ANALYSIS OF READING EXPERIENCE WITH HEART RATE VARIABILITY AND GALVANIC SKIN RESPONSE SENSOR

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Abstract. *This research attempts to find a continuous, objective, and convenient wearable device-based method to detect the changes of psychological state in the process of reading. In the experiment, we arranged participants to read a variety of books, and recorded their heart rate and skin resistance data during their reading. Each experiment lasted for 5 minutes. Each time after the experiment, participants would be asked to use keywords to evaluate what they just read. By analyzing the relationship between physiological information and keyword, we found that we could classify psychological states during the reading into four states: concentration, climax, relaxation and distraction by observing changes in Heart Rate Variability (HRV) and Galvanic Skin Response (GSR). This study can serve as reference for research on reading-assistance systems or daily-activity recording systems.*
Keywords: Reading experience, FLOW, Learning-support system, HRV, GSR

1. **Introduction.** In the recent years, the reading amount of young people has been found gradually declining both in China and Japan. In China, according to National Reading Survey in 2015, the spread of mobile devices has offered access to reading on the mobile phone, while the time spent on paper publications decreased. Meanwhile, the average reading amount of teenagers fell as well [1]. In Japan, the one who reads less than one book per month is called *Fudokusha* (person who does not read). The proportion of Fudokusha in university has already increased from 13.4% in 1990 to 40.1% in 2012 with an annual increase of 1 percent. Currently *away from reading books* has become a trend [2]. In the researches on the actual reading situation of college students conducted in 2006 and 2012, Hirayama also arrived at a similar conclusion. With the rapid increase in the daily use of mobile phone and computer, teenagers have been spending less time on watching TV and reading paper publications.

Besides, for reading motivation, the purpose of self-cultivation, such as improving one's inner quality like intellect, reason, and will power, now has been proved of less importance to readers while the acquisition of a second language has been regarded as the most important benefit from reading. In a word, reading motivation now lays emphasis on usefulness and effectiveness. Aki's research on Japanese college students showed that the reading habit cultivated in high school will disappear in the college. Though reading motivation varies in the period of high school, it would eventually be turned into obtaining

of the specific and practical knowledge [3]. Moreover, researches on reading motivation suggested that it could be divided into two aspects: accomplishment-oriented (aiming at the acquisition of knowledge and skills) and consumption-oriented (aiming at the process of reading) [4].

According to the FLOW theory, how relevant skills and activities match each other will directly influence the engagement level of readers in reading. High skills usually lead to the feeling of boredom while low skills cause anxiety [5]. Therefore, making sure that reader's skill matches the book is very important in reading which mainly focuses on the acquisition of knowledge.

As for the phenomenon of *away from reading books*, Yukari and Katsuhide argued that apart from the accomplishment-oriented aspect which is regarded as the basis of reading activity, consumption-oriented aspect which makes reading one type of entertainment also deserved much attention [4]. Therefore, learning about the emotional experience in reading is essential to the restoration of reading habits.

Researchers usually analyze the participants' reading experience by questionnaires. However, the immediacy of this method is found low, and unable to reflect the changes of experience in the process of reading. In this research, we tried to find a technique using physiological sensors embedded in wearable devices which can measure the reading experience continuously and objectively. With the miniaturization of physiological sensors and spread of wearable devices, we can easily obtain the physiological data such as heart rate. We believe that it will help improve the reading experience in the future and develop a more personalized book recommendation system.

2. **Research Methods.**

2.1. **Experiment.** In the experiment, we asked five participants to read a specified book for just five minutes (since long-time reading might cause mental fatigue) and use several keywords to describe their feelings about the book.

After their assessment on the book, we gave them a two-minute break to restore their physiological indices back to their baseline levels, and then ask them to continue to read the next book. The process above was repeated ten times.

2.2. **Measures.** We used LED pulse sensor and Grove-GSR sensor to record the changes of participants' heart rate and Galvanic Skin Response in reading (Figure 1).
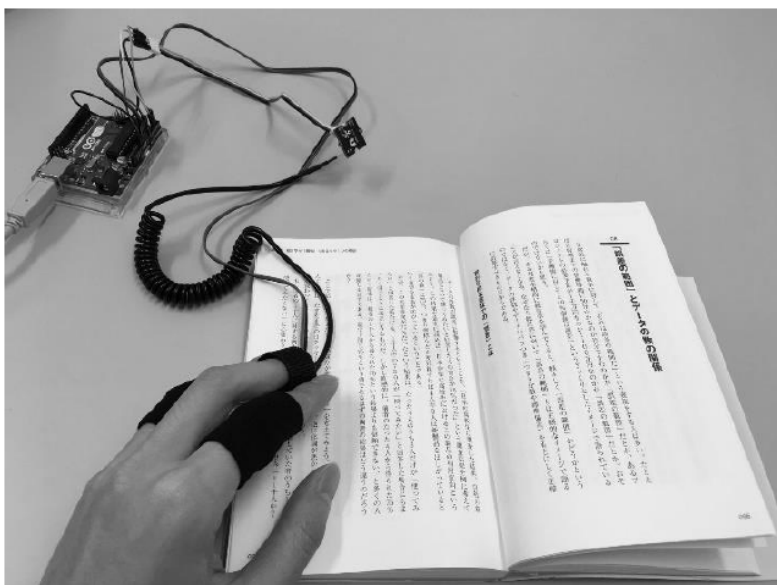

FIGURE 1. Pulse sensor and Grove-GSR sensor installation method

Heart rate: We plan to use pulse sensor to measure their heart rate. Since fingertips detection can be easily interfered with book flipping, we will fix pulse sensor to the earlobes of the participants for examination. In the analysis, we use one of indexes of heart rate variability, Low Frequency/High Frequency (LF/HF), which is considered to be able to reveal the predominance of sympathetic or parasympathetic nervous systems over each other according to the different circumstances [6,7]. If the value of LF/HF is high, it indicates that sympathetic nervous systems predominate over the other one. On the contrary, if the value is low, it means that parasympathetic nervous systems predominate.

Skin conductance: We will use Grove-GSR sensor. It modulates the amount of sweat secretion from sweat glands. Skin conductance is not under conscious control. Instead, it is modulated autonomously by sympathetic activity which drives human behavior, cognitive and emotional states [8,9]. Therefore, skin conductance offers direct insights into autonomous emotional regulation. Murai found that when people are highly concentrated, GSR reaction would decrease or even disappear. However, an increase could also be seen in GSR attributed to novelty. This research suggested that GSR could be used to evaluate the effects of classroom teaching [10].

For skin response sensor is not sensitive to book flipping, we will fix the sensors on their index fingers and middle fingers during the experiment.

Keyword recording: Each time after the experiment, participants were asked to use several keywords to describe their feelings about the book. To make it clear, we summarized the keywords with similar meanings into one word as below (Table 1).

TABLE 1. Keywords

New Keywords	Original Keywords
concentration	concentration concentrated
reading slowly and carefully	read slowly and carefully, worth reading, read it twice, read it again
interesting	interesting, very interesting, fresh
highly-concentrated	highly-concentrated, highly focused, time has passed so fast
agree	agree, quite agree, helpful, useful, approval
climax	climax, excited
mystery	worry, want to read more, want to find out what happened, want to read the next chapter of book, concerned about the development of the story
horror	horrible, nervous, fear
skimming	easy to read, skim, fast reading
funny	laugh, amusing, funny
easy to understand	easy to understand, comprehensible
hard to read	hard to read, unreadable, suffer from reading
hard to understand	hard to understand, have trouble understanding it
boring	uninteresting, boring, dull, lack of interest

2.3. **Participants.** Five college students from the same country with different language levels were chosen for the experiment. They all had a basic language skill and knowledge for understanding the alternative article.

2.4. **Reading material.** We used textbooks, common books, regular short stories, short detective stories, comics, common books in second foreign language (English) as the reading materials. To check the influence from ups and downs of the story plot, we also informed participants that they would continue to read the material in the next five minutes if they were unable to finish reading in this five minutes.

2.5. **Experiment environment.** The experiment was conducted in a room at 26°C with an area of 4 meters wide × 6 meters long. Participants were required to sit in front of a desk and read specified book with an electronic book reader. A small video camera was set in front of them to record their facial expressions and postures. The participants were also allowed to use a dictionary when they were reading English materials.

3. **Data Preprocessing.** As for heart rate signals, we analyzed the duration between two adjacent R-wave peaks of normal QRS complex which is known as RR intervals with the approach of frequency analysis (Window Size: 100 Second), and figured out the value of LF/HF of the participants (LF: 0.04-0.15Hz, HF: 0.15-0.4Hz).

GSR signal is divided into two components: the tonic component which is usually measured by Skin Conductance Level (SCL) or Skin Resistance Level (SRL) and the phasic component which is usually measured by Skin Conductance Response (SCR) or Skin Resistance Response (SRR). In this research, we focus on the SRR which is sensitive to the emotional arousal by specific stimuli.

For the original signals output by the Grove-GSR sensor used in this experiment actually indicate resistance instead of conductivity, SRR peak brought by emotional arousal could be seen as a fast decline from one to three seconds in original signals. In this research, we paid attention to the amplitude of change of GSR sensor signals in each peak, or the resistance variation from onset to peak.

As is illustrated in Figure 2, the middle line represents LF/HF in heart rate variation, and the upper line represents the original Grove-GSR signals. Besides, the circles on the peak stand for onset of SRR, the circles on the bottom stand for peak, and the bottom line stands for GSR peak amplitude.
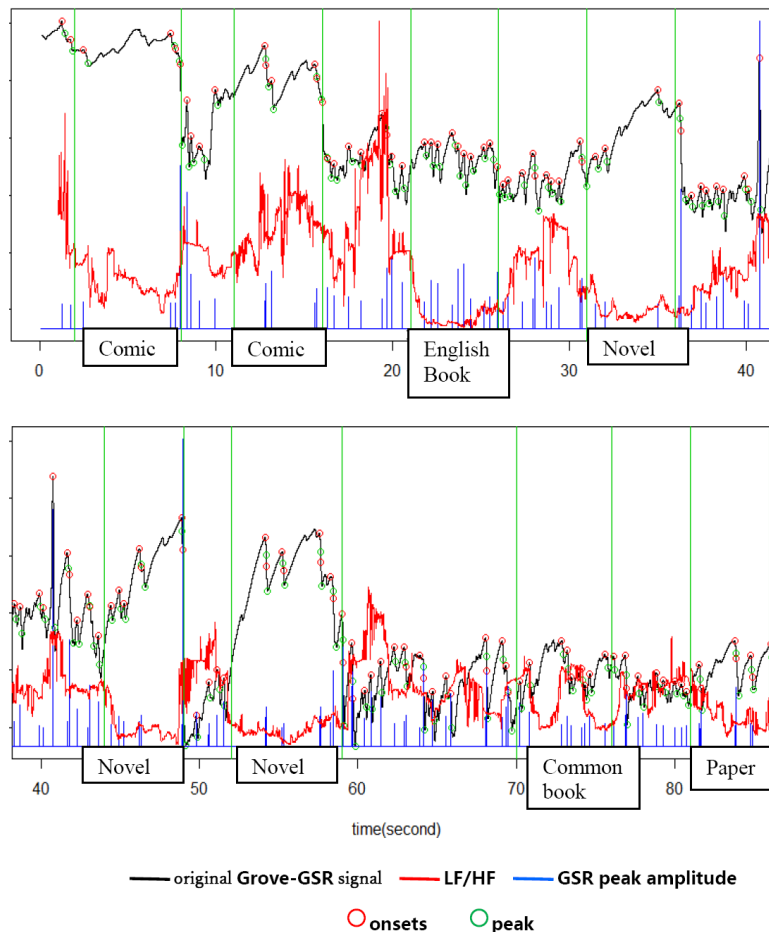

FIGURE 2. One example of experimental data

4. **Discussion.** We figured out the gradient of LF/HF and GSR peak amplitude based on the average values of LF/HF and GSR peak amplitude in reading and in the break before reading. After mapping the keywords onto the gradient of LF/HF and GSR peak amplitude, we found four patterns which are shown in Table 2.

TABLE 2. Pattern of reading

	GSR peak amplitude −	GSR peak amplitude +
LF/HF +	**Pattern 1** **Keywords:** concentration, agree, climax, mystery, horror	**Pattern 2** **Keywords:** skimming, interesting, funny, easy to understand, easy to read
LF/HF −	**Pattern 3** **Keywords:** concentration, reading slowly and carefully, interesting	**Pattern 4** **Keywords:** skimming, hard to read, hard to understand, boring

Unexpectedly, *concentration* and *reading slowly and carefully* appeared both in second and third quadrant, and skimming appeared in second and fourth quadrant.

In pattern 3, we can see that both GSR and LF/HF decline. The keywords here are the words indicating high engagement in reading, such as *concentration*, *reading slowly* and *carefully*, *interesting*. Previous researches proved that performance on cognitive tasks would lead to the decrease of amplitude of LF bands, and further reduce the ratio of LF and HF. The concentration on classroom teaching and math calculations contributes to the decline of GSR [10,11]. As a result, pattern 3 could be considered consistent with the previous studies.

In pattern 4, GSR increases while LF/HF decreases. The keywords here mainly convey negative impressions such as *skimming*, *hard to read*, *hard to understand*, and *boring*. And it is worth noting that pattern 4 almost appeared when participants with poor English skills were asked to read English materials, or to read specialized books with which they were not familiar. We suggest that LF/HF of participants also underwent a decline like pattern 3 did for cognitive load. When the participants found their skills not enough for the books, they would feel anxious and suffer from emotional stress which causes the increase of GSR.

In pattern 2, GSR and LF/HF increase together. The keywords here are the words with a relaxing image, such as *skimming*, *interesting*, *funny*, *easy to understand*, and *easy to read*. This pattern mainly appeared in the experiment using comics, novels, and other common books these participants showed great interest in. This result happens to correspond to the phenomenon that novel stimuli made GSR increase in classroom teaching [10]. However, reason for the increase of LF/HF still remains unclear. We think it may be due to the sympathetic arousal caused by novel stimuli having already surpassed the influence of cognitive load. Pattern 2 also appeared when participants were asked to read common books which seemed too easy for them. However, the mechanism of this phenomenon differs from the previous one related with novel stimuli. We suggest that it might be caused by their low level of cognitive load. In other words, the participants tended to feel boring when they found their skills far beyond what was required.

In pattern 1, LF/HF increases while GSR decreases. The keywords here include more specific information, such as *concentration*, *agree*, *climax*, *mystery* and *horror*. And this pattern only appears under the circumstance in which the participants are reading a common book they are particularly interested in or strongly agree with the author's opinion. In addition, the mysterious part, horrible part, or climax of a novel also has the same function. We believe that the high level of cognitive load has restrained GSR, yet the reason for increase of LF/HF remains unclear as well.

GSR and LF/HF are both regarded as the index related with autonomic nerve and increase with human's activities [7,12]. However, the variations of them are not always consistent with each other. As the indices indicate the balance between sympathetic nervous system and parasympathetic nervous system, they showed different aspects of autonomic nerve activity. There also exists researches which claimed that more details about autonomic nerve activity could be found through the measurement of these indices [13].

5. **Conclusion.** Through the analysis of heart rate and GSR signals in reading, we found that the emotional experience during reading could be divided into four states: *concentration*, *climax*, *relaxation* and *distraction* in this research. *Relaxation* and *distraction* are considered associated with a premise whether the skills of readers match the books or not. And *concentration*, *climax*, *relaxation* have a close connection with emotional experiences brought by books.

Due to the result, it becomes possible for us to detect the state of readers in real time and boost their reading motivation from accomplishment aspect and consumption aspect. For example, we could recommend more suitable books for readers based on the assessment of matching degree of their skills and books in reading activities with the main purpose of acquiring knowledge. Moreover, in reading activities for fun, we could offer readers diversified reading experiences through the feedbacks of their emotional states and provide useful information to authors for improving their works.

This research also indicates that though heart rate variability and galvanic skin response are both regarded as the indices of autonomic nervous system, their changes are not exactly the same. More information could be found by the measurements concerning autonomic nervous system. In this study, the factors of skills and emotional experiences are not clearly distinguished from one another. The keywords with the opposite meaning like *Agree* and *horror* exist in the same pattern. Therefore, we will try to control the types of books and apply more analytical methods for more accurate classification in the future.

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