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Effects of online synchronous instruction with an attention monitoring and alarm mechanism on sustained attention and learning performance

Chih-Ming Chen[a] and Jung-Ying Wang[b]

[a]Graduate Institute of Library, Information and Archival Studies, National Chengchi University, Taipei City, Taiwan, ROC; [b]Department of Multimedia and Game Science, Lunghwa University of Science and Technology, Taoyuan, Taiwan, ROC

ABSTRACT

Many studies have shown that learners' sustained attention strongly affects e-learning performance, particularly during online synchronous instruction. This work thus develops a novel attention monitoring and alarm mechanism (AMAM) based on brainwave signals to improve learning performance via monitoring the attention state of individual learners and helping online instructors or teaching assistants to improve the sustained attention levels of learners with low-attention states as they perform online synchronous instruction activities. Totally, 83 and 65 Grade 7 students were randomly assigned to the experimental and control groups that respectively underwent online synchronous instruction with and without AMAM support. Analytical results reveal that the experimental group of learners exhibited significantly better learning performance and sustained attention than those in the control group, verifying that the AMAM efficiently promotes the learning performance and sustained attention of learners. Moreover, the proposed AMAM was more helpful in improving the learning performance of female learners than those of male learners and improved the sustained attention of both male and female learners. Furthermore, the sustained attention, frequency of attention alarms, and learning performance of the learners in the experimental group were strongly correlated, and the sustained attention and frequency of attention alarms strongly predicted learning performance.

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KEYWORDS
Online synchronous instruction; attention monitoring and alarm mechanism; sustained attention; brainwave; learning performance

1. Introduction

With the rapid development of Internet-based technologies, the use of computers and networks to assist in online synchronous instruction and learning has become increasingly popular. However, online synchronous instruction environments are limited by the fact that teachers cannot immediately monitor the attention states of individual learners because face-to-face interaction is lacking (Chen, Wang, & Yu, 2017). Many teachers and educational scholars believe that technology-assisted teaching and learning (TATL) can contribute to the reform of education and bring innovation to traditional teaching (Dexter, Anderson, & Becker, 1999; Dias, 1999). Although TATL can help in implementing diverse teaching methods, students are likely to cease paying attention in the absence of a teacher's supervision (Zhang, Zhou, Briggs, & Nunamaker, 2006). Clearly, students who can fully concentrate on their learning activities can absorb the greatest

CONTACT Chih-Ming Chen chencm@nccu.edu.tw

possible amount of information. Therefore, the attention states of students during the learning process must commonly be monitored because attention is a key factor in determining learning performance.

The many non-physiological means of identifying attention in real time include head pose tracking (Ba & Odobez, 2009, 2011), face tracking (Stiefelhagen, Yang, & Waibel, 2002), and eye gaze tracking (Toet, 2006). However, as physiological sensor technology, including electroencephalographic (EEG) sensors, heartbeat sensors, and blood oxygen sensors, becomes mature e-learning research has increasingly used physiological signals to determine the attention levels of students (Chen & Huang, 2014; Chen & Lin, 2016; Hsu, Chen, Su, & Huang, 2012). Many studies have used human physiological signals to assess emotion (Chen & Lee, 2011; Chen & Sun, 2012; Chen & Wang, 2011) and attention (Chen & Lin, 2016; Chen & Wu, 2015; Rebolledo-Mendez et al., 2009). Obviously, the integration of physiological sensor technology into e-learning systems to assess the attention statuses of learners to provide useful feedback has become an important research issue in the field of e-learning (Specht, 2014). Chen et al. (2017) developed a novel attention-aware system (AAS) for accurately evaluating the attention of students based on EEG signals; the proposed AAS was integrated into a video lecture tagging system to help students recognize their own periods of low attention while watching a video lecture. Their results demonstrated that the effectiveness of the proposed AAS in assisting online instructors in evaluating the attention of their students to enhance their online learning performance. Moreover, Chen and Huang (2014) developed a web-based reading annotation system with an attention-based self-regulated learning mechanism (ASRLM) that detects brainwaves to improve the sustained attention of learners as they read annotated English texts online, thus further improving online reading performance. Their study designed an attention alarm mechanism via displaying an attention-based radar photo and text message, such as "Pay more attention! Cheer up!" to remind learners to keep on good sustained attention during performing self-regulated learning activity. Experimental results show that sustained attention and reading comprehension of the learners with an ASRLM are better than those of the learners without an ASRLM. The study confirmed that using text as the message type of attention alarm to remind learners' attention statuses for promoting self-regulated learning performance is a practicable and effective method. Also, Wiczorek and Manzey (2014) investigated potential benefits of likelihood alarm systems (LASs) over binary alarm systems in a multitask environment. Their study confirmed that LASs improve participants' attention allocation between two different tasks and therefore lead to an increase in alarm task and concurrent task performance. Accordingly, the use of physiological sensor technologies in developing attention-based alarm mechanism to improve learning performance warrants further study. However, to the best of our knowledge, few studies paid attention to this research issue. According to Chen and Huang's study (2014), this work tried to develop a novel attention monitoring and alarm mechanism (AMAM) that uses text and photo as the message types of attention alarm to remind learners' attention statuses for promoting online synchronous instruction performance.

In this work, the MindSet headset, developed by NeuroSky (http://www.neurosky.com/) and based on human EEG signals, is used to develop an AMAM to improve the sustained attention and learning performance of learners in an online synchronous English instruction environment. This mechanism enables online instructors to monitor the attention states of 20 learners simultaneously and alarm individual learners with a low-attention level using an alarm message of text type or photo type from an online teaching assistant (TA). Whether significant differences exist in the sustained attention and learning performance of the learners who undergo online synchronous English instruction with and without the AMAM is tested. Also, whether the genders differ in learning performance and sustained attention in online synchronous English learning with and without the AMAM support is also studied. Whether significant correlations and cause-effect exist among the frequency of attention alarms, sustained attention, and learning performance is also examined.

2. Literature review

2.1. Effects of sustained attention on learning performance

Generally, attention takes different forms, such as focused attention, shifting attention, sustained attention, selective attention, and divided attention (Driver, 2001; Lezak, Howieson, & Loring, 2004; Wager, Jonides, & Reading, 2004). Among the various forms of attention, sustained attention involves continuous maintenance of alertness and receptivity to a particular set of stimuli or stimulus changes over time (Davies, Jones, & Taylor, 1984). Sustained attention has been considered to be critical in the field of cognitive psychology owing to its close relationship with learning performance (Steinmayr, Ziegler, & Träuble, 2010). Corno (1993) argued that sustained attention improves the learning performance of learners with ordinary learning motivation or competitive intention. As a result, instructors can improve the quality of their teaching by considering learner attention and providing effective learning strategies. Many studies have demonstrated that the performance on a sustained attention task is strongly correlated with academic achievement and attentional behavior in the classroom (Campbell, D'Amato, Raggio, & Stcphcns, 1991; Lam & Beale, 1991). Several recent studies have also pointed out that attention is closely correlated with learning performance in web-based learning environments. For example, Börner, Kalz, and Specht (2014) examined the effectiveness of ambient learning display designs by using a custom-built sensor to measure the attention paid by their users. Their study found a positive relationship between the degree of attention paid to the display and participants' scores in a test of knowledge. Chen and Huang (2014) confirmed a correlation between reading comprehension and the sustained attention of learners who used the ASRLM while reading annotated English texts online. Using a specially designed mobile reading experiment with a two-factor experimental design, Chen and Lin (2016) evaluated how selected static, dynamic, and mixed text displays that are used in sitting, standing and walking contexts, respectively, affect reading comprehension, sustained attention, and the cognitive load of learners. Their work demonstrated that reading comprehension of learners in the high-reading-comprehension group was significantly and positively correlated with sustained attention.

To assess the sustained attention statuses of learners and further increase their attention to learning targets for improving their learning performance in online synchronous instruction and learning environments, this work develops an AMAM to assess the attention paid by students in real time based on human EEG signals and integrates it with the Web meeting system JoinNet to support instructors' online synchronous teaching and students' online synchronous learning.

2.2. Evaluation of attention to support learning

The field of cognitive psychology emphasizes the fact that attention is a key determinant of an individual's learning outcomes (Steinmayr et al., 2010). Attentional processes are supported in various stages, which are the detection of a user's attentional state, the determination of possible alternative attentional states, and the implementation of strategies for the switching or maintenance of focus (Roda & Nabeth, 2007; Roda & Thomas, 2006). Rapp (2006) assessed the applications of attention-aware systems in educational settings and pointed out that attention critically affects motivation, engagement, and learning performance. Therefore, the development of attention-aware systems to support effective learning has become an emerging and rapidly growing field of educational research (Roda & Thomas, 2006). For example, Raca and Dillenbourg (2013) developed a system that monitors the attention paid by teachers in the classroom and gives teachers feedback when their attention drops. The system uses a set of cameras and performs an analysis based on using computer vision technologies to determine how students are reacting to the teacher and to help teachers to identify weaknesses in their teaching.

Currently, various biological signals, such as EEG (Chen & Huang, 2014; Chen et al., 2017; Li et al., 2010; Liu, Chiang, & Chu, 2013), heart rate (Hsu et al., 2012), and blood oxygen saturation (Hsu et al., 2012) have been used to measure the attention levels of human subjects. For example, Hsu et al. (2012) developed a reading concentration monitoring system for use with e-books in an intelligent classroom. Their study used three kinds of sensors including webcam, heartbeat sensor, and blood oxygen sensor to capture the physiological signals of students to evaluate the reading concentration of students. Their study revealed that the proposed system can help instructors to identify the concentration of reading students in a classroom learning environment. Of the aforementioned physiological signal measures, EEG is considered to be the most useful and objective indicator of attention (Li et al., 2011). Li et al. (2010) developed an effective learning prototype that was based on EEG signals to determine the attention statuses of learners. Their system integrated a real-time EEG feedback window and an attention report to improve learners' affective learning performance. Also, Liu et al. (2013) employed EEG data to analyze the learning statuses of students, enabling teachers and students to determine whether students are attentive. They showed that EEG signals from attentive students are easier to identify than those of inattentive students. Chen et al. (2017) developed a novel AAS that was based on human EEG signals for assessing the attention levels of students as high or low, with an average accuracy rate of as high as 89.52%. They also found that a learner's high-attention level can be identified from EEG signals more easily than can a low-attention level. Their study integrated the proposed AAS with a video lecture tagging system to help students detect their own periods of low attention while watching a video lecture, so their integrated system has high potential to provide timely alarms as feedback concerning low-attention levels to online instructors in an e-learning environment.

Generally, compared with traditional classroom instruction, learners lack face-to-face social interaction and contact with instructor in online synchronous instruction courses. Thus, monitoring immediately whether or not students are paying attention to learning activities from their learning sides is extremely difficult to online synchronous instructors because face-to-face supervision is lacking (Chen et al., 2017). More importantly, keeping high sustained attention on online course for a long time is also difficult to learners because of tired spirit or attention being bothered by something. To improve the sustained attention of learners and improve their learning performance in online synchronous instruction environments, this work proposes the AMAM, which is based on the detection of the EEG signals of individual learners to assess their attention levels, with the goal of supporting online synchronous instruction and learning on a web-based learning platform. The proposed AMAM helps instructors monitor the attention statuses of individual learners and alarms learners of low-attention levels by sending an alarm message from online teaching assistant (TA), improving their learning performance and sustained attention.

3. Methodology

3.1. Research architecture

Figure 1 shows the research architecture of this study, in which the independent variable is the presence or absence of AMAM support in online English learning. The experimental group undertook online English learning with AMAM support, whereas the control group performed online English learning without AMAM support. Dependent variables are the level of sustained attention and learning performance. Sustained attention is quantified as an attention value from 0 to 100 that is obtained using NeuroSky's MindSet headset. Participants' posttest scores in English are compared to their pretest scores to assess the learning performance. The background variables are gender and the frequency of attention alarms for the learners in the experimental group with high or low attention. The same English texts are used for online instruction, the same experimental period, and the same teacher are used for the two treatments, representing the control variables.

3.2. Participants and experimental design

The quasi-experiment nonequivalent control group design was used because randomly selecting examinees as targets is difficult in real teaching scenarios. The participants in the work were randomly recruited 148 Grade 7 students from 5 classes at a junior high school in New Taipei City, Taiwan. All

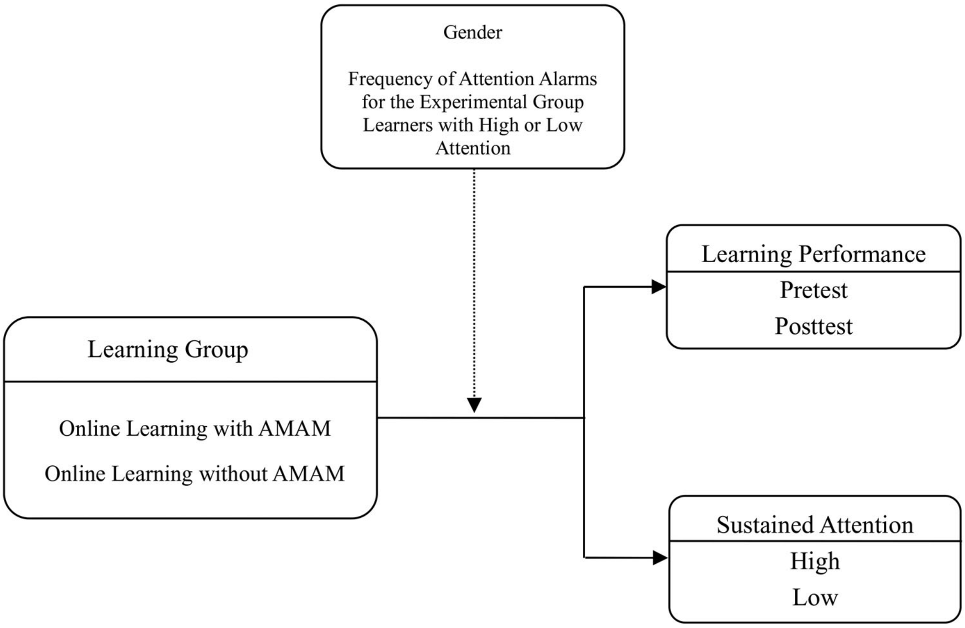

Figure 1. Research architecture of the study.

participants are native Chinese speakers who have been studying English for six years and English is their foreign language. They have never experienced online synchronous learning before participating in the experiment, but they ever experienced TATL, such as online asynchronous learning, electronic whiteboard, and instant response system, from their instructors. This work focused on improving online synchronous English instruction for junior high school students because Taiwan's schools in grades K-12 paid much more attention to promoting TATL than did Taiwan's universities. Although most online synchronous learning was performed for university students, using online synchronous learning for students in grades K-12 can help instructors conduct remedial teaching utilizing available time off class. Besides, the self-control abilities of sustained attention of junior high school students are generally more worse than those of university students. Therefore, junior high school students are chosen as the research participants in this work. Consistent with the nonequivalent control group design in quasi-experimental research, 83 students (42 males and 41 females) from three classes were randomly assigned to the experimental group, whereas 65 students (33 males and 32 females) from the remaining two classes were assigned to the control group. The students in the experimental group undertook online English learning with AMAM support using two selected English texts, whereas the control group students did the same without AMAM support.

To consider the research ethics of the designed experiment that involves recording attention states of the research subjects, written informed consent was obtained from the research subjects following full explanation of the experiment. The informed consent letter contains the specific nature of the research, including that assessing EEG signals by the MindWave headsets developed by NeuroSky is safe as well as it would not result in any potential risks to human body, the data that collect from them are only for the research, their name will never appear on any data collected and that instead we will provide a unique identification number on their data and that this information will remain secure such that only the principal investigator of this study will have access to it, the collected data that are no longer needed will be destroyed, and how participation will make a contribution to our study's goals.

3.3. Experimental procedure

First, a pretest of selected English texts was used to assess the English language proficiency of both groups. Learners in both groups then wore the MindSet headsets, which recorded the level of their sustained attention during their learning of the selected two English texts online. The learners in the experimental group had AMAM support while those in the control group students did not. Both groups were taught the same English texts by the same teacher for the same learning period. After they had completed the learning activities, the learners in both groups were given posttests to measure their learning performance. After the sustained attention values and posttest results were obtained for both groups, whether the learning performance and sustained attention of the experimental group were better than those of the control group was assessed.

3.4. Research tools

3.4.1. Evaluation of sustained attention based on EEG

A safe sustained attention detector, NeuroSky MindSet headsets, were used to measure and output participants' EEG power spectrums. Figure 2 presents the device, which comprises a headset, an ear-clip, and a sensor arm. The attention value was obtained using a patented algorithm that was developed by NeuroSky and was wirelessly transmitted to a computer on the server side via a 1-to-20 wireless receiver. The MindSet headset, which resembles a standard stereoscopic wireless headset, has a comfortable noninvasive dry electrode. The user wears the headset, whose forearm is placed on the user's forehead to measure an attention value in the range 0–100 based on collected real-time EEG signals. Chen and Huang (2014) confirmed the reliability of, and validated, the patented algorithm that was developed by NeuroSky for identifying attention states using EEG signals by means of an attention training game, Birdwatching, that was developed by Lumosity (http://www.lumosity.com/).

3.4.2. The proposed AMAM

The proposed AMAM includes the following user interfaces.

(1) *Observation interface of multi-channel attention status on the server side.*Figure 3 presents the interface that displays the multi-channel attention status on the server side. It is a special brainwave–computer interface that allows the computer to record electrical activity that is associated with brainwaves (EEG). It also uses a 1-to-20 wireless receiver, which is a low-power wireless network that is designed to satisfy all short-range wireless communication requirements, to monitor the attention states of various users. The attention value that is obtained using the NeuroSky's MindSet headset is displayed on the right side of the interface and categorized into one of five ranges, which are no signal, 0–40, 41–60, 61–80, and 81–100, to provide a quick summary of the attention status.
(2) *User interface for monitoring learning status of learners on the client side.*Figure 4 presents the user interface for monitoring the learning status of learner on the client side, which enables online instructors or TAs to access the relevant information about each learner's learning statuses, including the learner's ID number, attention state, client connection status, and the frequency of attention alarms. When the attention value of a learner assessed by using the NeuroSky's MindSet headset was less than 40 for 8 s on an online synchronous English instruction activity, then the low-attention state of the learner was recorded once and the message "No # student is a lack of concentration" was displayed on the user interface of monitoring learning status of learners on the client side for an online course TA. The TA used the user interface of Yahoo messenger to deliver an alarm message, such as the text message titled "Your attention is now low. Please pay more attention to the course! Cheer up!" or a photo with the meaning of arousing attention to the learners to induce them to concentrate on their learning activities. The

Figure 2. NeuroSky MindSet headset.

system accumulated the frequency of attention alarms of each learner and displayed the information on the user interface of monitoring learning status of learners on the client side.

(3) *User interface for delivering alarm message.* Although the JoinNet provides a synchronous chat room in which instructor and students are able to deliver text messages each other, this work used Yahoo messenger to deliver alarm messages to individual learners with low-attention levels because the communication software that provides the fast, easy way to chat and share lots of photos, videos, and animated GIFs instantly with other users is free. The TA can use Yahoo messenger to deliver different types of alarm message, such as text or photo, to individual learners with low-attention levels. These powerful communication features provide benefit in promoting the effects of alarm message.

(4) *User interface for receiving alarm message.* The learners used Yahoo messenger to receive alarm messages from the TA because it is a free communication software that provides the

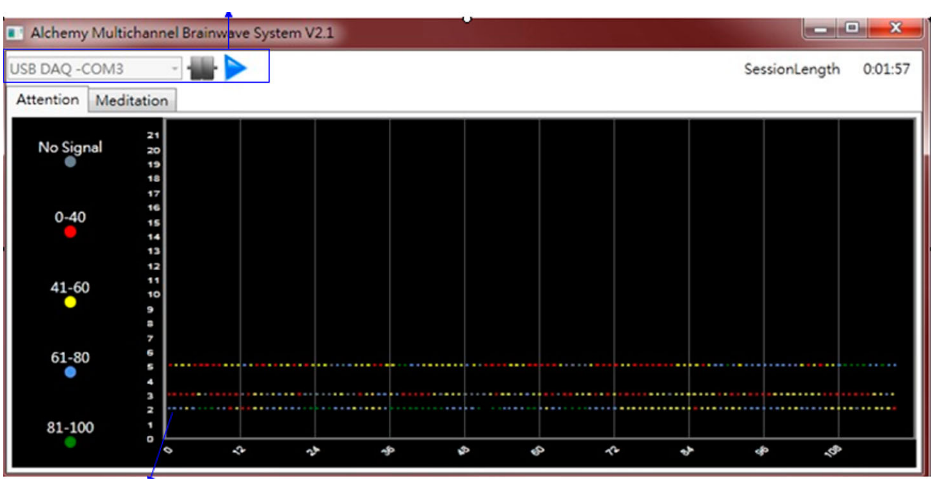

Figure 3. Observation interface of multi-channel attention status on the server side.

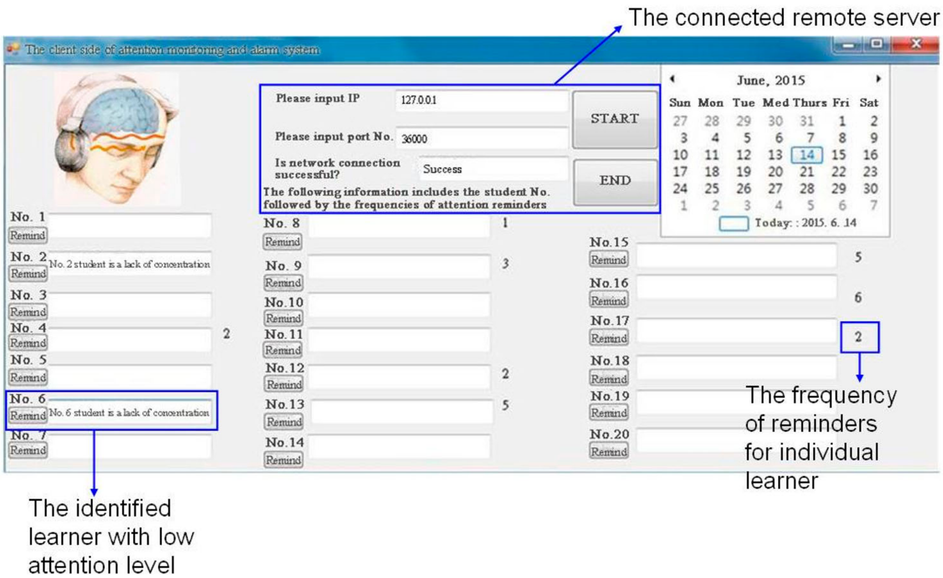

Figure 4. User interface for monitoring learning statuses of learners on the client side.

fast, easy way to chat and share lots of photos, videos, and animated GIFs instantly with other users.

3.4.3. Test sheet for assessing learning performance

Learning performance was evaluated by designing a test sheet based on the learning English contents and the test sheet was designed and scored by an experienced junior high school English teacher. The test sheet consisted of 20 items that assessed their literal comprehension. Each correct answer on the test received 5 points. Restated, total score for the test was 100. This work designed the pretest sheet performed before lesson learning and posttest sheet performed after lesson learning that contain the same questions with different sequences of selecting items in a multiple-choice design. The aim is to control the two test sheets have the same difficulty and to reduce the probability of giving correct answer based on guessing. Based on the statistical analysis and classic testing theory, the pilot test revealed that the difficulty of each test item in the test sheet is close to .5, indicating the difficulty of each test item is moderate, and the discrimination of each test item is higher than .4, indicating the discrimination of each test item is satisfactory. Analytical results suggest that the test sheet for the pretest and posttest is highly reliable in assessing learning performance.

3.5. Learning scenario of learners in the experimental group with AMAM support

The Web meeting system JoinNet (http://www.homemeeting.com/) was used to support instructors in teaching an English course online and to facilitate communication with learners using audio, video, and text chat. Teachers and learners shared and discussed slides, figures, documents, websites, and desktops, and could even remotely control the PCs or laptops of other learners using this system. The developed AMAM, based on brainwave signals, was embedded into JoinNet to help instructors monitor the attention states of learners in the experimental group and to improve their attentiveness by delivering timely alarms. When the learners in the experimental group were not paying enough attention during online English learning, the teacher interface with AMAM assessed the low-attention state according to detection of the relevant brainwaves. The TA used the user interface of Yahoo messenger to deliver an alarm message to the learners to induce them to concentrate on their learning activities. The frequency of attention alarms of each learner was recorded by the AMAM and displayed on the teacher interface on the client side. Accordingly, the learners' learning statuses were monitored for further analysis by the online instructor on the client side. Figure 5 presents the learning scenario of the learners in the experimental group with AMAM support who wore the NeuroSky MindSet headsets during online English learning.

4. Experimental analysis

4.1. Analysis of initial English abilities of learners in both groups

The initial English abilities of both groups were assessed by the test sheet designed for assessing the learning performance before performing online synchronous English instruction and were termed as pretest scores in this work. Before performing the teaching activity, the independent samples *t*-test was applied to confirm differences in the initial English abilities of both groups. Table 1 shows the results. The analytical results show that the difference in pretest results for both groups was not significant ($t = 0.715$, $p = .476 > .05$). It means that the learners in both groups generally had equivalent English ability in the learning English contents. Moreover, gender was analyzed by the independent samples *t*-test to assess the effects of prior English abilities for both groups. Males in both groups were tested first. The pretest result was not significantly different between both groups ($t = 0.287$, $p = .775 > .05$), revealing that prior English abilities of males in both groups were equivalent. Females in both groups were then tested. The result shows the pretest result between both groups did not differ significantly ($t = 0.744$, $p = .459 > .05$). That is, the learners of both genders in both groups had equivalent prior English ability.

4.2. Analysis of difference in learning performance between both groups

The posttest scores of both groups after performing online synchronous English instruction were termed as the learning performance in this work. Whether the learning performance with AMAM

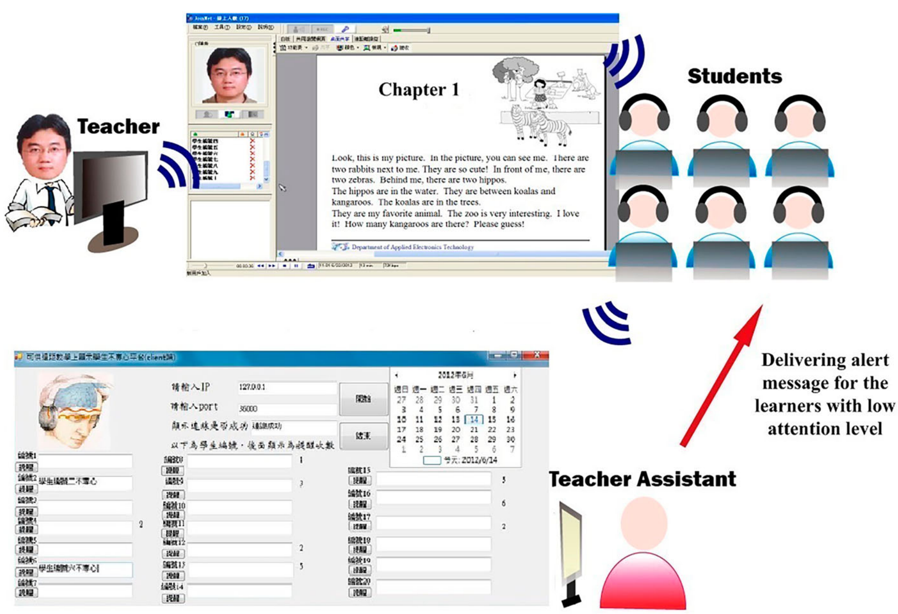

Figure 5. The learning scenario of the experimental group learners with AMAM support in an online learning environment.

Table 1. The independent samples *t*-test results of the initial English ability of both groups.

					t-test for equality of means	
Test item	Group	Number of learners	Mean score	Standard deviation	*t*	Two-tailed test of significance
Pretest score	Experimental group	83	49.04	17.85	.715	.476
	Control group	65	46.92	17.85		
Pretest score	Males of experimental group	42	47.62	19.85	.287	.775
	Males of control group	33	46.36	17.29		
Pretest score	Females of experimental group	41	50.49	15.64	.744	.459
	Females of control group	32	47.50	18.67		

differed significantly from that without was determined. Table 2 shows the analytical results, which confirm that the posttest scores of both groups differed significantly ($t = 2.935$, $p = .004 < .05$). The experimental group exhibited better learning performance than the control group, demonstrating that the proposed AMAM significantly improved the learning performance of the learners in the experimental group while undertaking online English learning.

4.3. Analysis of difference in learning performance between both groups with different genders

The effects of the gender on learning performance were assessed. Tables 3 and 4 present the results of independent sample *t*-tests for males and females in both groups. The results reveal that the learning performance of male learners did not differ significantly between both groups ($t = 1.522$, $p = .132 > .05$). Restated, the learning performance of male learners in the experimental group equaled that of male learners in the control group.

The learning performance of female learners differed significantly between groups ($t = 2.628$, $p = .011 < .05$) and the posttest score of the females in the experimental group exceeded that of those in the control group. Therefore, a gender difference in learning performance existed while both groups performed online English learning with and without the use of AMAM. Clearly, the proposed AMAM was more helpful in improving the learning performance of female learners than that of male learners.

4.4. Analysis of difference in learning performance of learners in the experimental group with different frequencies of attention alarms

The frequency of attention alarms was increased once while a learner received an attention alarm message from the TA in this work. To assess how the frequency of attention alarms from the online TA affected learning performance in the experimental group, the 27% rule created by Cureton (1957) was applied for classification purposes. That is, 27% of experimental group learners with the highest frequency of attention alarms were divided into sub-groups with high frequencies of attention alarms, and 27% of experimental group learners with the lowest frequency of attention

Table 2. The independent samples *t*-test results of the learning performance of both groups.

					t-test for equality of means	
Test item	Group	Number of subjects	Mean score	Standard deviation	*t*	Two-tailed test of significance
Posttest score	Experimental group	83	66.988	16.728	2.935**	.004
	Control group	65	58.923	16.405		

**Indicates $p < .01$.

Table 3. The independent samples *t*-test results of the learning performance for the male learners of both groups.

Test item	Group	Number of subjects	Mean score	Standard deviation	*t*-test for equality of means: *t*	*t*-test for equality of means: Two-tailed test of significance
Posttest score	Experimental group	42	65.0000	17.56521	1.522	.132
	Control group	33	59.0909	15.48460		

Table 4. The independent samples *t*-test results of the learning performance of the female learners of both groups.

Test item	Group	Number of subjects	Mean score	Standard deviation	*t*-test for equality of means: *t*	*t*-test for equality of means: Two-tailed test of significance
Posttest score	Experimental group	41	69.0244	15.78051	2.628*	.011
	Control group	32	58.7500	17.55177		

*Indicates $p < .05$.

alarms were divided into sub-groups with low frequencies of attention alarms. The means of the frequency of attention alarms of the two sub-groups in the experimental group are, respectively, 11.26 and 5.38, while the standard deviations of the frequency of attention alarms of the two sub-groups in the experimental group are, respectively, 1.86 and 0.64. Table 5 shows the comparison of the learning performance of the experimental group learners with high and low frequencies of attention alarms based on an independent sample *t*-test. Analytical results reveal that the learning performance of the sub-group with high frequencies of attention alarms differed significantly from that of the sub-group with low frequencies of attention alarms, based on posttest scores ($t = -6.632$, $p = .000 < .05$), and the sub-group with low frequencies of attention alarms outperformed that of sub-group with high frequencies of attention alarms.

4.5. Analysis of difference in sustained attention between both groups

This section assesses whether sustained attention of both groups differed significantly. Table 6 shows the results, which demonstrate that the sustained attention of the two groups differed significantly ($t = 5.287$, $p = .000 < .05$): the sustained attention of the experimental group exceeded that of the control group, so AMAM support significantly improved the sustained attention of learners.

4.6. Effects of gender on sustained attention of both groups

The effects of the gender on sustained attention in both groups are assessed using the independent samples *t*-test. Table 7 shows the results, which indicate that the sustained attention of male learners

Table 5. Comparison of the learning performance of the experimental group learners with high and low frequencies of attention alarms.

Test item	Group	Number of Learners	Mean score	Standard deviation	*t*-test for equality of means: *t*	*t*-test for equality of means: Two-tailed test of significance
Posttest score	Sub-group with high frequencies of attention alarms	23	52.61	13.56	−6.632***	.000
	Sub-group with low frequencies of attention alarms	37	75.96	14.43		

***Indicates $p < .001$.

Table 6. The independent samples *t*-test results of the sustained attention of both groups.

Test item	Group	Number of subjects	Mean score	Standard deviation	*t*-test for equality of means: *t*	*t*-test for equality of means: Two-tailed test of significance
Sustained attention	Experimental group	83	57.26435	6.759577	5.287***	.000
	Control group	65	52.33303	4.556223		

***Indicates $p < .001$.

differed significantly between the two groups ($t = 2.757$, $p = .007 < .05$): male learners in the experimental group exhibited greater sustained attention than those in the control group. Table 8 shows that the sustained attention of female learners in the experimental group significantly exceeded that of female learners in the control group ($t = 4.687$, $p = .000 < .05$). Evidently, the proposed AMAM improved the sustained attention of both male and female learners, and female learners exhibited better sustained attention than male learners.

4.7. Analysis of difference in sustained attention between learners in experimental group with different frequencies of attention alarms

The effect of the frequency of attention alarms on the sustained attention of learners in the experimental group was examined. Table 9 shows the results. Analytical results reveal that the sustained attention of the high-attention and low-attention sub-groups of learners in the experimental group learners differed significantly ($t = -6.990$, $p = .000 < .05$): the sustained attention of the high-attention sub-group, with fewer attention alarms, was greater than that of the low-attention sub-group with more attention alters.

4.8. Analysis of correlation and regression between sustained attention and learning performance in both groups

Pearson correlation analysis was conducted to evaluate correlations between sustained attention and learning performance in both groups. Table 10 shows the results. The analytical results demonstrate a strongly positive correlation ($r = .697$, $p = .000 < .05$) between sustained attention and learning performance in the experimental group. The learners in the experimental group with high sustained

Table 7. The independent samples *t*-test results of the sustained attention for the male learners of both groups.

Test item	Group	Number of subjects	Mean score	Standard deviation	*t*-test for equality of means: *t*	*t*-test for equality of means: Two-tailed test of significance
Sustained attention	Experimental group	42	56.00236	6.164693	2.757**	.007
	Control group	33	52.58048	4.578632		

**Indicates $p < .01$.

Table 8. The independent samples *t*-test results of the sustained attention for the female learners of both groups.

Test item	Group	Number of subjects	Mean score	Standard deviation	*t*-test for equality of means: *t*	*t*-test for equality of means: Two-tailed test of significance
Sustained attention	Experimental group	41	58.55712	7.164464	4.687***	.000
	Control group	32	52.07784	4.591852		

***Indicates $p < .001$.

Table 9. Comparison of the sustained attention of the experimental group learners with different frequencies of attention alarms.

Test item	Attention alarm	Number of subjects	Mean score	Standard deviation	*t*-test for equality of means: *t*	Two-tailed test of significance
Sustained attention	More frequencies	46	53.454	4.006	−6.990***	.000
	Less frequencies	37	62.001	6.512		

***Indicates $p < .001$.

Table 10. Correlation analysis of the sustained attention and learning performance in both groups.

Group			Sustained attention	Posttest score
Experimental group	Sustained attention	Pearson correlation	1	.697***
		Significance (two-tailed)		.000
		Number of learners	83	83
Control group	Sustained attention	Pearson correlation	1	.510***
		Significance (two-tailed)		.000
		Number of learners	65	65

***Indicates $p < .001$.

attention exhibited better learning performance. A strongly positive correlation also existed between sustained attention and learning performance in the control group ($r = .510$, $p = .000 < .05$), but this correlation was weaker than for the experimental group.

Since sustained attention and learning performance in the experimental and control group were strongly correlated, linear regression analysis was performed to determine whether sustained attention successfully predicted learning performance. Table 11 shows the results. The analytical results reveal that sustained attention effectively predicted learning performance in the experimental group ($\beta = 1.72$, $p < .001$), explaining as much as 48.5% of the variance thereof. Additionally, sustained attention effectively predicted learning performance in the control group ($\beta = 1.84$, $p < .001$), explaining as much as 26% of the variance thereof. Accordingly, the power of sustained attention to predict learning performance was greater for learners in the experimental group than for those in the control group.

4.9. Analysis of correlation and regression between frequency of attention alarms and learning performance in the experimental group

Pearson correlation analysis was conducted to evaluate correlations between frequency of attention alarms and learning performance in the experimental group. Table 12 shows the results. The analytical results demonstrate a strongly negative correlation ($r = -.640$, $p = .000 < .05$) between frequency of attention alarms and learning performance in the experimental group. Since frequency of attention alarms and learning performance in the experimental group were strongly correlated, linear regression analysis was performed to determine whether frequency of attention alarms successfully predicted learning performance. Table 13 shows the results. The analytical results reveal that

Table 11. Linear regression analysis of the sustained attention and learning performance under considering the attention as independent variables and the posttest score as dependent variable for both groups.

	Model summary				ANOVA		Unstandardized coefficient		
Group	Model	Selected variable	*R*	R^2	*F*	Sig.	β distribution	*t*	Sig.
Experimental group	1	Sustained attention	.697	.485	76.43	.000	1.72	8.742***	.000
Control group	1	Sustained attention	.510	.260	22.13	.000	1.84	4.705***	.000

***Indicates $p < .001$.

Table 12. Correlation analysis of the frequency of attention alarms and learning performance in the experimental group.

Group			Frequency of attention alarms	Posttest score
Experimental group	Frequency of attention alarms	Pearson correlation	1	−.640***
		Significance (two-tailed)		.000
		Number of learners	83	83

***Indicates $p < .001$.

Table 13. Linear regression analysis of the frequency of attention alarms and learning performance under considering the frequency of attention alarms as independent variables and the posttest score as dependent variable in the experimental group.

	Model summary				ANOVA		Unstandardized coefficient		
Group	Model	Selected variable	R	R^2	F	Sig.	β distribution	t	Sig.
Experimental group	1	Frequency of attention alarms	−.640	.409	56.09	.000	−3.996	−7.49***	.000

***Indicates $p < .001$.

frequency of attention alarms effectively predicted learning performance in the experimental group ($\beta = -3.996$, $p < .001$), explaining as much as 40.9% of the variance thereof.

5. Discussion

The main contribution of this work is to develop a novel and effective AMAM based on human EEG signals that can help online instructors and teaching assistants monitor the attention statuses of individual learners and alarm them of a low-attention level by sending an alarm message, thus promoting learning performance and sustained attention of online synchronous instruction. Namely, the developed AMAM breaks through the limitation that online synchronous instruction activity is difficult to monitor immediately whether or not students are paying attention to learning activities. Analytical results in this work revealed that the experimental group with AMAM support had significantly better learning performance and sustained attention than those of the control group without AMAM support, verifying that the AMAM improved the learning performance and sustained attention of learners who are learning English online. The results also demonstrated that the learning performance of male learners did not differ significantly between the two groups, but those of female learners in the experimental group significantly differed from those of female learners in the control group, so the effect of AMAM on learning performance was gendered. Clearly, the proposed AMAM was more effective in improving the learning performance of female learners than those of male learners. This result is similar to Chen and Huang's finding (2014), indicating that the web-based reading system with ASRLM support improves the sustained attention and online annotated English reading comprehension of female learners more than those of male learners. Moreover, analytical results revealed that the high-attention sub-group of the experimental group who required fewer attention alarms exhibited significantly better learning performance than the low-attention sub-group, who required more attention alarms. This result echoes with Börner, Kalz, and Specht's finding (2014), indicating that the amount of attention paid was positive correlated with scores on knowledge tests when knowledge gain was facilitating using attention-aware ambient learning displays.

Learning performance was strongly correlated with sustained attention in both groups, but the correlation for the experimental group was slightly stronger than that for the control group: the power of sustained attention to predict the learning performance of learners in the experimental group exceeded that of those in the control group. Therefore, learners in both groups with high sustained attention exhibited higher learning performance, and AMAM support may be the key reason why the significant correlation between sustained attention and learning performance in the experimental group is higher than that in the control group. This is an important finding. This result echoes with Margolis's finding (1972), indicating that a strong correlation between sustained attention and reading test scores exists in a classroom environment. Lam and Beale (1991) also found that attention was strongly correlated with reading comprehension scores for normally developing children. The result is also similar to Chen and Huang's finding (2014), indicating that a strongly positive correlation between reading comprehension of annotated English texts online and sustained attention exists. Chen et al. (2017) examined whether a correlation exists between low-attention periods of learners who are watching a video lecture, identified by the proposed AAS and posttest scores, and whether a correlation exists between the low-attention periods of learners who are watching a video lecture, identified using the proposed AAS and progressive score. Analytical results reveal that the total duration of periods of low-attention during the watching of a video lecture, identified by the proposed AAS, was strongly negatively correlated with posttest scores ($r = -.806$, $p = .016 < .05$), and that the total duration of periods of low attention during the watching of a video lecture as identified using the proposed AAS was also negatively correlated with progressive score ($r = -.768$, $p = .026 < .05$). Clearly, those findings are consistent with this work.

According to standard measure, this work has good results and important contributions, but more stringent criteria are needed to overcome for future work. This work has following several limitations. First, owing to the functional limitation of the 1-to-20 wireless receiver, the learning scenario of the learners in the experimental group who wore the NeuroSky MindSet headsets for online English learning with AMAM support was at a computer classroom, not at the homes of the students, because the 1-to-20 wireless receiver cannot yet transmit human EEG signals over the Internet. This limitation may influence the naturalness of online synchronous instruction. Second, owing to the limitations on wireless transmission by the 1-to-20 wireless receiver and the number of available NeuroSky MindSet headsets, online synchronous instruction of the experimental group of 83 students and the control group of 65 students was performed 5 and 4 times, respectively.

6. Conclusions and future work

Experimental results concerning the use of the AMAM, which was based on human EEG detection technology, to support students' online English learning, verify that AMAM support improves learning performance and sustained attention. Analytical results show that the AMAM provides greater benefits for female learners than for male learners. The AMAM simultaneously improved the sustained attention of both genders. Learners of English online in the high-attention sub-group with AMAM support exhibited better learning performance and sustained attention than those in the low-attention sub-group. The sustained attention and learning performance of learners in both groups were strongly correlated with learning performance: the correlation was linear and provided favorable predictability, indicating that learners with high sustained attention exhibited good learning performance. The correlation between learning performance and sustained attention in the experimental group was slightly higher than that in the control group and sustained attention more strongly predicted learning performance for the learners in the experimental group than for those in the control group. More importantly, the analytical results demonstrate a strongly negative correlation between frequency of attention alarms and learning performance in the experimental group and frequency of attention alarms effectively predicted learning performance in the experimental group.

Additional studies are warranted. First, participants could be expanded to include primary school students, senior high school students, college students, or adult learners to determine whether participants with different levels of academic achievement exhibited different outcomes when learning English online with and without AMAM support. Second, physiological signal detection technology for determining attention statuses could be integrated with other sensing technologies, such as video monitoring and recognition, eye-tracking, and behavior monitoring and identification, to enhance the accuracy of attention detection. Finally, the ability of the 1-to-20 wireless receiver to transmit wirelessly brainwaves to a server-side computer should be improved to support online synchronous instruction with AMAM support at the homes of students – rather than only in a computer classroom. In conclusion, we hope that this work reaches others who share our objectives and can carry on such work in the future.

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Notes on contributors

Chih-Ming Chen is currently a distinguished professor in the Graduate Institute of Library, Information and Archival Studies at National Chengchi University, Taipei, Taiwan. He received his B.Sc. and M.Sc. degrees from the Department of Industrial Education at National Taiwan Normal University in 1992 and 1997, respectively, and received his Ph.D. degree from the Department of Electronic Engineering at National Taiwan University of Science and Technology in 2002. His research interests include digital library, e-learning, data mining, machine learning and intelligent agents on the web.

Jung-Ying Wang is currently a professor in the Department of Multimedia and Game Science at Lunghwa University of Science and Technology, Taoyuan County, Taiwan. He received his B.Sc. and M.Sc. degrees from the Department of Chemical Engineering at National Taiwan University of Science and Technology in 1987 and 1989, respectively, and received his Ph.D. degree from the Department of Computer Science and Information Engineering at National Taiwan University of Science and Technology in 2007. His research interests include game AI, machine learning and intelligent systems on the web.

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