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# The Effects of Biofeedback-based Stimulated Recall on Self-Regulated Online learning: A Gender and Cognitive Taxonomy Perspective

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## Abstract

Previous studies posited the effectiveness of Stimulated Recall (SR) by exposing learners to recorded videos enhancing their personal perceptions and authentic understanding of knowledge in an interactive classroom. However, few studies explored how SR is implemented in a relatively static context, e.g., online self-directed learning, or took human factors, e.g., cognitive style and gender, into consideration in such a context. To fill this gap, the current study, based on previous psychological research findings, aims to introduce biofeedback as a stimulus for learners to engage in retrospection regarding their learning behavior. A quasi-experimental design study was carried out over a 12-week set of EFL (English as a Foreign Language) self-regulated online reading activities. The participants consisted of an experimental group (54 undergraduate students) and a control group (52 undergraduate students) at one Chinese university. Pre-post tests on reading performance and their association with a specific cognitive taxonomy were assessed through a developed scale instrument, whereas physiological signals (e.g., gazing duration, verbal fixation and brain wave) were captured via eye-tracking and electroencephalograph (EEG) technology. The results emphasized that (a) students' reading ability and cognitive hierarchy significantly improved through biofeedback stimulation. Moreover, (b) learners in single level-one cognitive hierarchic groups had significant improvements in both cognitive abilities and reading comprehension, whereas learners in multi-level hierarchic groups had no significant enhancements. Finally, (c) the optical data results and EEG reports showed that males favor procedural feedback and females have a preference for a conclusive assessment.

**Keywords:** Biofeedback; Stimulated Recall; Self-Regulated; Taxonomy

## 1. Introduction

The technique of stimulated recall (SR) is considered a valuable tool for learners to capitalize on introspection and cognitive processes (King, 1980; Peterson & Clark,

1 1978). Although many researchers have applied SR to assess learners' thoughts in a  
2 traditional learning pattern, the challenge is how to implement this method in the  
3 context of self-regulated online learning (Meier & Vogt, 2015), the reason being that  
4 online self-regulated learning is generally carried out in a relatively static mode,  
5 which lacks the interactivity to generate a stimulus (Duo & Song, 2012). In addition,  
6 some researchers maintain that learners' response to the SR, mainly in the form of a  
7 self-reported verbal protocol, suffers from a lack of validity (Meade & McMeniman,  
8 1992). Moreover, a plethora of studies suggest that learning performance is closely  
9 associated with human factors (Li & Kirkup, 2007; Lu & Chiou, 2010), which has led  
10 us to take learners' human factors into consideration in the current research.

11  
12  
13 The prior psychological findings suggest that the biofeedback training in SR could  
14 significantly improve children's attentive behavior (Linden, Habib, & Radojevic,  
15 1996), and we propose that biofeedback techniques may be incorporated into SR as a  
16 stimulus in the context of online autonomous learning. Specifically, the inclusion of  
17 physiological information increases accuracy and provides an intelligent identification  
18 of users' individual emotional and learning status, allowing for more personalized  
19 pedagogical design. Additionally, the biological signals captured from learners  
20 minimize the superficiality of self-reported data. Considering the popularity and  
21 overall widespread usage of various physiology measurement devices, eye trackers  
22 and portable electroencephalograph (EEG) readers were chosen for the current study.

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24  
25 The participants were selected from a university in China and assigned to either an  
26 experimental group or to a control group and administered an EFL online reading task  
27 for a period of 12 weeks. Their reading abilities and cognitive taxonomy levels were  
28 tested before and after the experiment, and their physiological measurements were  
29 incorporated in the study. With this quasi-experimental setup, this study tries to  
30 answer the following questions:

- 31  
32  
33 (1) Can biofeedback as a stimulus significantly influence students' reading  
34 comprehension and cognitive hierarchy when in an online autonomous learning  
35 mode?  
36 (2) In light of different personal cognitive hierarchic levels in learners, how does  
37 biofeedback affect students' cognitive taxonomies and reading abilities?  
38 (3) In light of gender differences, how does biofeedback influence students' learning  
39 behavior?  
40

41 The paper is structured in the following way: After this introduction, section two  
42 deals with the research background, section three describes the methodology, section  
43 four reports the results, section five provides a discussion in light of the current  
44 literature, and section six concludes the paper, highlighting some implications.  
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## 48 2. Literature Review

### 49 2.1 Self-Regulated Learning

50  
51  
52 Self-regulated learning (SRL) ~~are~~is defined as an active, constructive process by  
53 which learners initiate monitor, regulate, and control their cognition, motivation, and  
54 behavior processes to achieve their learning goals (Pintrich, 2000). Zimmerman (1989)  
55 posited that self-regulated learning is the triadic interaction between self-observation,  
56 self-judgment and self-reaction for their thoughts, feelings and actions (Zimmerman,  
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1 1989). With the increasing development of information technology, SRL has been  
2 closely integrated with an online context, which provides flexible accessibility and  
3 additional resources for learners to perform asynchronous learning without the  
4 barriers of space and time.

5 Although many previous studies have examined the positive effect of an  
6 appropriate online SRL strategy on leaning outcomes and perceptions (Devolder, van  
7 Braak, & Tondeur, 2012; Panadero, Kirschner, Järvelä, Malmberg, & Järvenoja, 2015),  
8 some critical arguments requiring further exploration remain, and learners'  
9 disengaging from online SRL suggests that strategies are of special value for  
10 achieving SRL. Firstly, although the content and results of learning behavior could be  
11 observed in some online SRL systems, learners' feelings related to actual behaviors  
12 are difficult to be examined. Additionally, learners may fail to make a corrective  
13 self-judgment of their personal characteristics, which may lead to the impairment of  
14 individualized learning environments in online SRL (Kizilcec, Pérez-Sanagustín, &  
15 Maldonado, 2017). Moreover, the measurements of SRL are commonly limited to  
16 self-reported instruments and/or a think-aloud approach, which possibly distract  
17 learners from the target task and cause cognitive overload (Mey & Mruck, 2010). It is  
18 suggested that informative assessment and process mining techniques be employed in  
19 online SRL (Houben, 2016).

20 Stimulated recall is regarded as an applicable approach for recollecting and  
21 assessing learners' thoughts about their self-regulated learning, because the  
22 retrospection can be conducted without distracting students from their learning tasks  
23 and provide an additional description of a particular event. Furthermore, some open  
24 questions can be designed during the process (Meier & Vogt, 2015). Moreover,  
25 simulated recall with a biofeedback stimulus can offer learners' emotional situations,  
26 which helps us to investigate and explain learners' performances from the perspective  
27 of human feelings, which may be valuable for the construction of an individualized  
28 learning context in SRL. Additionally, stimulated recall with biofeedback stimulus is  
29 considered a useful formative measurement that provides reliable objective  
30 information about learners to assess their learning behavior in the context of online  
31 SRL.

## 32 **2.2 Stimulated Recall**

33 Stimulated recall comprises introspective procedures through which participants'  
34 cognitive processes help learners engage in more effective learning by adopting a  
35 stimulus (normally a recorded video) to be delivered to the student at the time of  
36 learning (Iovane, Salerno, Giordano, Ingenito, & Mangione, 2012). Bloom (1953)  
37 observed that SR could be useful for examining humans' covert cognitive behavior. In  
38 addition, many constructivists, based on the theory of constructivism, have found that  
39 stimulated recall is a valid approach to aid students' learning strategies (Jensen, 2000).

40 The decades of research in the domain of SR-enhanced learning can be categorized  
41 into three main categories. The *first* is the effectiveness of this method with regards to  
42 both learning outcomes and interactive cognitions. Lindgren's (2002) research  
43 presented that learners' EFL writing skills were significantly improved when SR was  
44 adopted (Lindgren, 2002). Furthermore, a study using video clips and photographs to  
45 stimulate primary school children to recall science center exhibits resulted in higher  
46 engagement with the science center (Lindgren, 2002). Additionally, SR is regarded as  
47 a useful method for constructing individuals' relationship between cognition and  
48 behaviors within learners (Meade & McMeniman, 1992). *Second*, SR has been  
49 extensively implemented in various research contexts within a variety of academic

1 subjects as diverse as second language learning (Gass, 2001; Selinker & Gass, 2008)  
2 and nursing education (Wang, Liang, Blazeck, & Greene, 2015), as well as a variety  
3 of learning setups (e.g., traditional face-to-face delivery versus online setups) and a  
4 variety of participants (e.g., primary school students and mature students). *Third*, the  
5 stimulus source may differ from one research context to another. For instance, some  
6 studies indicated that although SR generally includes audio-video replay, another  
7 variant of the stimulus could include participants' physiological data (Jennett &  
8 Affleck, 1998).

9 Although the majority of studies have shed light on the strengths of SR, the  
10 different applications of SR and the variety of stimuli that may potentially be used  
11 highlight some questions. For instance, current research does not explain an issue that  
12 is mostly concerned with SR as a method (Tjeerdsma, 1997): the supplement of  
13 information to incomplete memories or rather introspection. This question may be  
14 attributed to the observation that the stimulus sources, normally presented in  
15 audio-video narrative episodes, may not be able to produce cognition per se (Wilcox  
16 & Trudel, 1998). This assumption is consistent with Gass' (2001) research, which  
17 points out that recall may decay with delayed protocols since learners may treat a  
18 stimulus as a recollection instead of a reflection. It is therefore plausible that the type  
19 of stimulus used in SR may stimulate users' cognitive activity in different ways. In  
20 what follows, we discuss the effects of biofeedback on learning.  
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### 25 **2.3 Biofeedback**

26  
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28 Biofeedback, which includes a series of physiological stimuli, has been widely  
29 employed to investigate users' emotional states when operating many smart devices  
30 (Huang, Hwang, & Chen, 2014; Picard & Picard, 1997). Biofeedback makes it  
31 possible to narrow the gap between the human and the machine (Sano & Picard, 2013)  
32 by computing humans' affection through the recognition and analysis of humans'  
33 physiological signals. We propose that the usage the biofeedback could benefit the  
34 enhancement of personalized human-computer interactions.  
35

36 With the increase of research improvements in physiology, many smart devices and  
37 systems have been improved and are being used extensively in different fields of  
38 application (e.g., psychology, neuro-sciences, and education). Among these tools, eye  
39 trackers and portable EEGs are normally recommended as a method, especially in  
40 E-learning settings, due to their portability and economical costs. As far as eye  
41 tracking is concerned, researchers take into consideration seven research themes and  
42 three eye-tracks measurements, namely, the position of fixation (to test location of  
43 interest), the fixation duration (to examine the extent to which readers focus on a  
44 target), and the scan-path (to explore reading habits); all of these provide a promising  
45 channel to help connect learners' cognition to learning outcomes (Lai et al., 2013).

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47  
48 Current studies in technology and education often utilize eye-tracking techniques  
49 to test online reading activities. For instance, Kang (2014) used eye-trackers to  
50 compare online reading patterns and comprehension between readers whose reading  
51 language is their first language and those whose reading language is their second  
52 language. Another study analyzed readers' scan-path data collected by an eye tracker  
53 to explore the ways in which readers view the different features of different genres, or  
54 topics, in a text document (Clark, Ruthven, Holt, Song, & Watt, 2014).  
55

56 In addition to eye tracking, EEGs have also been extensively used in many research  
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1 fields ranging from psychology to education. Some psychologists found that EEG  
2 signals could be used in the biofeedback training mode and that the attentive behavior  
3 of children affected by Attention Deficit Disorder (ADD) or Attention Deficit  
4 Hyperactivity Disorder (ADHD) were significantly improved (Linden, Habib, &  
5 Radojevic, 1996).

6  
7 Furthermore, the relationship between EEG features and corresponding emotional  
8 states have been tested and confirmed in many learning contexts (Wang, Nie, & Lu,  
9 2014). For instance, some research based on EEG analysis found that personal local  
10 features can significantly enhance students' prediction performance in a self-paced  
11 learning environment (Yamauchi, Xiao, Bowman, & Mueen, 2015). In light of the  
12 current literature, there is strong evidence of the effectiveness of biofeedback in  
13 enhancing the human-machine interaction and, as a consequence of this interaction,  
14 the ability of the biofeedback to generate a change in behavior. Thus, we propose that  
15 eye movement tracking and EEG data can be utilized as personalized feedback to  
16 enhance online learners' reading outcomes and belonging to multi-level cognitive  
17 taxonomies. In what follows, we deal with human factors and their effects on learning  
18 behavior.  
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#### 23 ***2.4 Human Factors and Learning Behavior***

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25 A number of empirical studies have demonstrated that learning behavior has a close  
26 relationship with different human factors, such as cognitive style, knowledge level  
27 and gender. For this very same reason educational technology development has been  
28 increasingly highlighted in personalized learning systems and applications. Learners'  
29 cognition has been demonstrated to be a significant variable predicting students'  
30 learning performance (Hung, Lin, Fang, & Chen, 2014).

31  
32 Some authors maintain that the cognitive taxonomy may be utilized as a significant  
33 educational instrument in teaching critical reading in EFL classes (Surjosuseno &  
34 Watts, 1999). Most of the various cognitive hierarchy instruments are essentially  
35 similar to Bloom' cognitive taxonomy. Bloom's cognitive taxonomy is a six-level  
36 classification system whose categories are knowledge, comprehension, application,  
37 analysis, synthesis and evaluation. These are ranked from "lower order" to "higher  
38 order" thinking and used to measure the level of cognitive achievement (Krathwohl,  
39 Bloom, & Masia, 1964). These six categories in the taxonomy are useful tools for  
40 planning and guiding various teaching activities to encourage students' critical  
41 reading in EFL (Athanassiou, McNett, & Harvey, 2003). Some research on EFL  
42 reading has indicated that thought-provoking exercises based on Bloom's taxonomy  
43 can guide learners to develop reading skills (Khorsand, 2009).

44  
45 Furthermore, a copious amount of studies have demonstrated that learning  
46 tendencies and behavior are reflected in different manners by gender (Tsai & Tsai,  
47 2010). For instance, Brantmeier (2001) found that gender was a key concern  
48 associated with reading comprehension in a group of readers whose reading language  
49 was their second language. Moreover, Pae (2004) investigated the effect of gender on  
50 EFL reading comprehension, and the results showed females were in favor of  
51 Mood/Impression/Tone items whereas males preferred Logical Inference items. From  
52 the perspective of tech-supported learning, Terzis and Economides (2011) found that  
53 males focused on the usefulness of computer-based assessment whereas females  
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1 focused on how easy or difficult it was. Thus, in light of the human factors affecting  
2 behavior, we propose that biofeedback will affect students' cognitive taxonomies and  
3 reading abilities in light of different personal cognitive hierarchic levels and genders.  
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### 7 **3. Methodology**

9 In this section, we explain the detailed procedures of this experiment to investigate if  
10 learners' reading performance and cognitive levels are affected by SR though  
11 biofeedback, and what roles learners' cognitive taxonomy and gender play. The  
12 biofeedback data were captured by eye-tracking and EEG devices. In addition, the  
13 scores from Bloom's taxonomy survey and reading tests were collected by means of a  
14 questionnaire and standardized test materials, respectively, and then analyzed with  
15 IMB SPSS 19.  
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#### 18 **3.1 Quasi-Experimental Design and Participants Selection**

20 A quasi-experimental design was carried out with an experimental group and a control  
21 group. Participants were recruited from a university in China, which has offered since  
22 2004 an EFL self-regulated online learning program. The experimental design criteria  
23 were as follows. *First*, participants should strictly adhere to the arrangements made by  
24 their instructors in a specific set time and location. This requirement was set to limit  
25 environmental biases considering the complexity of factors that may affect the results  
26 of experiments involving physiological measurements. *Second*, comparisons should  
27 be as accurate and objective as possible. To improve consistency within groups, we  
28 recruited participants based on their knowledge background and learning experience  
29 to try to improve the between-group relative homogeneity. *Third*, since gender is an  
30 important human factor affecting SR and biofeedback, the gender ratio should be  
31 balanced between the two groups.  
32  
33

34 By following the selection criteria above, 106 participants majoring in economics  
35 at undergraduate level grade one were selected randomly from lists of original  
36 university cohorts. After a random selection and screening to the set criteria, random  
37 student allocation generated an experimental group with 54 students and a control  
38 group with 52 students. Compared with other majors in this university, the gender  
39 ratio in economics is relatively balanced, and students' general proficiency of EFL  
40 reading ranged from band three to band four of the College English Test (CET 4),  
41 which is a standardized test adopted by the Chinese education system. All participants  
42 had little or no familiarity or background on physiology tests.  
43  
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#### 47 **3.2 Procedures and Instruments**

49 The current teaching experiment was conducted from September 2015 to Jan 2016,  
50 and provided students with the opportunity to engage in multi-level learning activities.  
51 The experiment consisted of five EFL classes each week, of which two were 45  
52 minute *reading and writing* (R&W) classes in a physical classroom, two were 45  
53 minute *collaborative learning* (CL) classes in an interactive classroom, and one was 1  
54 hour *autonomous learning* (AL) classes in a language lab with a computer for each  
55 individual participant. In addition, the teaching experiments were fairly designed for  
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1 both the control group and experimental group, because the learning conditions were  
2 exactly the same for both groups; that is, the same material, contents and instructors  
3 were used. Biofeedback was administered only for the experimental group.

4 The above arrangement ensured that almost all the teaching and learning processes  
5 were given utmost control, so as to minimize sources of bias and to enable us to  
6 identify whether SR is a valid tool for enhancing learners' performance. The current  
7 experiment was performed for nearly a semester, and [figure 1](#) shows that the learning  
8 experiments consisted of three stages with the different instruments.  
9  
10

### 11 **3.2.1 Homogeneity Test**

12  
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14  
15 In the first stage, both Bloom's taxonomy scale and standard EFL reading material  
16 were used to test the homogeneity of the subjects. To ensure the quality of the  
17 pre-post test, both a cognitive hierarchy questionnaire and a reading comprehension  
18 test were conducted during the R&W class under the teachers' supervision.  
19 Furthermore, to minimize psychological interference on the participants, this  
20 experiment employed a double-blind approach.  
21

22 A rating-scale questionnaire was developed from Nicholas' study ([Athanassiou et  
23 al., 2003](#)) and consisted of 6 items ([shown in Appendix 1](#)), which correspond to  
24 Bloom's six cognitive hierarchies. Achievement was coded 1 to 6 respectively to  
25 represent knowledge (1), comprehension (2), application (3), analysis (4), synthesis  
26 (5), and evaluation (6). Two experienced EFL teachers were involved in translating  
27 the instrument into Chinese for its reliability and validity with a Chinese audience.  
28 Participants were required to select the items they supposed they had achieved  
29 according to their perception of their current cognitive level. Then, an average score  
30 was computed for each of their submissions. Learners' perceived cognitive taxonomy  
31 was tested using a developed self-reported questionnaire, which explained to both  
32 groups in detail their learning activities. A series of individual assignments and group  
33 discussion were conducted to ensure students' comprehension and the measurement of  
34 the levels with which they engaged in the EFL context.  
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39 •*Knowledge*: This cognitive category simply focuses on recalling learned concepts.

40  
41 In the current EFL learning context, *knowledge* represents remembering concepts,  
42 such as words, collocations, and grammatical knowledge. These are the primary  
43 learning activities for EFL learning.  
44

45 •*Comprehension*: This is the cognitive category that highlights the capability to seize  
46 the inner meaning of a text through comparison and contrast. In the current study,  
47 *comprehension* was presented to EFL learners as the understanding of the text based  
48 on comparison and contrast of the material given as text and the extrapolation of  
49 meaning rather than simple information recall.  
50  
51

52 •*Application*: This concept in the current EFL learning context was explained to  
53 students as their ability to recall what they learned before, such as a related linguistic  
54 approaches or logical features, and apply them to the current text analysis, which led  
55 them to develop a close relationship between current materials and previously learned  
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1 principles and methods.

2  
3 •*Analysis*: This was explained to learners as the ability to understand both the  
4 content and structural forms of the material given to them.

5  
6 •*Synthesis*: This was presented as the cognitive level at which students can pull  
7 together different ideas and creative thinking as an output generated from original  
8 materials.

9  
10  
11 •*Evaluation*: This last element was explained to learners as the ability to appraise the  
12 value of some material. In addition to making sense of the concept, data and theory,  
13 learners can build conscious value judgments derived from their existing schemata to  
14 solve the problem with which they are confronted.

15  
16  
17 Finally, the reading materials that were adopted from CET 4 consisted of four short  
18 articles (250-280 words) with 5 single choice items per article, and 40 minutes in total  
19 was allotted for students to take the pretest. To estimate whether the two groups were  
20 homogeneous in terms of their cognitive level and language proficiency, the Wilcoxon  
21 matched-pairs test of analysis and an independent t-test were utilized.

### 22 23 24 **3.2.2 Physiological Computing and SR**

25 In the second stage of the experiment, the instructor explained the harmlessness of the  
26 eye-trackers and EEG to the experimental group during their first meeting. Both the  
27 experimental and the control groups were given one hour of self-regulated online  
28 reading activities every week. Language labs were open to students from Monday to  
29 Friday, and the control group students could freely choose their study time at their  
30 convenience and perform their reading activities online. However, only three sets of  
31 biofeedback devices were utilized in the current research; the experimental group  
32 students were thus required to attend a pre-scheduled appointment in specialized labs  
33 (figure 2) under the guidance of a lab assistant.

34  
35  
36 The stimulated recall for learners lasted around 10 minutes after their 1-hour  
37 reading tasks. To improve the validity of the SR experiment, time delay between the  
38 reading task and the recall was minimized (Lyle, 2003; Schepens, Stapley, & Drew,  
39 2008). The biofeedback data were presented to learners immediately after they  
40 finished with their reading tasks. The physiological data collected by eye trackers and  
41 portable EEG devices were utilized as feedback stimulating learners to recall their  
42 learning behaviors.

43  
44  
45 The optical data captured by the eye tracker involved fixation allocation, fixation  
46 duration and scanning path data, which are presented in the forms of both descriptive  
47 data and a heat map. These key clues could help learners recognize their reading  
48 behavior as follows.

49  
50 •*Fixation allocation* is the point on which eyes focus. According to Rayner's (Rayner,  
51 2009) suggestion based on prior research, the current fixation parameter should be set  
52 at 200 millisecond (ms). The fixation presented was offered for learners to examine  
53 their interested areas, which may help learner to engage in retrospection if they seized  
54 the key components during reading activities. Furthermore, the visualization of the  
55 fixation allocation reminds learners about the neglected reading areas, encouraging  
56  
57

1 speculation on the text-related mental space. For example, although some logic  
2 connectors were emphasized in the R&W class to comprehend the structural style,  
3 learners may still neglect their important roles in their reading task, and the worse is  
4 they barely realize it. Fixation location may intuitively help them recall the key  
5 components for the analysis of the logic relationship amongst parts.

6  
7 •*Fixation duration* is the total time spent on fixation. For the heat map, ranging  
8 gradually from red to blue, passing through yellow and green represents the fixation  
9 duration (from long to short time) on a specific location. Biofeedback helps learners  
10 to review rationally what proportion of time they assigned to a specific point on the  
11 text. Students are encouraged to make a comparison between their previous reading  
12 behavior and current thinking. Furthermore, the fixation duration may offer  
13 opportunities for students to remember teachers' instructions and switch on starting to  
14 follow them in subsequent reading. Although opportunities to encourage exist,  
15 comments from peers and instructors may challenge them in their behavior. For  
16 example, although readers should pay more attention to predictive verbs than  
17 non-finite verbs in general, within an EFL context, the concentration on non-finite  
18 verbs may stimulate learners to ratiocinate on authors' ideas beyond words, which is  
19 of great significance to enhance learners' creative thinking.

20  
21 •*Scanning path*, which is a valid approach to identify the patterns of fixation (Just &  
22 Carpenter, 1980), show students' logical sequence during the reading activities.  
23 Learners' cognitive levels were inspired through the recalling of their previous mental  
24 logic and the processing of psychological conflicts. For example, in an EFL context, it  
25 is difficult for Chinese native speakers to deal with the transformation of  
26 intertextuality. Since English is a language characterized by hypotaxis, the  
27 achievement of textual coherence is dependent upon several contextual themes, and  
28 meaning can be identified through a logic of coordination and subordination of the  
29 words into sentences; in contrast, Chinese is a paratactic language, and therefore the  
30 meaning is built on a logic constructed by sequential and non-subordinated ordering  
31 of words. Thus, the scanning path can clearly show learners' processing, be it  
32 hypotactic or paratactic, and may stimulate learners to understand the structural style  
33 and pragmatic characteristics of the language they read.

34  
35 In addition, the portable EEG detector named Neurosky could collect four original  
36 wavebands on a real time basis: Alpha ( $\alpha$ ), Beta ( $\beta$ ), Theta ( $\theta$ ) and Delta ( $\delta$ ). The  
37 supporting software Minxp was used to analyze the original brain wave data and  
38 generate the mind-wave report containing both real-time information and the  
39 cumulative state of the users throughout the process. Specifically, the four-page  
40 reports contained three sections: the first section in the first page present the  
41 demographic information of the participants inputted before the experiment; the  
42 second section in the second and third pages consists of line/pie/bar charts recording  
43 the detailed information about learners' instant EEG parameters, and learners'  
44 attention and relaxation via procedural evaluation of visual signals was reported on  
45 the basis of the centesimal system; the last section in the forth generated verbal report  
46 in a conclusive assessment, evaluating learners' conclusive learning status during the  
47 online autonomous learning period with suggestions in terms of attention and  
48 relaxation. Learners are therefore guided towards a comprehensive understanding of

1 their attention and fixation features, and through questions, they are prompted to  
2 recall, for example, why they felt relaxed or concentrated on a particular section of the  
3 text.

4 To investigate learners' reactions to different EEG recorded events, we used eye  
5 trackers to collect users' optical data during their SR stage and when reading their  
6 EEG reports. Their optical data corresponded to their EEG reports during the reading  
7 phase. Due to the experimental settings and application of portable devices, all  
8 students reported that they did not feel distracted by the eye tracker or EEG devices  
9 after the SR.  
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### 12 **3.2.3 Post-test**

13 Both the experimental and the control groups were required to complete a reading  
14 comprehension test and Blooms' cognitive hierarchy questionnaire in the 12<sup>th</sup> week of  
15 the class. To increase the validity of the pre-post tests between the two groups, a  
16 reading comprehension quiz was implemented similarly to the pretest in terms of the  
17 format (four passages with 5 items each), test time (40 minutes) and exam level (CET  
18 band 4); additionally, participants were required to fill the same cognitive taxonomy  
19 questionnaire.  
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### 23 **3.3 Data Collection and Analysis**

24 Both qualitative and quantitative research methods were employed in the current  
25 research. To compare participants' cognitive taxonomy, a Wilcoxon matched-pairs test  
26 analysis was used to examine the rating-scale questionnaire data. Then frequency  
27 analysis was applied to distinguish groups with relative lower cognition from the  
28 higher group in the experimental class. Regarding learning performance, paired  
29 sample *t*-test were conducted to measure the score changes between the pre-post tests  
30 scores. To find the statistical differences of the reading scores of the experimental  
31 group and control group, some independent *t*-tests were employed in both the pretest  
32 and post-test measurement phases.  
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37 Furthermore, to investigate the effect of the two human factors in terms of gender  
38 and cognitive levels on learning performance, independent *t*-tests were performed to  
39 compare statistical differences in scoring. To explore the effect of learners' gender  
40 differences on EEG reports, data on the fixation duration and fixation allocation  
41 collected by the eye tracker was compared with *t*-test results as well. Finally, to  
42 explain and analyze the statistical results, 12 participants (experimental group and  
43 control group each half with equal ratio of gender) were randomly selected to have a  
44 face-to-face interview with the instructors.  
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## 50 **4. Results**

### 51 **4.1 Effects of Biofeedback**

52 To answer the first research question, this research uses the Wilcoxon test and *t*-test to  
53 compare the pre-post scores, which indicate the effects of biofeedback on learners'  
54 cognitive taxonomy and reading abilities. As shown in [Table 2a](#), no significant  
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1 difference existed between the experimental group and control group in terms of  
2 cognitive taxonomy ( $z = -0.17, p = 0.87$ ) and reading abilities ( $t = -0.36, p = 0.72$ ) in  
3 the pretest, which verified the homogeneity of the two groups. However, the results  
4 from the pre-post tests showed that the experimental group had significant  
5 improvements in cognitive taxonomy ( $z = -4.35, p < 0.001$ ) and reading scores ( $t$   
6  $= -2.47, p = 0.017$ ), whereas no significant distinction existed in the control group for  
7 cognitive taxonomy ( $z = -0.44, p = 0.66$ ) and reading ( $t = 1.38, p = 0.17$ ). However,  
8 all six of the interviewees in the experimental group reported a special interest in the  
9 biofeedback technique. Synthesizing those data leads to the result that students  
10 adopting biofeedback as a stimulus demonstrated significant improvement in the  
11 dimensions of the cognitive level and reading comprehension, compared to those who  
12 studied in the traditional self-regulated online settings without SR.  
13

#### 14 15 **4.2 Cognitive Hierarchy and SR**

16 With regards to the results of the cognitive hierarchy in the experimental group and  
17 the effects of SR, Table 1 shows that in the experimental group, 52 (96.3%) students  
18 asserted their taxonomy in *knowledge*, followed by *comprehension* (28 students,  
19 51.85%), *application* (7 students, 12.96%), *analysis* (7 students, 12.96%), *synthesis* (4  
20 students, 7.41%), and *evaluation* (none). The proportions indicate that the  
21 tendency was towards lower-level cognitive taxonomies on the whole. According to  
22 Table 1, 25 participants who selected *knowledge* scored 0.17, 17 participants scored  
23 0.5, 1 participant scored 0.67, 1 participant scored 0.83, 4 participants scored 4, 2  
24 participants scored 1.17, 2 participants scored 2, and 2 participants scored 2.5. For the  
25 frequency analysis based on multiple responses, nearly half of the participating  
26 students (46.3%) recognized only *knowledge* as their cognitive status, and students  
27 with such status were defined as the "single level-one" group, whereas the rest of  
28 students with at least two taxonomies were labelled as the "multi-levels" group.  
29

30 To understand the role of cognitive hierarchy and learning performance in the  
31 context of biofeedback, a series of Wilcoxon nonparametric tests and independent  
32 samples *t*-tests were conducted. As shown in Tables 2b and 2c, surprisingly, the  
33 single-level students in the experimental group had satisfactory significant  
34 enhancement of taxonomy ( $z = -4.36^{***}, p < 0.001$ ) and reading capacity ( $t =$   
35  $-5.29^{***}, p < 0.001$ ) according to the pre-post scores, whereas the reading scorings  
36 from single-level students in the control group significantly decreased ( $t = 2.51^*, p =$   
37  $0.02$ ). However, beyond what we expected, the students in high-cog group of both  
38 groups had no significant improvement in cognitive taxonomy ( $z = -1.42, p = 0.16; z$   
39  $= -0.24, p = 0.81$ ) or reading capacity ( $t = -0.96, p = 0.34; t = -0.22, p = 0.81$ ).  
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#### 45 46 **4.3 Gender and SR**

47 To answer how the gender differences relate to the effect of biofeedback on students'  
48 self-regulated learning performance, a family of Wilcoxon matched-pair tests and  
49 paired sample *t*-tests were implemented to explore the differences in the pre-post  
50 scores of male/female groups. Table 2d shows that the ratio of gender in the  
51 experimental class is coincidentally 50:50 (27 males, 27 females), and in the pretest,  
52 there was no significant distinction between males and females in terms of taxonomy  
53 ( $z = -0.43, p = 0.66$ ) and reading abilities ( $t = 0.59, p = 0.56$ ). Unexpectedly, although  
54 many previous studies verified that gender difference was a significant variable  
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1 predicting learners' reading behavior, the results of the current study show no  
2 significant relationship between gender and SR.

3  
4 However, according to the comparison analysis of the optical data on EEG reports,  
5 we surprisingly found that there is a significant gender difference regarding learners'  
6 average fixation duration and average fixation count. As shown in Table 3, the males'  
7 average fixation duration on page 2 of the reports is longer than the females' ( $t = 2.4$ ,  
8  $p = 0.02$ ). In addition, males had higher fixation counts than females ( $t = 3.84$ ,  $p <$   
9  $0.001$ ). Similarly, these significant distinctions were also found on page 3 of the  
10 reports ( $t = 3.1$ ,  $p = 0.03$ ;  $t = 4.1$ ,  $p < 0.001$  respectively). In contrast, the eye  
11 movements on page 4 were totally reversed such that females had longer fixation  
12 durations ( $t = -2.91$ ,  $p = 0.005$ ) and higher fixation counts ( $t = -4.72$ ,  $p < 0.001$ ) than  
13 males. The average fixation duration and average fixation count in paper one indicate  
14 that insignificant gender difference was found in terms of attention of demographic  
15 information ( $t = -0.59$ ,  $p = 0.56$ ;  $t = -1.91$ ,  $p = 0.06$  respectively). The surprising  
16 findings prompted the researchers in this study to carefully analyze all report pages  
17 for gender differences, ~~and two screenshots in Figure 3 exported from the eye tracker~~  
18 ~~system display the heat map for two interviewees (one male and one female).~~  
19 ~~According to the heat map, The, forth pages 1 and 4,~~ with a conclusive evaluation of  
20 readers' EEG, attracted much more attention from females, whereas pages 2 and 3,  
21 presenting various charts filled with detailed and procedural information, highlighted  
22 males' preferential style.  
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## 30 5. Discussion

31  
32 The pre-post scores, in terms of cognitive taxonomies and reading abilities, were  
33 compared, and the results showed that there was no significant improvement in the  
34 post-test outcome for the control group. It is suggested that the current efforts on  
35 traditional online autonomous learning are not working. One possible explanation is  
36 that metacognition and critical thinking have a significant positive relationship with  
37 SRL achievement (Broadbent & Poon, 2015); however, the traditional SRL model  
38 sometimes is so flexible that learners may tend to select materials in which they are  
39 interested while ignoring their weaknesses and shop boards through reliable feedback.  
40 Additionally, from the perspective of the subject, foreign learning environments fail to  
41 provide learners with sufficient input, output, or interaction opportunities, and a high  
42 level of language achievement is difficult to obtain without the effective regulation of  
43 learning behavior and the context of learning outside the classroom (Kormos &  
44 Csizer, 2014).  
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49 However, learners' using physiology signals to recall their experience in  
50 retrospection did facilitate their reading performance and cognitive hierarchy. The  
51 findings were consistent with some psychologists' suggestion that biofeedback can be  
52 used as an effective method to treat some psychology issues, such as attention deficit  
53 disorder (Linden et al., 1996). One possible reason is the following aspects:

54 First, eye movement data leave students much mental space for re-examine their  
55 areas of interest and neglected areas, which may transform their rigid thinking mode  
56 into an open and speculative style. Furthermore, the visual scanning path may  
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1 stimulate them to compare and contrast their prior learning behavior and current  
2 retrospection, which helps to enhance their cognitive level and learning performance.  
3 Second, students may come across many emotional issues, such as a sense of anxiety  
4 and helplessness, in the process of their autonomous learning activities. Biofeedback  
5 may act as a metacognitive method to help learners realize their personalized learning  
6 habits and cognitive modes and to provide retrospection on their personal learning  
7 strengths and weaknesses. This benefits their cognitive structure and learning habits  
8 when studying in a self-directed mode. Third, as mentioned in section 4.1, the  
9 students in the experimental group presented their special interests in their  
10 biofeedback information as evidence of learning references. That may be attributed to  
11 the fact that learners showed robust belief in their physiology signals, since the signals  
12 were very personalized and unique to their own learning status. They were thus  
13 willing to adjust their autonomous learning to their personal traits.

14 Furthermore, the pre-post results showed that the multi-level students had higher  
15 reading comprehension mean scores than that of the single level students' scores in  
16 both groups, which supports [that high-order cognitive skills are usually associated  
17 with better performance \(Goradia & Bugarcic, 2017\)](#) However, the results showed  
18 that the students in the "single level-one" group showed significant enhancement,  
19 whereas the "multiple-levels" group students showed no significant improvement.  
20 One possible explanation is that biofeedback, such as attention, relaxation, and  
21 fixation, are superficial and basic information. These have a close relationship with  
22 learning habits but rarely a relationship with deep cognitive behavior. Therefore,  
23 physiological information may be helpful for ameliorating some superficial and  
24 inappropriate learning behavior, whereas it is difficult to help "multiple-levels"  
25 learners improve to a higher taxonomy. In addition, compared with the multi-level  
26 students with top-tier language proficiency, single-level students who performed  
27 comparatively poor had a larger possibility of making significant improvements.

28 According to the pre-post test results in [Table 2d](#), there is no significant distinction  
29 for reading and cognitive scores between males and females through biofeedback,  
30 which indicated that stimulated recall with physiological signals is a suitable learning  
31 instrument for both males and females in terms of learning outcomes and cognitive  
32 level. However, regarding the examination of eye movement data on EEG reports,  
33 researchers surprisingly found that females were more in favor of conclusive  
34 evaluation, while males tend to prefer procedure assessments. Pae's (2004) research  
35 about the effects of gender on EFL reading comprehension supported the finding that  
36 males were more likely to favor logical inference than females. Another study by  
37 Terzis and Economides (2011) demonstrated that females were more likely to  
38 emphasize the ease of use, whereas males focused on usefulness in the context of  
39 computing-based assessment. Therefore, it is suggested that males tend to care more  
40 about useful information through various data charts, whereas a conclusive  
41 assessment would be accepted by females to guide their learning strategy directly.

## 52 **6. Conclusion and limitation**

53 This research provides, through empirical evidence, a variety of insights into the  
54 domain of autonomous learning. With the explosive development of Artificial  
55

1 Intelligence, constructivism needs to be highly considered in the context of  
2 information technology. Previous studies have addressed the significance of  
3 human-computer interaction to constructivism (Al-Huneidi & Schreurs 2011;  
4 Reidsma, Nijholt, Tschacher, & Ramseyer 2010), and this study empirically tested  
5 whether biofeedback could be used as a variable in the interaction between human  
6 and computers, through which constructivists may be provided a special perspective  
7 when considering the construction of a student-centered learning context.

8  
9 From the perspective of learners, with the rapid expansion of the online learning  
10 model, it is important to understand how to enhance effective learning performance in  
11 an autonomous learning setting. Considering that computers can read learners'  
12 mental mechanisms via biofeedback, machines are more desirable for learners who  
13 want to learn independently without a human teacher but who do not want to miss on  
14 the useful learning feedback traditionally communicated by teachers.

15  
16 We suggest that SR through biofeedback be utilized to help learners not only  
17 engage in retrospection about their learning behavior to improve their learning  
18 performance by refining their study skills but also embark in the often daunting  
19 journey of independent learning. Furthermore, as far as instructors are concerned,  
20 learners' biofeedback is valuable data for adjusting their pedagogic design and  
21 improving teaching arrangements according to learners' emotional status. This could  
22 have great applications to enhancing the learning of students with mild learning and  
23 cognitive impairments. Thus, we see it possible for some firms operating in the  
24 education sector to develop tools based on Affective Computing and Physiology to be  
25 used within the traditional education system. Moreover, this study has implications for  
26 software developers, providing them with some ideas for the application of  
27 technology to integrate biofeedback-based pedagogy and information technology.  
28 These findings may enable, through purposefully built software, easily transferrable  
29 learner profiles based on the identification of learners' personal traits, such as  
30 cognitive levels, gender, and the need to pay attention, which can be used to offer an  
31 individually tailored education experience.

32  
33 This study also bears some limitations. For instance, this study limited the  
34 biofeedback administration via eye trackers and EEG to participants recruited  
35 amongst university freshmen, making the study not generalizable to the overall  
36 student population but rather specific to that student cohort. Furthermore, the material  
37 used for the experiment was selected from EFL learning materials, and biofeedback  
38 and SR may differ with the exposure of learners to different subject areas, some of  
39 which are more suitable for artistic minds and some of which are more suitable for  
40 more scientific minds. Furthermore, the variety of physiological information of  
41 learners was limited because of the limited functionality of the technology used.

42  
43 Finally, future research could try to replicate this study by differentiating some  
44 elements of our quasi-experimental design, for instance by increasing the sample size  
45 and by looking at different education stages and subjects, which may provide other  
46 insights into the effect of SR by biofeedback and a wider capture of physiological  
47 data.

## 48 49 50 51 52 53 54 55 56 57 58 59 60

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## Practitioner Notes

### What is already known about this topic:

- The stimulated recall (SR) technique, considered being a valuable tool for learners to capitalize on introspection, have positive effect on learning outcomes and cognitive processes in physical context.
- The recorded audio and video are generally used as the stimulus in physical learning context.
- The stimulus source may differ from a research context to another.
- Learning performance has close relationship with different human factors, such as cognitive taxonomy and gender differences.

### What this paper adds:

- Students adopting the biofeedback as stimulus demonstrated significant improvement in the dimensions of cognitive level and reading comprehension.
- Biofeedback, such as EEG and eye-movement, may be applicable stimulus for stimulated recall in online self-directed learning context.
- The lower-cognitive students have more significant enhancement of taxonomy and reading capacity, when conducting biofeedback-based stimulated recall.
- Eye-track reports showed that males favor procedural feedback and females have a preference for the conclusive assessment.

### Implications for practice and/or policy:

- Biofeedback may act as a meta-cognitive method to help learners realize their personalized learning habits and cognitive modes, and encourage them to embark in the often daunting journey of autonomous learning.
- Biofeedback data could be used as valuable measurements for instructors to adjust their pedagogic design and improve teaching arrangements according to learners' emotional status and human factors.
- Procedural feedback is adaptive and should be considered utilizing for male students in self-access learning context; while conclusive assessment approach is more applicable for female learners.

## Tables

**Table 1.** The Cognitive Taxonomy Data in The Experimental Group

students	<i>Pre-test</i>						Student Score	<i>Post-test</i>						Student Score
	<i>Bloom's Level</i>							<i>Bloom's Level</i>						
	1	2	3	4	5	6		1	2	3	4	5	6	
1	1	2					0.50	1	2					0.50
2	1						0.17	1	2					0.50
3	1	2	3				1.00	1	2	3		5		1.83
4	1	2					0.50	1						0.17
5	1						0.17	1	2	3	4			1.67
6	1	2		4			1.17	1	2	3	4			1.67
7	1	2					0.50	1	2					0.50
8	1						0.17	1	2					0.50
9	1						0.17	1	2	3				1.00
10	1	2	3				1.00	1	2	3	4			1.67
11	1	2					0.50	1						0.17
12	1						0.17	1	2					0.50
13	1						0.17	1	2	3				1.00
14	1						0.17	1	2					0.50
15	1	2	3				1.00	1	2	3				1.00
16	1	2		4	5		2.00	1	2	3	4	5		2.50
17	1						0.17	1	2		4	5	6	3.00
18	1	2	3	4	5		2.50	1	2	3	4			1.67
19	1						0.17	1	2	3				1.00
20	1						0.17	1	2					0.50
21	1	2					0.50	1	2					0.50
22		2	3				0.83	1	2	3				1.00
23	1	2					0.50		2	3		5		1.67
24	1	2					0.50	1	2	3				1.00
25	1	2		4	5		2.00	1	2	3				1.00
26	1	2					0.50	1		3				0.67
27	1		3				0.67	1		3				0.67
28	1	2					0.50	1	2					0.50
29	1						0.17	1	2		4			1.17
30	1						0.17	1	2					0.50
31	1						0.17	1	2	3	4			1.67
32	1						0.17	1	2					0.50
33	1	2					0.50	1	2					0.50
34	1	2					0.50	1	2					0.50
35		2		4			1.00	1	2	3	4			1.67
36	1	2					0.50	1	2					0.50
37	1						0.17	1	2	3				1.00
38	1						0.17	1						0.17
39	1	2					0.50	1						0.17
40	1						0.17	1	2					0.50
41	1						0.17	1	2	3				1.00
42	1						0.17	1	2					0.50
43	1						0.17	1	2					0.50
44	1	2					0.50	1	2	3				1.00
45	1	2					0.50	1	2					0.50
46	1						0.17	1	2		4	5		2.00
47	1						0.17	1	2	3				1.00
48	1	2	3	4	5		2.50	1			4	5	6	2.67
49	1						0.17	1	2	3				1.00
50	1	2					0.50	1	2					0.50
51	1	2					0.50	1	2					0.50
52	1						0.17	1	2					0.50
53	1						0.17	1	2					0.50
54	1	2					0.50	1	2	3				1.00
total	52	28	7	7	4	0		53	47	25	11	6	2	

**Table 2.** The Comparisons of Learners' Taxonomies and Reading Capacity

stages	Sample types	Wilcoxon Test of Taxonomy			t-test of Reading Capacity			
		n	z-value	p	Mean	SD	t-value	p
<i>a: The comparison of pre-post tests between experimental group and control group</i>								
pretests	Experimental group	54	-0.17	0.87	24.15	4.63	-0.36	0.72
	Control group	52			24.46	4.31		
pretests	Experimental group	54	-4.35***	<0.001	24.44	4.23	-2.47*	0.017
post-tests		25.93	3.98					
pretests	Control group	52	-0.44	0.66	24.46	4.31	1.38	0.17
post-tests		23.81	4.56					
<i>b: The comparison of pre-post tests between the "single level" and the "multiple levels" in experimental group</i>								
pretests	single level students	25	-4.36***	<0.001	21.28	3.55	-5.29***	<0.001
post-tests		24.56	3.68					
pretests	multiple levels students	29	-1.42	0.16	26.62	4.00	-0.96	0.34
post-test		27.10	3.91					
<i>c: The comparison of pre-post tests between the "single level" and the "multiple levels" in control group</i>								
pretests	single level students	22	-1.34	0.18	21.91	3.29	2.51*	0.02
post-tests		20.18	2.54					
pretests	multiple levels students	30	-0.24	0.81	26.33	4.04	-0.22	0.81
post-test		26.47	3.81					
<i>d: The comparison of pre-post tests between male and female in experimental group</i>								
pretests	male	27	-0.43	0.66	24.52	3.87	0.59	0.56
	female	27			23.78	5.33		
post-test	male	27	-0.05	0.96	26.59	2.93	1.24	0.22
	female	27			25.26	4.78		

**Table 3.** The Comparison Analysis of Eye-movements Between Genders

Materials	Gender	<i>n</i>	Average Fixation Duration				Average Fixation Count			
			Mean	SD	<i>t</i> -value	<i>p</i>	Mean	SD	<i>t</i> -value	<i>p</i>
Page 1	Male	27	498.26	50.38	-0.59	0.56	39.59	8.68	-1.91	0.06
	Female	27	510	90.92			43.89	7.82		
Page 2	Male	27	474.19	44.72	2.4*	0.02	43.26	5.82	3.84***	<0.001
	Female	27	441.26	55.60			37.81	4.48		
Page 3	Male	27	458.63	38.85	3.1*	0.03	49.22	7.59	4.1***	<0.001
	Female	27	420.37	51.05			41.44	6.3		
Page 4	Male	27	358.63	53.41	-2.91**	0.005	37.04	6.87	-4.72***	<0.001
	Female	27	407.11	68.26			45.44	6.22		

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**Appendix 1** The Blooms' cognitive hierarchy instrument on the reading comprehension

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1. When conducting English reading, I focus on recalling learned concepts, such as vocabulary , collocations, and grammatical knowledge. (Knowledge)

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  2. My understanding of the text based on comparison and contrast of other materials, current events, etc. to extrapolate the meaning. (Comprehension)

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  3. I connect the ideas from the current text to other readings, class discussions, such as a related linguistic approach or logical features, and even my work or other experiences. (Application)

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  4. I identified the author's theories, assumptions, fallacies, and reconstruct the components and structure of the texts (Analysis)

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  5. I explore the reading material and use this exploration to build a new understanding and challenging of the material, or to formulate new ideas or solutions? (Synthesis)

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  6. I make use of course concepts,data, and theories rather than personal opinion as a criterion for evaluation of my study and work ? (Evaluation)
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figures

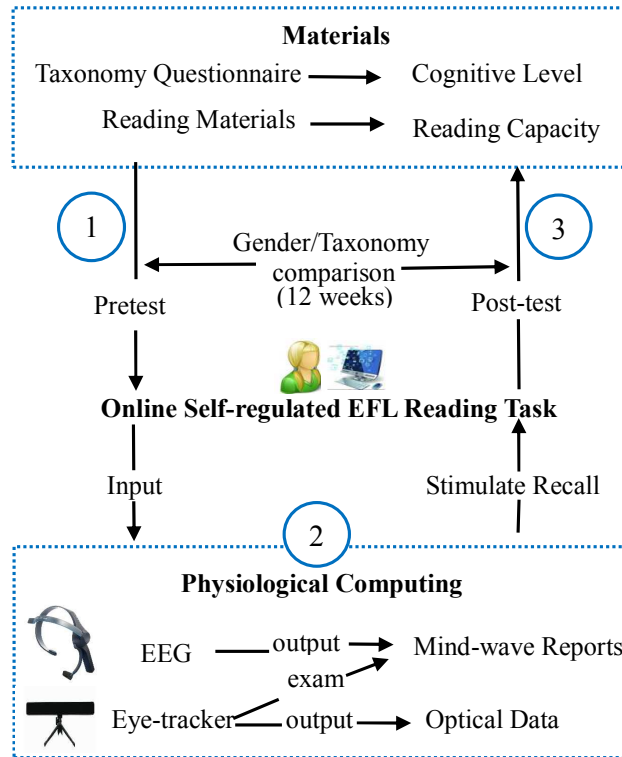


Figure 1. The procedure of biofeedback in pre-post tests

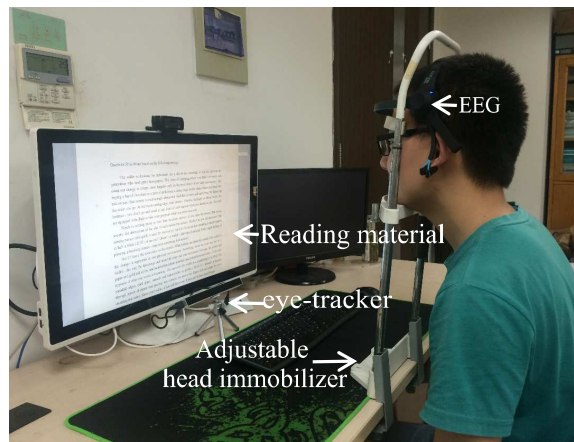


Figure 2. The sample test and physiological devices