Analyzing Situational Stress Using Multiple Wearable Devices

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SUMMARY Visually impaired people are typically at a high risk of accidents such as collisions while walking. To reduce these risks, smart canes that use sensors to detect obstacles have been developed. However, redundant notifications may interfere with their walking even if the notifications include valuable information. Generally, visually impaired people feel psychological stress when they fail to understand their physical surroundings. This stress is manifested through various biological changes in the body, such as increased heart rate. In this study, we estimated the stress experienced by visually impaired individuals by measuring their biometric information using multiple smart wearable devices. We also evaluated the effectiveness of estimating stress using various vital biological changes in the body under different situations.
key words: *Wearable device, biological information, psychological factor, stress estimation, visually impaired people*

1. Introduction

Visually impaired people are exposed to various accident risks during walking, such as collisions with obstacles and people [1]. Smart canes have been developed to reduce such risks [2]–[5], which use sensors to detect obstacles such as stairs and send a range of notifications to the user. Conventionally, visually impaired people would typically avoid obstacles independently using a standard white cane. We consider that a user with a smart cane device that provided redundant or complex notifications might tend to ignore the feedback even if the notification included some useful information. As a result, it might confuse cane users by interfering with their independent walking. Hence, sufficient essential notifications are required for actual risky situations.

To identify the risks in the daily lives of visually impaired people, the psychological stress caused by anxiety about their surroundings needs to be considered [6]. Generally, visually impaired individuals feel stressed when they cannot understand their physical surroundings. In general, stress responses are linked to vital reactions such as accelerating heart rate [7]–[9], increased blood pressure [10], and sweating [11]. Recently, various easy wearable devices that can record these biological changes, such as smart wristbands [12], [13], smart headbands [14], [15], and smart clothing [16], have been developed. Hence, the stress experienced by a visually impaired individual due to uncertainty about the surroundings can be estimated with such devices. Additionally, the accuracy of stress estimation can be improved by using several such devices simultaneously.

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This study estimates the stress experienced by visually impaired individuals by measuring their biometric changes using multiple wearable smart devices. Furthermore, this study analyzes the effectiveness of stress estimation using vital biological changes depending on situations towards the walking support of visually impaired people respects their independence.

2. Related Work

A previous method [9] realized stress estimation with high accuracy based on heart rate variability (HRV) from an electrocardiogram (ECG). However, subjects were not evaluated while they were walking or moving; rather, the authors only evaluated subjects in the resting state. A brain stress observation system [10] was developed to estimate mental stress by analyzing changes in the total hemoglobin concentration (HbT) in the brain using near-infrared spectroscopy (NIRS). This study indicated the HbT changes in the right side of the brain changes depending on the stress level. However, as the NIRS sensor cannot measure deep brain activity, it might be difficult to detect minute stress using only the NIRS sensor.

3. Stress Estimation by Wearable Devices

3.1 Wearable devices and stress estimation

Wearable devices can easily measure the body's biometric information in real time without interfering with a user's daily activities. This real-time biometric information can then be used to estimate a user's level of stress. Herein, we focused on three types of biometric information: HRV obtained using an ECG sensor, HbT in user's brain obtained using an NIRS sensor, and galvanic skin response (GSR) of the user's hand using a GSR sensor. All of these wearable devices were connected to a smartphone via Bluetooth.

3.2 Estimation methods using wearable devices

This section describes the stress estimation methods using wearable devices. Many previous studies estimated stress by acquiring a single type of biometric information using medical instruments. Recently, it has become possible to acquire information related to biological changes by making the person wear multiple wearable devices simultaneously.

Therefore, we focus on the simultaneous use of multiple wearable devices to acquire multiple types of biometric information for estimating the various stress depending on situations. The estimation methods and wearable devices are described as follows and in Fig. 1, respectively.

Stress estimation based on HRV. HRV is calculated from ECG measured using the hitoe wear [16]. This is a clothing-type wearable device that can measure the ECG reading by simply wearing it as different from existing medical instruments. In addition, the hitoe wear can be used while exercising because it is moisture resistant. This clothing wear measures ECG at 5 ms intervals, and then extracts the peaks of ECG implying the heartbeat called R waves. Next, the changes of the R-R interval (RRI) are calculated using the time differences of R waves. RRI varies depending on the various conditions of the user. Especially, the low-frequency (LF) component is mainly affected from the respiration and the high-frequency (HF) component is mainly affected from the blood pressure changes, respectively. This analysis performs time-frequency analysis using the wavelet transform to extract the LF (0.05–0.15 Hz) and HF (0.15 –0.40 Hz) components. The wavelet transform is applied to the RRI for the previous 180 s at every 20 s interval. In general, the HF component represents the activation of the parasympathetic nervous system, and the LF component represents the activation of the sympathetic and parasympathetic nervous systems. The sympathetic nerves are activated during stress and the parasympathetic nerves during relaxation, and hence the stress can be estimated from LF/HF.

Estimation based on HbT change. Changes in HbT were obtained from an NIRS sensor called a HOT-1000 [15]. This is a headband-type wearable device that can measure changes in blood flow related to brain activity using an NIR light. The HOT-1000 can measure brain activity while worn on the head and does not interfere with the wearer's activities. In the NIRS system, the NIR light is irradiated on to the measurement site, and the reflected light is measured. The NIR light that passes through the brain is partially absorbed by hemoglobin in the blood, after which the hemoglobin concentration is determined using the NIRS based on the NIR light reflected after absorption in the blood. The HbT data obtained from the HOT-1000 at 100 ms intervals were used for the estimation. In general, stress increases HbT as the metabolism in the brain is activated and the blood supply to the brain is increased. Thus, stress can be estimated based on changes in HbT. Similarly, we estimated stress from the average value of the measured data every 20 s.

Estimation based on GSR change. GSR change was obtained from a GSR sensor called a Shimmer3 GSR+ [13]. This is a wristband-type wearable device used to measure skin resistance. It can measure the conductivity of the skin via electrodes attached to the index and middle fingers of one hand. The GSRs obtained from the device at 20 ms intervals were used for the estimation. Under the influence of stress, the sympathetic nervous system is activated and the muscles tense, which causes the limbs to sweat. Since sweating decreases the electrical resistance on the skin, the stress can be estimated based on these changes. As in the above two cases, stress was estimated using the average value of the data measured every 20 s.

hitoe wear HOT-1000 Shimmer3 GSR+

Fig. 1 Wearable devices used in our experiments.

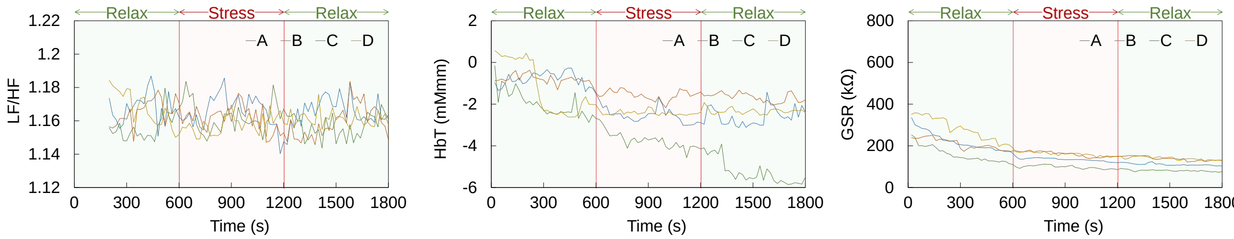
4. Experiment on Stress Estimation

We conducted experiments to estimate various types of stress using wearable devices in different situations.

To examine stress estimation using these three types of biometric information, we conducted experiments in four different situations, including a single applied situation.We considered the following stimuli: (1) construction noise as an external environmental factor, (2) the Uchida-Kraepelin performance test as an internal psychological factor, and (3) gripping ice as a physical stimulus. The Uchida-Kraepelin test can evaluate personality and occupational aptitude based on the number of calculations performed and the percentage of correct answers provided per minute in one-digit addition after 15 min. To measure the subject's biometric information, the subjects were asked to wear the Hitoe wear, HOT-1000, and Shimmer3 GSR+ devices. In this experiment, we continuously measured biometric information in a sequence including periods of 10 min of rest, 10 min of work, and 10 min of rest. Additionally, for the applied situation, we conducted an experiment in which participants simulated a visual impairment while walking with a conventional cane in a corridor of a building on our campus. Sighted participants wore a blindfold to simulate a visual impairment while walking in unfamiliar surroundings. We experimented an empty corridor for safety purposes. In this experiment, we continuously measured biological information in a sequence of 5 min of rest, 5 min of walking, and 5 min of rest.

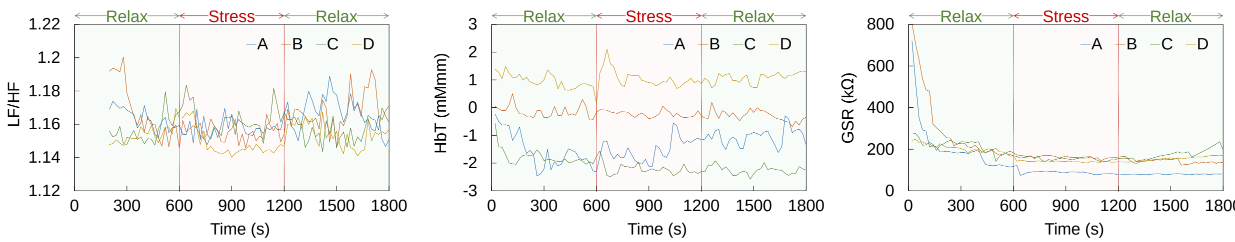
4.1 Discussion of stress caused by noise

Fig. 2 shows the results of stress response to noise. Fig. 2(a) indicates that there were no changes in the LF/HF of all subjects. Additionally, the ranges in which their vital signs fluctuated were smaller than those of the other situations, as described below. Fig. 2(b) indicates that the HbTs for A, B, and D did not show significant changes, whereas C's HbT continuously decreased. Hence, the stress caused by noise might not have been estimated adequately based on the changes in HbT. Fig. 2(c) indicates that all subjects' GSR decreased from immediately after the start of the experiment until the moment they began to hear a noise; however, A, C, and D's GSR decreased immediately after hearing the noise. Hence, the subjects might have experienced some stress due



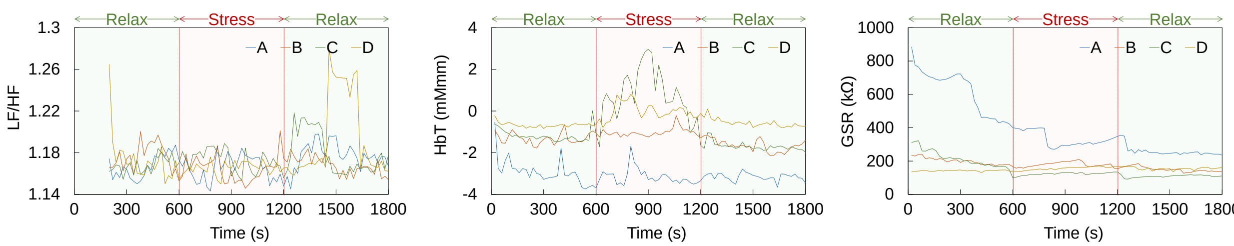
(a) LF/HF (b) HbT (c) GSR

Fig. 2 Experiment 1: Experimental results when hearing noise.



(a) LF/HF (b) HbT (c) GSR

Fig. 3 Experiment 2: Experimental results when doing repetitive calculation task.



(a) LF/HF (b) HbT (c) GSR

Fig. 4 Experiment 3: Experimental results when gripping ice.

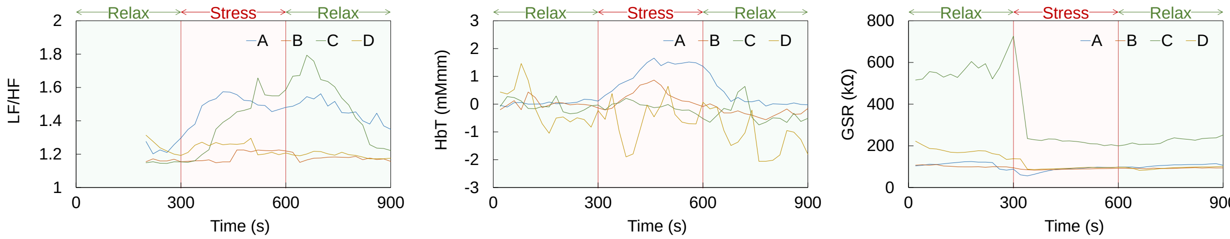
to the experiment itself. Therefore, the noise stimuli might have been insufficient to estimate stress in a noisy situation, or the participants' vital reactions were not have been sufficiently large to be measured by the devices. In contrast, visually impaired people might experience significant stress from an unexpected noise, as they tend to rely more on their hearing in realistic situations.

4.2 Discussion of stress caused by calculation

Fig. 3 shows the results of a repetitive calculation task. Fig. 3(a) indicates that A, B, and D's LF/HF slightly increased after a certain period from the beginning of the calculation task. Therefore, the effect of stress in LF/HF appeared with delays after experiencing the source of stress. Fig. 3(b) indicates that A and D's HbT increased immediately after the start of the calculation. Meanwhile, their HbT decreased during the calculation. We consider that the subjects' psychological responses to the repetition of simple calculation tasks depended on whether they were each accustomed to such tasks. Therefore, the relationship between stress induced by such calculation tasks and more more concrete stresses should be examined and defined. Fig. 3(c) indicates that A and D's GSR decreased almost simultaneously with the start of the calculations. B and C's GSR repeatedly increased and decreased even after the start of task, which cannot be regarded as a response to stress. There were few clear vital reactions, which can be attributed to the fact that the effect of calculation tasks on GSR was small, or the stress intensity from the repetitive calculation tasks was insufficient, which is comparable to the experiment with the noisy situation.

4.3 Discussion of stress caused by physical stimulation

Fig. 4 shows the results of estimating the stress caused by the physical stimulation of gripping ice. Fig. 4(a) shows that C and D's LF/HF increase at the end of the task of gripping ice. This occurred because the vital reaction was delayed in response to the onset of the load. Fig. 4(b) shows that C and D's HbT increase immediately after gripping the ice. Therefore, their reactions rapidly appeared in the presence of physical stimulation, though there were individual differences in the the extent of reactivity in terms of changes in HbT. Fig. 4(c) shows that B and C's GSR decrease immediately after gripping the ice as a vital reaction to the physical stimulus. A and B's GSR significantly decreased with a delay after gripping the ice. Hence, individual differences in vital reactions were evident in terms of the the beginning, timing, and delay of their reactions. In contrast, A and C's GSR decreased at the



(a) LF/HF (b) HbT (c) GSR

Fig. 5 Experiment 4: Experimental results when walking while wearing a blindfold.

same time after gripping the ice. Therefore, the end of the physical stress might be detected in some cases.

4.4 Discussion of stress caused by walking with blindfold

Fig. 5 shows the results of the experiment with walking while wearing a blindfold. Fig. 5(a) shows that A and D's LF/HF increase almost immediately after they start walking, C's LF/HF increases after approximately 40 s from the start of walking, and B's LF/HF increases after approximately 140 s from the start of walking. This shows that the vital reaction were evident in subjects' ECG readings, although the timing of the psychological reactions differed among subjects. A and C's LF/HF were large, while that of B and D were relatively small. This occurred because A and C felt a strong sense of stress due to walking in an unfamiliar situation, or their vital reactions were larger in a term of LF/HF in this situation. Fig. 5(b) shows that A and B's HbT increased or decreased depending on the presence of the stress. In contrast, A and C's HbT temporarily increased after they finished walking. However, it was difficult to determine whether this was an effect of stress. D's HbT irregularly increase and decrease from the start to the end of the experiment, which means that determining the effect of stress might be difficult in D's case. Fig. 5(c) shows that all subjects' GSR decrease almost simultaneously when they begin walking, and there are no significant changes after they stop walking. However, based on these results, changes in GSR might be suitable to detect the start of stress in case of walking in unfamiliar situations. Furthermore, most subjects might remain stressed in terms of their LF/HF and GSR even after changing their status from walking to resting. In contrast, the vital reaction of A and B in terms of changes in HbT appeared when their status changed from resting to walking. Thus, The changes in HbT can be useful to estimate the stress caused by walking in unfamiliar situations, although individual differences in HbT changes may be expected.

5. Conclusion

In this study, we analyzed various types of stress based on situational factors using biological information obtained from multiple wearable devices to estimate the stress of visually impaired people in real time. Large-scale experiments involving visually impaired people must be conducted in future researach to accurately assess the approach used in the present work. Additionally, a real-time stress estimation method based on various biometric data should be developed.

References

[1] N. Abe and N. Hashimoto, "Walking accident national survey to maintain visually handicapped persons walking environment," Bull. Hachinohe Inst. Tech., vol. 24, pp. 81–92, Feb. 2005. (in Japanese)
[2] WeWALK, website, `https://wewalk.io`.
[3] H. Husin and Y.K. Lim, "InWalker: smart white cane for the blind," Disability and Rehabilitation Assistive Tech., vol. 15, no. 6, pp. 1–7, Nov. 2019.
[4] M.F. Saaid, A.M. Mohammad, and M.S.A. Megat Ali, "Smart cane with range notification for blind people," Proc. 2016 IEEE Int. Conf. Automatic Control and Intelligent Systems (I2CACIS 2016), pp. 225–229, Oct. 2016.
[5] M.H.A. Wahab, A.A. Talib, H.A. Kadir, A. Johari, A. Noraziah, R.M. Sidek, and A.A. Mutalib, "Smart cane: Assistive cane for visually impaired people," arXiv preprint, arXiv:1110.5156, 7 pages, Oct. 2011.
[6] P. Morgado, N. Sousa, and J.J. Cerqueira, "The impact of stress in decision making in the context of uncertainty," J. Neuroscience Research, vol. 93, no. 6, pp. 839–847, Dec. 2014. DOI: 10.1002/jnr.23521
[7] H.-G. Kim, E.-J. Cheon, D.-S. Bai, Y.H. Lee, and B.-H. Koo, "Stress and heart rate variability: A meta-analysis and review of the literature," Psychiatry Investig., vol. 15, no. 3, pp. 235–245, March 2018. DOI: 10.30773/pi.2017.08.17
[8] S. Shirasaki, K. Kanai, and J. Katto, "Deep learning-based R-R interval estimation by using smartphone sensors during exercise," 2021 IEEE Int. Conf. Consum. Electron. (ICCE 2021), Las Vegas, United States, pp. 1–6, Jan. 2021. DOI: 10.1109/ICCE50685.2021.9427634
[9] Y. Matsumoto, N. Mori, R. Mitajiri, and Z. Jiang, "Study of mental stress evaluation based on analysis of heart rate variability," J. Life Support Eng., vol. 24, no. 2, pp. 62–69, Jan. 2012.
[10] K. Sunthad, Y. Niitsu, M. Inoue, and T. Yokemura, "Brain's stress observation system using 2-channels NIRS based on classroom activity," Proc. IEEE 37th Int. Conf. Consum. Electron. (ICCE 2019), Las Vegas, USA, 4 pages, Jan. 2019.
[11] J. Bakker, M. Pechenizkiy. and N. Sidorova, "What's your current stress level? Detection of stress patterns from GSR sensor data," Proc. 2011 IEEE 11th Int. Conf. Data Mining Workshops (ICDMW 2011), pp. 573–580, Vancouver, Canada, Dec. 2011. DOI: 10.1109/ICDMW.2011.178
[12] fitbit, Fitbit, Inc., `https://www.fitbit.com`.
[13] Shimmer3 GSR+ Unit, Shimmer, `https://shimmersensing.com/product/shimmer3-gsr-unit`.
[14] SmartSleep, Koninklijke Philips N.V., `https://www.usa.philips.com/c-e/smartsleep.html`.
[15] HOT-1000, NeU Corporation, `https://neu-brains.co.jp/solution/nirs/hot-1000`.
[16] hitoe, TORAY Industries, Inc., `https://www.hitoe.toray/en`.