitive load (e.g., identifying a letter X between five O's), ED interferes with their reaction times regardless of the valence. On the other hand, when the task requires high cognitive load (e.g., identifying X between H, K, W, M, Z) a negative valence ED did not impose interference while positive ED still shows interference (Gupta et al., 2016). Their findings confirm the previously found pattern of ED interference under different loads (Forster & Lavie, 2008; Lavie, 2005, 2010). The important factor to note here is that in this context, emotional stimuli are goal-irrelevant, that is, they do not directly relate to the task at hand. When the emotional stimuli are directly related to the memory materials, this could facilitate its performance (Adelman & Estes, 2013; Buchanan & Lovallo, 2001; Meng et al., 2017; Schaefer et al., 2009). This facilitating effect has also been observed in the multimedia learning context, in which ensuring the learning material itself contains emotional information facilitates students' performance (Plass et al., 2014; Plass & Kaplan, 2016; Um et al., 2012).

Considering that the task of our experiment requires a relatively high cognitive load and is presented in a goal-irrelevant manner, the data of our study indeed indicated a similar pattern to the ED interference framework, for the first group (positive-first block order), that is, positive ED impairs their performance (compared to neutral ED), presumably by interfering with their attention in the learning phase. Positive ED interference was not observed for the second group (negative-first block order), and one explanation might be that this pertains because of the learning effect and habituation toward emotional stimuli as indicated by the pattern of the skin conductance data. It also suggests the intertwined balance of cognitive and affective processes, in which the attention-capturing effect of emotional stimuli reduces cognitive resources in processing the information (Gupta et al., 2016; Lavie, 2010; Tavares et al., 2016). While, in turn, habituation toward emotional information somehow tips the balance back to allocate cognitive resources more. This is quite a novel finding that deserves more investigation—specifically, does habituation toward the emotional stimuli reduce the interference effect of the positive ED?

Another factor that may have an effect is the time lag of the recall/recognition task. LaBar and Cabeza (2006) in their review, argue that emotions may benefit memory by facilitating the consolidation process. Giving recall/recognition tasks with a relatively long time lag (1 hour to 1 day) showed an increase in memory for affective items (LaBar & Cabeza, 2006). Knight and Mather (2009) confirmed this idea that the decline in memory performance caused by emotion is generally found when memory testing is carried out in a short or immediate time lag. On the topic of consolidation, sleep-dependent memory consolidation is an increasingly popular research topic, and the word-pairing task is one of the frequently used tests to measure this process see, for example, (Bueno-Lopez et al., 2020; Prehn-Kristensen et al., 2020; Reda et al., 2021). Implementing a sleep phase to investigate the ED effect on the consolidation of memory would clarify this interaction.

The design of the experiment could be improved further, for example, by refining the declarative memory task. In this study, the task was divided into three blocks, so that it did not reflect a complete task. The WPA task used in this study also has not been tested on a wider sample to be able to adjust the level of difficulty of each item. Several things could be done, first by compiling the words stimuli based on a better corpus. The words selected for this WPA task were taken from the *Kamus Bahasa Indonesia* since we need neutral sources for calculating word frequency to minimize bias from the specific category, e.g., the word "*Menteri*" would likely be more frequent in the political context. A more general corpus for the Indonesian language has recently been proposed, for example, IndoNLU (Wilie et al., 2020). Subsequently, a validation study of this task could also be done by comparing it against a different test that measures declarative memory, as well as predictive power toward academic outcomes for example, considering the purpose of this measurement as the benchmark of learning processes.

Looking into the physiological response measurements, we found a significant GSR mean amplitude difference, however, the difference we observed was mainly due to the experimental block order. A habituation and stress adaptation pattern has generally been observed, especially in electro-dermal responses see (Herman, 2013), and could even be used to predict resilience (Walker et al., 2019). However, habituation turned out affecting not only the trials in the block but also the subsequent blocks, even with the break between the blocks (the neutral block) that we added to control this effect. This pattern suggests that the use of simple mean amplitude in a similar context would potentially be confounded by the order effect and is not robust enough to be associated with learning performance.

In the case of FAA measurement, we found no significant differences in all conditions. While there are several potential measurement errors, another possibility is that this measurement is not suitable for this task. Regarding the potential for measurement error, for example, related to channel references (Davidson, 2004), data acquisition time window (Winkler et al., 2010) and to the type of wave being measured (Coan & Allen, 2004). There might also be confounding factors arising from the setting of the experiment, such as the experiment room, and the EEG device quality see (Hairston, 2012).

In addition, related to the time window, the FAA index takes longer to acquire data to compensate for the low reliability due to artifacts, so the FAA index may not be detectable in a narrow time window (Winkler et al., 2010). Research on the FAA index is generally carried out on subjects in a resting state or without a task (Coan & Allen, 2004), while in this experiment the subjects were cognitively active. Alpha waves are associated with cognitive inactivity which is characterized by a negative relationship between alpha waves and the glucose metabolism in the brain (Davidson, 2004) so it can be concluded that the measurement of the FAA index is less effective when applied in an experimental protocol that assigns cognitive tasks to subjects. Davidson (2004) recommends measuring frontal asymmetry with gamma waves that are consistently more correlated with the glucose metabolism in the brain. However, as the gamma oscillations are high-frequency in nature (> 30 Hz), this oscillation is frequently masked by artifacts such as electrical interference and muscle activity (electromyogram; EMG), and thus require a higher sampling rate and a highly conditioned recording environment (Luck, 2014) which would be challenging to implement in a practical setting.

Conclusion

In conclusion, based on the results of this study, we found an indication of the after-effect of emotional stimuli on declarative memory performance; however, it could also be explained using the ED interference effect and the intertwined balance of cognitive and affective processes. This result needed to be clarified further using different experimental protocols and refinement on the memory task. Future study design might also consider the effects of consolidation of memory, such as testing the memory after a certain amount of time or after overnight sleep. On the physiological data, the level of skin conductance was largely affected by the habituation of the participants toward emotional stimuli, hence, associating the arousal level with the memory performance in this context would likely produce an incorrect result. Additionally, the brain's marker of emotion as measured using FAA was not suitable in the context of an active cognitive task. Although the findings of this experiment were relatively inconclusive and raised more questions than they provided answers, this study could provide some considerations for future studies in investigating the role of ED on multimedia e-learning environments by taking account of the other intertwined cognitive processes, such as attention and consolidation, as well as physiological/emotional habituation. Ultimately, designing an adaptive e-learning system would require careful consideration of those factors.

Recommendation

More research is needed on ED's interference effect on declarative memory performance and the possible role of emotional habituation and consolidation. Since the GSR simple mean amplitude measurement is knowingly prone to habituation toward emotional stimuli, a different mode of analysis is recommended. Meanwhile, the FAA index is not suitable for use in this context.

Declaration

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Authors' contributions

This article was written based on undergraduate thesis research by ZK and supervised by SK.

Competing Interests

The authors declare no competing interests in the process of writing this article.

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