가상현실에서의 뇌파측정을 위한 디자인 고찰 및 제안

The New Design of Brain Measurement System for Immersive Virtual Reality

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요약 최근 인지과학의 활발한 연구와 기술의 발달로 인해 사회과학분야에서 정신생리학적 연구를 통한 뇌의 다양한 측정과 정교한 분석 기법이 개발 되었다. 그러나 뇌파를 이용한 뉴미디어활용에 관한 연구는 장비들을 장착하는 과정에서의 한계점으로 인해 진행되지 못하였다. 이러한 문제를 극복하고자, 가상현실장비를 착용한 상태에서도 전 영역의 뇌파측정이 가능한 캡을 디자인하고 활용방법을 제안한다.

Abstract With the technological development, benefits of Virtual Reality (VR) has become a key of medium in communication research. In addition, explaining human minds with physiological data has become more popular since more accurate and detailed data can be expressed. However, reading brain signals in a virtual environment setting with psychophysiological measures (e.g. EEG and fNIRS) has remained a difficulty for researchers due to a technical constraint. Since a combination of cables for brain measures attached to a head cap obstruct wearing a Head-Mounted Display (HMD) over the cap, measuring brain activities with multiple channels on several areas of the brain is inappropriate in the VR setting. Therefore, we have developed a new brain measurement cap that includes probe connectors and brackets enabling a direct connection to the HMD. We highly expect this method would contribute to cognitive psychology research measuring brain signals with new technology.

핵심어: Brainwave, Psychophysiology, EEG, fNIRS, Virtual Reality, Brain measurement method, VR caps

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1. INTRODUCTION

With the development and widespread distribution of advanced psychophysiological measurement methods, it has been able to explore human behaviors and minds in depth today.

Especially for media researchers, psychologists and sociologists, understanding human minds with physiological data is often used as their methodological tool box because it overcomes limitations of self-reported measures in some specific studies. Therefore, discovering and understanding brain waves have informed us many unanswered questions in both cognitive and social science.

2. PSYCHO-PHYSIOLOGICAL MEASUREMENTS

A cognitive neuroscience method is a technique to comprehend human behaviors and minds through analyzing brain activity. This concept has been developed with the belief that the brain mainly controls physical and psychological human activities. For instance, this basic concept has widely contributed to develop brain-computer interfaces (BCI) using the brainwaves as an addition input device for broader users including disable patients[1].

In addition, psychophysiological approaches to the brain have contributed to explore human minds deeper and wider without getting responses from participants. For example, neuroimaging studies have proven that increased amygdala activity when viewing fear[2], sad, angry[3] or happy facial expressions[2]. In addition, it is also able to measure mental workload[4]. Therefore, this method would be more beneficial than getting results from self-reported measures in 5 or 7 scale posttest questionnaires. The reason is first, it does not instantly reflect the result at the time of exposure (delay in response). In most cases, a self-report is completed after exposure, not during exposure of stimuli. Therefore, to complete a post-test questionnaire, participants need to recall the time of the experiment. Secondly, the result from the 5 or 7 scale questionnaires does not accurately represent the details of participants' minds and thoughts because human's psychological process is lot more complicated than we expect. On the contrary, the brain imaging tool using a psychophysiological method continuously captures user's cognitive process on a millisecond scale. For these reasons, psychophysiological measurements have been widely used even though it requires more time, cost, and effort to set the experimental environment up.

Then, what types of brain waves we can measure and what do they represent? There are technically different methods to measure brain waves, and each method has a different approach to explore human minds.

There are several physiological measurements (e.g. PET, fMRI or TMS), however we discuss only methods that measure brain waves with a head cap and sensors since a purpose of this paper is to propose a new design of the cap for brain wave measurement system.

2.1 Electroencephalogram (EEG)

In contrast to other physiological measures such as heart rate, skin-conductance level, or facial electromyography (EMG), Electroencephalogram (EEG) is a direct measure of central nervous system activity from the active brain. It measures the performance or capacity of cortical information[5]. In other words, it can measure the arousal dimension of human emotions from peripheral signals and EEG that is non-verbal communication[6]. A benefit of this measurement is ease of use and low set-up cost. It generally uses 32 channels to see each area of the brain by wearing a head cap and putting measuring sensors (electrodes) into grommets over the cap. Grimes et al showed 99% accuracy in working memory states (WM) and four WM states with up to 88% accuracy with EEG[7]. Because of this accuracy, military also uses EEG to monitor pilots' mental states while they are in the air[8].

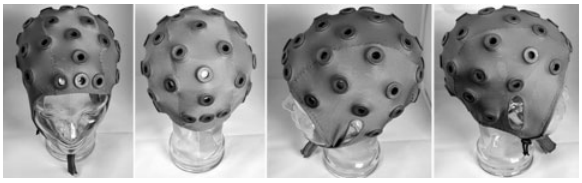

Figure 1. EEG head cap, developed by Mobita

2.2 Functional Near-Infrared Spectroscopy (fNIRS)

Functional near-infrared spectroscopy (fNIRS) is also another technique to measure brain waves. It was originally used in medical domain. However, it has been redesigned for a neurological research purpose. It is also a non-invasive measurement to see the changes in blood oxygenation, that can represent levels of brain activation while EEG captures waves. fNIRS uses optical fibers placed on the scalp and send light in the wavelength range of 650-850mm in to the targeted area on the head and captures any change of oxy and deoxy hemoglobin from the issue during brain function. This logic is based on the simple theory that human body needs more blood when it's working.

This method has been proven by many researchers as a valid method to measure hemodynamic levels originating from prefrontal cortex (PFC) activation[9] in emotion induction[10] and cognitive functions such as problem solving or memory that is related to mental workload[11].

Figure 2. fNIRs head cap, developed by Hitachi

3. BENEFITS OF PSYCHOPHYSIOLOGICAL MEASURES TO UNDERSTAND NEW MEDIA

The brain imaging tool we discussed above have several common advantages for research. First, it accurately measures human mental states or workloads with massive physiological data in milliseconds. Secondly, those are popular, non-invasive and widely proven techniques in research. Third, EEG or fNIRs can measure brain waves in real working conditions. For instance, other physiological measures such as PET or fMRI require participantrs not to move or must lie in restricted positions.

For those reasons, EEG and fNIRs have been widely used in human computer interaction (HCI) to see the effectiveness of usability testing or to develop more user-centered design for better human affordance[4]. We conclude that EEG and fNIRS are suitable for media communication research since it measures neural activations.

3.1 Virtual Reality (VR)

The concept of Virtual Reality (VR) is to experience a certain unreal environment as real. With the technological development in graphics, it is possible to depict a realistic environment in 3D. By wearing Head-mounted display (HMD), a user can be in the virtual world without seeing other real objects near the user that may distract experiencing immersive VR.

In addition, other functionalities that increase users' immersion such as head-tracking or motion-tracking system, make the virtual environment more realistic so that users feel "they are actually there"[12-14]. Therefore, in recent years communication researchers and sociologists have studied to see their minds when they interact with other objects or people in VR[15,16].

3.2 Technical Issues on Measuring Brain Waves with The Newest VR System

As we discussed above, it is essential to see users' cognition when they interact in VR in communication and other research fields. In other words, it is important to see how users accept and process information they get and interact in virtual environment with the psychophysiological methods we discussed above. However, since both EEG and fNIRS require to wear a head cap and attach sensors (probes) into sockets, it's difficult to wear VR devices over the head in this experimental setup. There were some studies that see some social effects of virtual reality with electroencephalography (EEG) or fNIRS previously[17,18], however they just see the effect of virtual object shown in a 2D display, not in immersive the virtual environment.

Figure 3. Virtual Reality Head-mounted Display: HTC VIVE and Oculus Rift

As shown in the Figure 3, both HTC VIVE and Oculus Rift use a 3-axix headband for a perfect fit. In addition, the headband should be tightened enough to cut off the light from outside of the HMD, so the user can fully focus in virtual environment. However, once the user already put the brain measurement cap on, it is not able to wear the HMD over the cap since there are already lots of cables and sensors attached to the cap. In addition, Since the HMD head bands are made with a flexible rubber, it pressures the sensors even though the HMD attached over the cap. This situation will finally result in gathering unreliable data. The reason is first, sensors (probes) attached to the head cap does not have equal pressure by the band. Secondly, the band itself interferes electric cables from the proves that connected to the computer. Third, to measure prefrontal cortex activity in VR, the HMD cannot be attached in the correct place of the forehead since the cap already covers the forehead from eyebrows. If the HMD is worn below the cap, then the HMD lens and eye are not aligned and centered, that finally results in a failure of setting up the virtual environment. Figure 4 shows the experimental setup of fNIRs. As shown in the picture, it is impossible to wear the HMD over the cap because of cables.

Figure 4. Example of brain measurement cap with probes and cables attached

For those restrictions, it has always been a difficulty for scholars to research an immersive virtual environment when they use brain measurements.

3.3 Previous Solution Suggested by Other Researchers

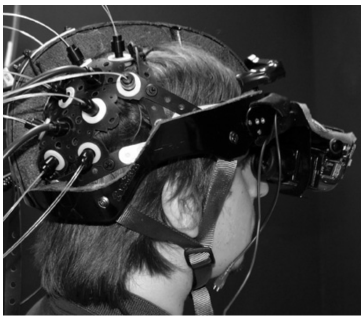

Figure 5. Suggested solution to use fNIRS in VR by Seragila et al[19]

Figure 5 shows a method to use fNIRS in VR setup suggested by Seraglia et al[19]. They developed a VR cap that does not interfere fNIRS cables. However, there is a limitation that it only measures small area of the head. In other words, it cannot measure the area of the band attached to the head.

4. CONCLUSION

To solve issues and restrictions discussed above, we have designed an innovative head cap that enables to wear the HMD and to attach brain measurement sensors at the same time without any restrictions we mentioned earlier.

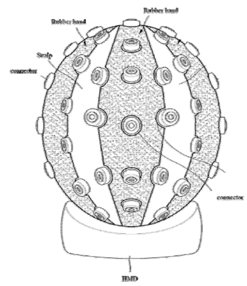

Figure 6. New design of the brain measurement cap for immersive virtual reality system (patent pending)

As shown in Figure 6 and 7, we have designed the new brain measurement cap that has connectors for probes and brackets to mount the HMD.

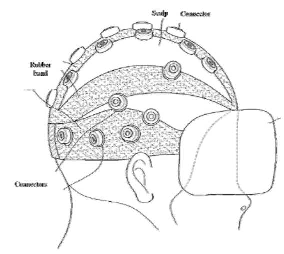

Figure 7. Right side view of new brain measurement cap

The benefits of this design are first, researchers do not need to negotiate the number of sensors to use for research because the cap covers most area of the head with sensors. Secondly, this cap saves time in setting up an experimental environment because subjects need to wear only one cap. In a previous setup, a subject wears the brain measurement cap first and then wear the HMD. Third, this cap design works on both EEG and fNIRS because the socket on the cap is designed to cover all probes and sensors.

The cap will be made of e-flex and ABS material with a 3D printer. The band will be made of e-flex so that it should have a malleable attribute like a soft rubber and sockets will be made of ABS that is stiff enough to hold probes and sensors tightly. We are currently working on making prototype of this cap, and will be shown to public soon.

Figure 8. Back side view of new brain measurement cap (3D modeling)

REFERENCES

[1] Girouard, A., Solovey, E. T., Hirshfield, L. M., Peck, E. M., Chauncey, K., Sassaroli, A., Fantini, S. and Jacob, R. J. K. From Brain Signals to Adaptive Interfaces: using fNIRS in HCI. Brain-Computer Interfaces. pp. 221-237. 2010.

[2] Breiter, H. C., Etcoff, N. L., Whalen, P. J., Kennedy, W. A., Rauch, S. L., Buckner, R. L., Strauss, M. M., Hyman, S. E. and Rosen, B. R. Response and habituation of the human amygdala during visual processing of facial expression. Neuron. 17(5). pp. 875-887. 1996.

[3] Johnson, B. T. and Eagly, A. H. Effects of involvement on persuasion: A meta-analysis. Psychology Bulletin. 106(2). pp. 290-314. 1989.

[4] Hirshfield, L. M., Chauncey, K., Gulotta, R., Girouard, A., Solovey, E. T., Jacob, R. J., Sassaroli, A. and Fantini, S. Combining electroencephalograph and functional near infrared spectroscopy to explore users' mental workload. In International Conference on Foundations of Augmented Cognition. pp. 239-247. 2009.

[5] Klimesch, W. EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. Brain Resource. 29(2). pp. 169-195. 1999.

[6] Chanel, G., Kronegg, J., Grandjean, D. and Pun, T. Emotion assessment: Arousal evaluation using EEG's and peripheral physiological signals. Lecture Notes Computer Science. 4105. pp. 530-537. 2006.

[7] Grimes, D., Tan. D. S., Hudson, S. E., Shenoy, P. S. and Rao, R. P. N. Feasibility and pragmatics of classifying working memory load with an electroencephalograph. In Proceedings of the 26th SIGCHI Conference on Human Factors in Computing Systems. p. 835. 2008.

[8] Karin, H., Schmidt, B., Dart, D., Beluk, N. and Huppert, T. Functional near-infrared spectroscopy (fNIRS) of brain function during active balancing using a video game system. Gait Posture, 35(3), pp. 367-372, 2012.

[9] Sato, H., Yahata, N., Funane, T., Takizawa, R., Katura, T., Atsumori, H., Nishimura, Y., Kinoshita, A., Kiguchi, M., Koizumi, H., Fukuda, M. and Kasai, K. A NIRS-fMRI investigation of prefrontal cortex activity during a working memory task. Neuroimage. 83. pp. 158-173. 2013.

[10] Herrmann, M. J., Ehlis, A. C. and Fallgatter, A. J. Prefrontal activation through task requirements of emotional induction measured with NIRS. Biological Psychology. 64(3). pp. 255-263. 2003.

[11] Izzetoglu, K., Bunce, S., Onaral, B., Pourrezaei, K. and Chance, B. Functional Optical Brain Imaging Using Near-Infrared During Cognitive Tasks. International Journal of Human-Computer Interaction. 17(2). pp. 211-227. 2004.

[12] Biocca, F. The Cyborg's Dilemma : Progressive Embodiment in Virtual Environments Minding the Body , the Primordial Communication Medium. Journal of Computer-Mediated Communication. 3(3). pp. 1-29. 1997.

[13] Heeter, C. Being There: The Subjective Experience of Presence. Presence, 1(2), pp. 262-271. 1992.

[14] Reeves, B. and Nass, C. How People Treat Computers, Television, and New Media Like Real People and Places. The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places. Communication Research. 34(3). pp. 19-36. 1998.

[15] McCabe, K., Houser, D., Ryan, L., Smith, V. and Trouard, T. A functional imaging study of cooperation in two-person reciprocal exchange. In Proceedings of the National Academy of Sciences. 98(20). pp. 11832-11835, 2001.

[16] Rilling, J. K., Gutman. D. A., Zeh, T. R., Pagnoni, G., Berns, G. S. and Kilts, C. D. A neural basis for social cooperation. Neuron. 35(2). pp. 395-405. 2002.

[17] Baumgartner, T., Valko, L., Esslen, M. and J ncke, L. Neural Correlate of Spatial Presence in an Arousing and Noninteractive Virtual Reality: An EEG and Psychophysiology Study. CyberPsychology and

Behavior. 9(1). pp. 30-45. 2006.

[18] Schilbach, L., Koubeissi, M. Z., David, N., Vogeley, K. and Ritzl, E. K. Being with virtual others: Studying social cognition in temporal lobe epilepsy. Epilepsy and Behavior. 11(3), pp. 316-323. 2007.

[19] Seraglia, B., Gamberini, L., Priftis, K., Scatturin, P., Martinelli, M. and Cutini, S. An exploratory fNIRS study with immersive virtual reality: a new method for technical implementation. Frontiers in Human Neuroscience. 5(1). 2011.