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Change in cognitive process during dance video game play with different appendages for motor output

Kota Suzuki[a*], Yumie Ono[a,b], Sotaro Shimada[a,b], Atsumichi Tachibana[c] and Jack Adam Noah[d]

[a] Dept. of Electronics and Bioinformatics, Meiji Univ., 1-1-1 Higashi-Mita, Tama-ku, Kawasaki-shi, Kanagawa, JAPAN 214-8571; [b] School of Science and Technology, Meiji University., 1-1-1 Higashi-Mita, Tama-ku, Kawasaki-shi, Kanagawa, JAPAN 214-8571;[c] Dokkyo Medical University., 880 Kita-Kobayashi, Mibu-machi, Shimotsuga-gun Tochigi 321-0293, JAPAN 321-0293;[d] Yale School of Medicine., 300 George Street, Suite 902 New Haven, CT, 06511 USA

ABSTRACT

Playing a dance video game (DVG) requires fine temporal control of foot positions based on simultaneous visuo-auditory integration. Despite the highly-demanding nature of its cognitive processes, DVG could offer promising exercise opportunities for elderly people to maintain their cognitive abilities due to its strong adherence. Using functional near-infrared spectroscopy, we have previously shown that DVG play with the foot activates prefrontal and temporoparietal cortices. However, it is still in debate whether this brain-stimulatory effect of DVG could also be maintained in case that DVG is played with the hand by people who have difficulty to play DVG in a standing position. We therefore investigated the regional brain activity of 12 healthy, right-handed young-adults when they played DVG with their dominant hand and foot. We found that the DVG-related hemodynamic activity was comparable in the prefrontal area regardless of the appendages while that was significantly smaller in case of playing with the hand related to the foot in the left superior/middle temporal gyrus (S/MTG). A similar trend was also observed in the right S/MTG. These results suggest that the motor preparatory function mediated by the prefrontal cortices is equally employed regardless of appendages while more cognitive load is required in the temporal cortices with foot-played DVG, possibly to integrate visual, auditory, and proprioceptive information. Hand-played DVG may partially substitute foot-played DVG in the sense of cognitive training in the elderly.

Keywords: rehabilitation, prefrontal cortex, temporal cortex, video game, functional brain mapping, cognitive function

1. INTRODUCTION

Playing a dance video game (DVG, Fig. 1) is a complex motor task that requires temporally accurate footsteps following the provided visual and auditory cues. Since its entertaining and competitive nature, DVG is thought to be a sustainable pastime exercise from which the elderly can improve or maintain their physical and cognitive function [1]. Previous study using functional near-infrared spectroscopy (fNIRS) has shown that regional brain activities in the frontal pole (FP) and the superior/middle temporal gyrus (S/MTG) differ depending on the performance of DVG [2]. Since FP is involved in making plans for future behavior [3] and its activity decreases with improvement of DVG performance through long-term training [2,4], the activity of FP during DVG play is considered to reflect the cognitive load required for preparing appropriate motor output. On the other hand, S/MTG is likely to play a role in integrating multimodal process of audio, visual, and proprioceptive information for successful motor output, since S/MTG is involved in the comprehension of the rhythm [5] and its activity duration correlates with the temporal accuracy of the responses in DVG play [2]. However, it is still unclear whether these cognitive brain processes of FP and S/MTG required for DVG could also be maintained in the case that DVG is played with the hand by people who have difficulty to play DVG in a standing position. We therefore investigated the regional brain activities in FP and S/MTG with young-adults when they played DVG with their dominant and non-dominant hands and foot.

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[*] ce171035@meiji.ac.jp; phone 81 44 934-7302; fax 81 44 934-7883

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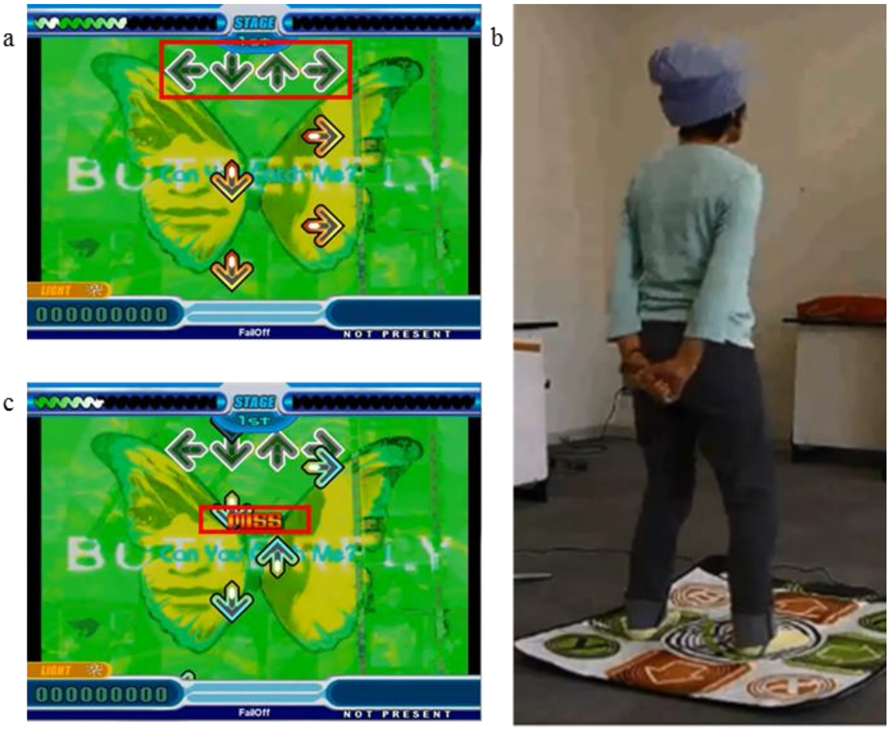

Figure 1. Game screen and typical playing style of DVG with foot on a dance pad. (a) Visual cues (arrow icons) are crawling up from the bottom to the top of the screen with music. (b) Player is encouraged to push the response button of the same direction on the dance pad with their foot when the cue is overlapped with its shadow image located in the response area (indicated by red box in (a)). The visual cues are aligned with the beat of the music and the sequence of the cue positions imitate dance step that matches with the music. (c) An immediate feedback for timing accuracy of the step (indicated by red box) is given to the participant for each visual cue.

2. MATERIAL AND METHODS

2.1 Participants

Twelve healthy male college students, aged 21-25 years (mean and standard error 22.7 ± 0.3 years, all right-handed) participated in the experiment. The investigation was approved by the ethics committee of Meiji University, and all participants gave written informed consent to participate.

2.2 fNIRS measurement

Left and right FP and S/MTG activity of the participants during DVG play with different appendages was measured using fNIRS (OMM-3000, Shimadzu Co., Kyoto, Japan). We used a 12-channel layout as shown in Figure 2. The layout consisted of one and four channels arranged over FP and S/MTG regions on each hemisphere, respectively. Inter-optode distance was 3 cm for each source detector pair. Data were sampled at 7.9 Hz. We used a 3D digitizer (PATRIOT, Polhemus, Colchester, VT) and obtained coordinates of all optode positions and the anatomical landmark positions (nasion, inion, auricles and Cz) of each participant immediately before data collection. Individual channel positions were normalized to the standard MNI coordinates using NIRS-SPM [6] to confirm their anatomical location.

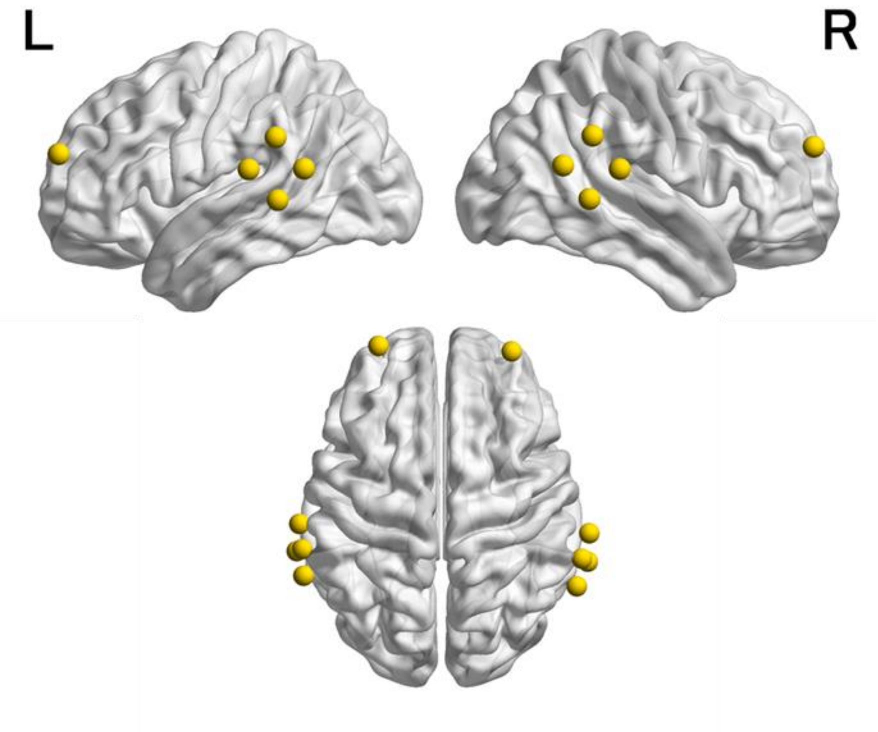

Figure 2. fNIRS channel layout. The mean channel positions across all participants were shown as yellow dots on the normalized brain. Channel positions were visualized with the BrainNet Viewer (http://www.nitrc.org/projects/bnv/) [7].

2.3 Experimental design

We used open source StepMania software version 3.9 to create DVG task. We used a dance pad (KONAMI) and a conventional video-game controller (BUFFALO BSGP801) connected to a computer to play DVG. In this experiment, we used 4 arrows, which were up, down, right and left. The participant had to press arrow buttons on the game controller with their finger (Figure 3a) or on the dance pad with their foot (Figure 1b) at the correct timing that is indicated as visual cues (arrows) on the screen while listening to the background music. Although the game controller was equipped with 4 buttons on both sides, participants were allowed to use those on the right side only. The game controller was fixed on the desk and the participants were instructed not to hold the controller in hands.

Figure 3b illustrates the experimental design. All participants performed DVG three times with different appendage conditions (dominant hand (DF), foot (F) and non-dominant hand (NH)) in a random order. The fNIRS measurement of each condition was always preceded by 30 s of practice with the corresponding appendage. A single measurement is consisted of 30 s of playing DVG and 30 s of rest alternately 5 times. A song entitled ‘Butterfly’ (recorded by SMILE.dk) used as the background music with total of 240 visual cues. The performance of DVG was determined by the number of correct arrow cues that were responded in accurate timing (those being responded within ± 22.5 ms from the exact timing). All participants answered a questionnaire on which appendages was the most difficult in this experiment after the fNIRS recording.

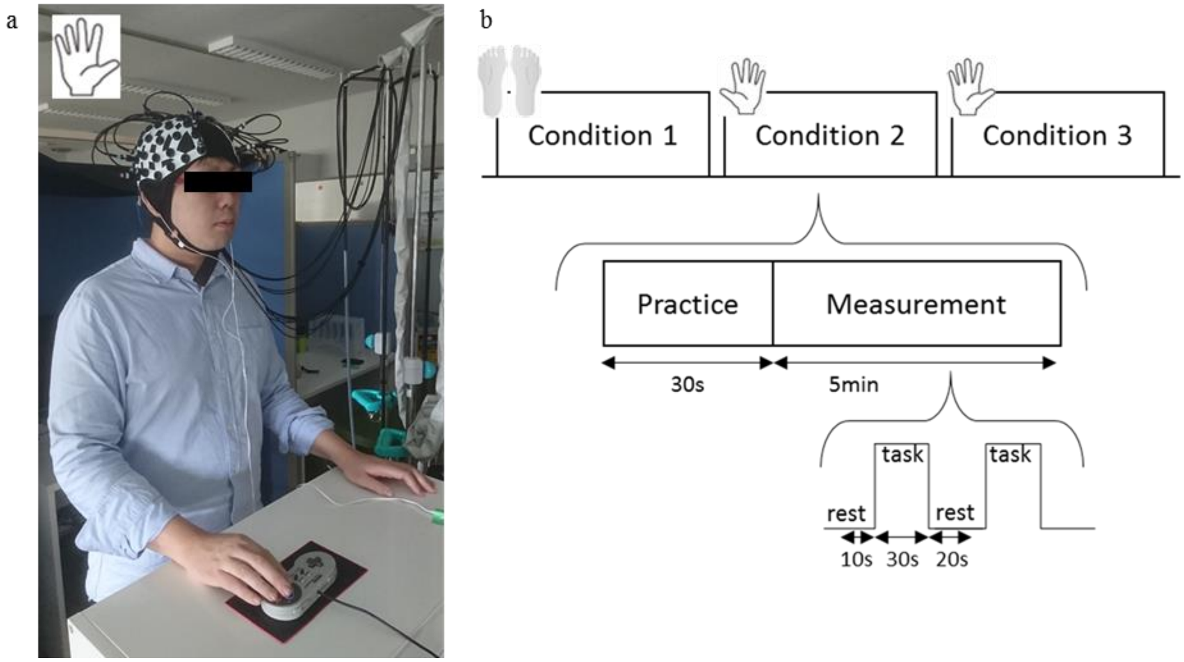
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Figure 3. fNIRS measurement during DVG play by hand (a) and an example of experimental design (b). The orders of appendages were randomized across participants.

2.4 Data analysis

Change in hemoglobin concentration (Oxy-Hb and Deoxy-Hb) signals were averaged and smoothed using the Savitzky-Golay filter (25 point, 5 times). The averaged data was then baseline corrected so that the signal amplitude of task onset was set to zero. Lastly, the averaged signals were normalized by dividing the averaged data by the standard deviation of those during the 10 s before the task onset. The averaged hemodynamic responses were manually examined for systemic and/or facial muscle artifact [8, 9]. The data were regarded as contaminated with systemic and/or muscle artifact and removed from further analysis if both Oxy-Hb and Deoxy-Hb responses continuously deflected to the same direction (either increasing or decreasing) for 10 s from the beginning of the task. Two, five, and three averaged datasets were excluded with this criterion at the left S/MTG, left FP, and right FP, respectively.

The cumulative amplitude of Oxy-Hb activity related to the baseline (area under the curve: AUC) was calculated during the 30 s of task period. In case of Deoxy-Hb, the AUC was calculated in the same way. The AUC was used as an index of regional brain activity.

To investigate the difference in hemodynamic activity among different appendages for motor output, we first compared AUC across DH, F, and NH in each region of interest of FP and S/MTG by Friedman test or repeated-measures analysis of variance test (ANOVA) depending on the normality of the data examined by Shapiro-Wilk test. Post-hoc multiple comparison was performed by Wilcoxon signed-rank test with Bonferroni correction. Second, we compared AUC between left and right hemispheres in the corresponding FP and S/MTG regions by paired t test or Wilcoxon signed-rank test with Bonferroni correction depending on the normality of the data. We also investigated the performance of DVG by the number of temporally accurate responses. The correlation of DVG performances across DH, NH, and F was also analyzed using Pearson’s correlation coefficient.

3. RESULTS

Figure 4 shows the grand average of normalized hemodynamic responses across all participants at S/MTG and FP. Most of the hemodynamic time-course showed task-related increases in Oxy-Hb and decreases in Deoxy-Hb, showing a cortical activity pattern [10]. The mean waveforms of Oxy-Hb and Deoxy-Hb signals in dominant hand condition at left S/MTG was the exception to show the same polarity in both hemoglobin species, however it is due to the large individual fluctuation in the polarity of hemoglobin concentration waveforms. In each individual data, the opposite polarity of Oxy-Hb and Deoxy-Hb deflection was confirmed. The Oxy-Hb increase in the bilateral S/MTG was the largest when DVG was played with foot. The mean AUC values in bilateral S/MTG were significantly different among appendages (Friedman test: left S/MTG: $\chi^2 = 7.80$, $p = 0.020$, right S/MTG: $\chi^2 = 7.16$, $p = 0.028$). Statistically significant difference in the mean AUC values were found between foot and dominant hand conditions in the left S/MTG (Wilcoxon test with Bonferroni correction: $p = 0.020$). There were also tendency of smaller AUC values in non-dominant hand condition relative to foot condition in the left S/MTG ($p = 0.065$). Similar tendencies was found in non-dominant ($p = 0.102$) hand conditions relative to foot condition in the right S/MTG as well. When AUC values in the corresponding region of interest (ROI: bilateral FP and S/MTG) were compared between hemispheres, the AUC value in the dominant hand condition in the left S/MTG was significantly smaller than those in the right S/MTG (paired t test: $p = 0.032$).

The Oxy-Hb responses in FP showed almost symmetrical activity pattern except for foot condition that showed lateralization to the right hemisphere. However, the mean AUC values showed no significant condition-related differences in both FP ROIs (Friedman test: Left FP: $p = 0.156$, Right FP: $p = 0.169$) and within-condition differences between bilateral ROIs.

The decrease of mean Deoxy-Hb responses in FP and S/MTG was the largest in foot condition, followed by dominant hand and non-dominant hand, however the statistical significance among conditions was not confirmed.

Figure 5 shows the timing accuracy of DVG play among three appendage conditions. There was a significant difference in the timing accuracy among appendages (ANOVA: $F = 22.00$, $p < 0.01$). DVG play with foot resulted in the worst performance compared to dominant and non-dominant hands (paired t test with Bonferroni correction: F and DH: $p < 0.01$, F and NH: $p < 0.01$) but there was no difference in timing accuracy between DH and NH (paired t test with Bonferroni correction: $p = 0.5$). The timing accuracy scores were in accordance with the result of the questionnaire in which all participants answered that DVG played with foot was the most difficult. Figure 6 shows a correlation between timing accuracies of DVG play with different appendage conditions. Performance level was preserved across appendages.

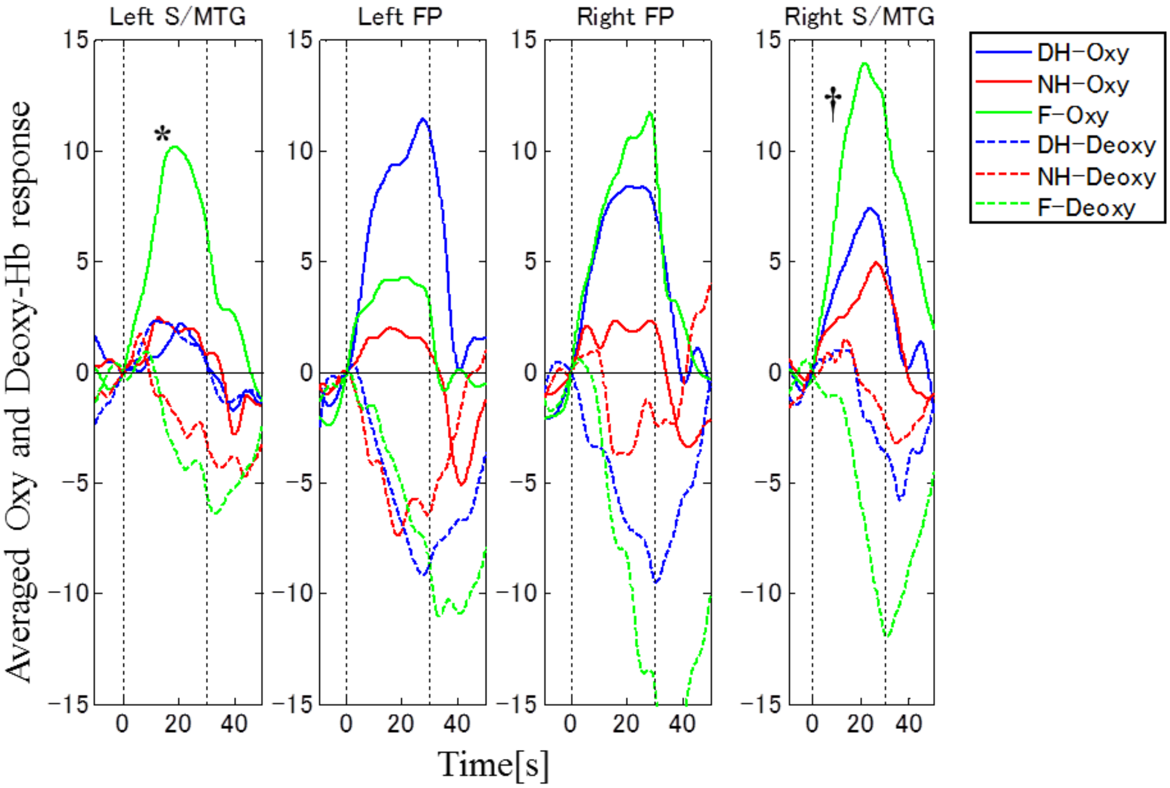

Figure 4. Grand average of normalized hemodynamic responses across all participants at S/MTG and FP. Statistically significant difference in mean AUC values during task period among conditions was found in bilateral S/MTG in Oxy-Hb. The asterisk shows statistically significant difference in Oxy-Hb AUC values between foot and dominant hand conditions and tendency of decreased AUC in non-dominant hand relative to foot (multiple comparisons after Friedman test). The dagger shows that the median Oxy-Hb AUC values were statistically different but only tendencies of differences among three appendages in the multiple comparison. In Deoxy-Hb AUC values, there were no significant differences between DH, NH and F. Details of statistical analysis are shown in the main text.

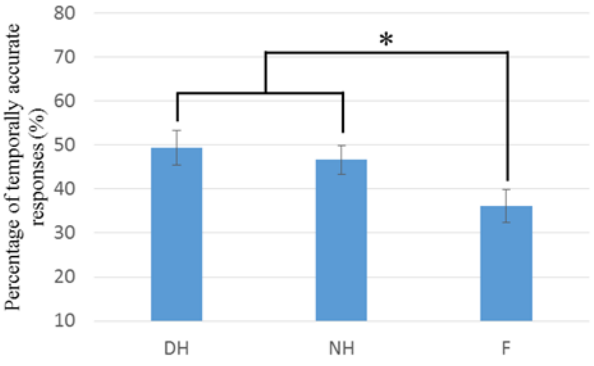

Figure 5. Change in the number of temporally accurate responses with different appendage conditions. Error bars show standard error. Asterisk shows statistically significant difference ($p < 0.05$, ANOVA and paired t test with Bonferroni correction).

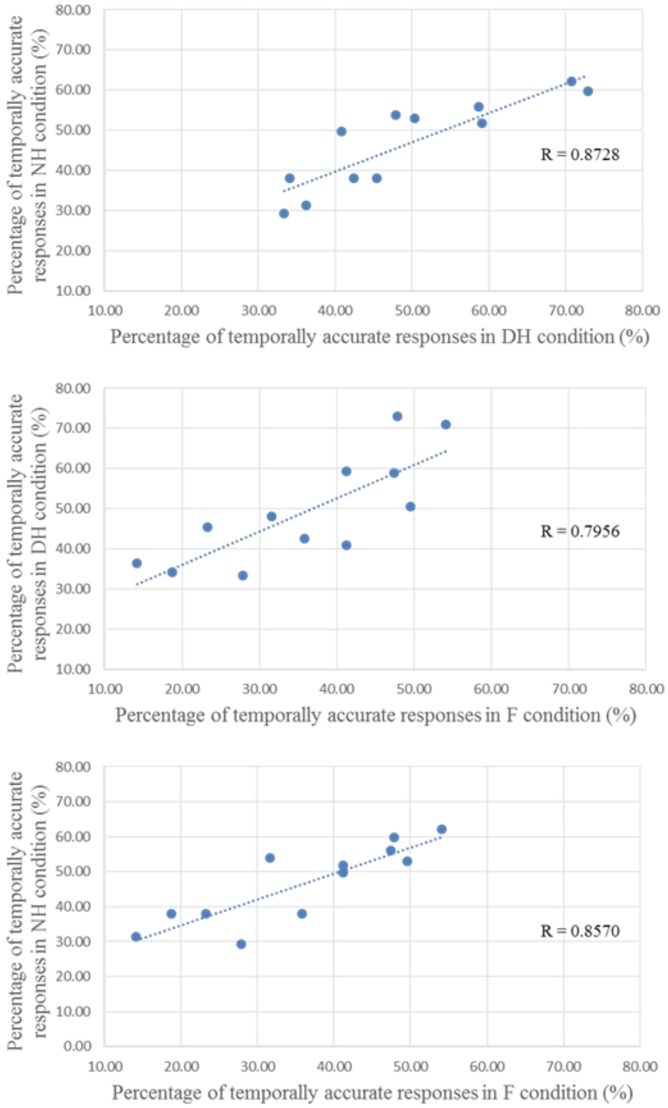

Figure 6. Correlation of temporal accuracy between different appendage conditions of DVG play. Each dot represents a single participant. Statistically significant correlation was found in all combinations.

4. DISCUSSION

We used fNIRS to investigate the effect of hand or foot use of playing DVG on the regional brain activities related to motor planning and audio-visual-proprioceptive integration during DVG play. Comparative intensity of FP activity across different appendages suggested the cognitive load for motor planning could be preserved regardless of hand-played DVG or foot-played one. On the other hand, the significantly increased S/MTG activity in foot played DVG indicated its advantage over hand-played DVG to facilitate brain activity related to multi-modal integration. Although the required cognitive load may be moderate, the hand-played DVG could be utilized as a cognitive exercise for person who has difficulty to play DVG with their foot.

The timing accuracy for button responses was the worst when DVG was played with foot compared to dominant or non-dominant hand. Accordingly, the Oxy-Hb increase in the bilateral S/MTG was the largest when DVG was played with foot, supporting the increased difficulty of the foot-played DVG. It is suggested that the difficulty in the multimodal information processing and motor output is reflected by the amount of AUC of S/MTG. Previous study showed that MTG is necessary for motor output at the correct timing that required audiovisual integration [11]. Another research reported that MTG becomes active when a person with limited ability of beat perception tried to perceive rhythm [12]. The relatively unfamiliar movement of pressing the button with the foot relative to hand might cause more complexity in the motor output along with the rhythmic cues, which resulted in the decrease in the behavioral performances, the increase of subjective difficulty of the task, and S/MTG activity. Less neural activity in S/MTG required for hand-played DVG may be the difference in dexterity of hands relative to foot. Hands are generally well trained to perform small movements while integrating multimodal sensory information on a daily basis such as note taking during a lecture, which possibly resulted in more efficient neural processing in multimodal integrating area of S/MTG for DVG task. Also, the ranges of the movement were different between hand- and foot- played DVG, in which the former was relatively smaller than the latter. The foot-played DVG is performed mostly using both feet but the hand-played DVG limits the body movement to either hand, More proprioceptive information including the trunk position should be simultaneously processed to maintain the body posture in case of foot-played DVG, which might also increase the activity of S/MTG.

Although the subjectively perceived difficulty and behavioral performance showed clear difference in foot-played DVG relative to hand-played DVG, there is no statistically significant difference in the mean AUC values among different appendages in FP. Previous studies suggested that FP activity shows a cognitive load necessary for DVG play and therefore the activity of FP could be utilized to determine the appropriate game complexity of DVG [13]. Our result further added that the cognitive load of motor planning in FP is not affected by the output motor complexity and rather reflecting the management activity of upcoming motor events such as the button selections and their order to be responded. In this sense, the hand-played DVG may be useful to train these executive functions in the elderly.

Analysis of AUC valued with Deoxy-Hb did not show any significant difference while the waveform showed similar time-course activity and changes among different appendages found in Oxy-Hb waveform. Since Deoxy-Hb waveform did not returned to the baseline until the end of the rest period, it may be necessary to find an optimal analysis time window for DVG experiment.

SUMMARY

Dance video game (DVG) has a potential to train the cognitive ability of elderly people, however it has not yet clarified whether the beneficial effect of the DVG training could be maintained when they play DVG with their hands instead of foot due to their impaired lower limb function. We therefore investigated the cortical hemodynamic activity patterns when a DVG was played either with the hand or the foot in healthy young adults. Regions of interest were set to the prefrontal area and superior/middle temporal area, which correspond to play a significant role in motor planning and multimodal sensory-information integration, respectively. Playing DVG induced comparable prefrontal activity regardless of the appendages, suggesting the equal employment of motor preparatory function in the prefrontal area. However the hemodynamic responses in the superior/middle temporal gyrus were smaller in hand-played DVG related to foot-played DVG, suggesting more demand for multi-sensory integration in the temporal cortices. Hand-played DVG may partially substitute foot-played DVG in the sense of cognitive training for the elderly people who have difficulty to play DVG in a standing position.

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REFERENCES

[1] Pichierri, G., Murer, K., de Bruin, E. D. (2012). A cognitive-motor intervention using a dance video game to enhance foot placement accuracy and gait under dual task conditions in older adults: a randomized controlled trial. BMC geriatrics, 12(1), 74.

[2] Ono Y, Nomoto Y. Tanaka S, Sato K, Shimada S,Tachibana A, Bronner S, Noah JA. (2014)., “Frontotemporal oxyhemoglobin dynamics predict performance accuracy of dance simulation gameplay: Temporal characteristics of top-down and bottom-up cortical activities”, NeuroImage.,vol.85, pt.1, pp.461-470

[3] Okuda J, Fujii T, Ohtake H, Tsukiura T, Tanji K, Suzuki K, Kawashima R, Fukuda H, Itoh M, Yamadori A. (2003): Thinking of the future and past: The roles of the frontal pole and the medial temporal lobes. NeuroImage. 19(4), pp.1369-138

[4] Ono, Y., Noah, J. A., Zhang, X., Nomoto, Y., Suzuki, T., Shimada, S., Tachibana A., Bronner S. & Hirsch, J. (2015). Motor learning and modulation of prefrontal cortex: an fNIRS assessment. Journal of neural engineering, 12(6), 066004.

[5] Liégeois-Chauvel C, Peretz I, Babaï M, Laguitton V, Chauvel P. (1998) Contribution of different cortical areas in the temporal lobes to music processing. Brain, 121: 1853-1867

[6] Ye, J.C., Tak, S., Jang, K.E., Jung, J.W., Jang, J.D.(2009). NIRS-SPM: Statistical parametric mapping for near-infrared spectroscopy. NeuroImage 44, 428-447.

[7] Xia M, Wang J, He Y. (2013) BrainNet Viewer: A Network Visualization Tool for Human Brain Connectomics. PLoS ONE 8: e68910.

[8] Schecklmann, M., Mann, A., Langguth, B., Ehlis, A. C., Fallgatter, A. J., & Haeussinger, F. B. (2017). The Temporal Muscle of the Head Can Cause Artifacts in Optical Imaging Studies with Functional Near-Infrared Spectroscopy. Frontiers in Human Neuroscience, 11, 456

[9] Zhang X1, Noah JA1, Hirsch J2. (2016) Separation of the global and local components in functional nearinfrared spectroscopy signals using principal component spatial filtering. Neurophotonics 015004

[10] Scholkmann, F., Gerber, U., Wolf, M., & Wolf, U. (2013). End-tidal CO 2: an important parameter for a correct interpretation in functional brain studies using speech tasks. Neuroimage, 66, 71-79.

[11] Suzuki K, Suzuki T, Ono Y.(2017) Effect of middle-temporal tDCS stimulation on dance game exercise performance. Transactions of Japanese Society for Medical and Biological Engineering, 55 (Proc), pp.503-505

[12] Grahn JA., McAuley JD. (2009) ‘Neural bases of individual differences in beat perception’, NeuroImage vol. 47, pp. 1894-1903

[13] Azman N, Suzuki K, Suzuki T, Ono Y, Edanaka Y, Kunieda F, Nakata M, Watanabe K. (2017) Effect of dance video game training on elderly’s cognitive function. Transactions of Japanese Society for Medical and Biological Engineering, 55 (Proc), pp.526-529