Haptic vs. Visual Neurofeedback for Brain Training: A Proof-of-Concept Study

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***Abstract*— The current practice of administering neurofeedback using the patients' visual and/or auditory channel(s) is known to cause fatigue, excessive boredom, and restricted mobility during prolonged therapy sessions. This paper proposes haptics as an alternative means to provide neurofeedback and investigates its effectiveness by conducting two user studies (Study-I & II) using a novel compact wearable haptic device that provides vibrotactile feedback to the user's neck. Each user study has three neurofeedback modes: visual-only, haptics-only, and visual-and-haptics combined. Study-I examines the participant's performance in a brain-training task by measuring their *attention level* (AL) and the task *completion time* (CT). Study-II , in addition to the brain-training task, investigates the participants' ability to perform a secondary task (playing a shape-sorting game) while receiving the neurofeedback. Results show that users performed similarly well in brain-training with haptics-only and visual-only feedback. However, when engaged in a secondary task, the users performed significantly better (AL and CT improved around 11% and 17%, respectively) with haptics, indicating a clear advantage of haptics over visual neurofeedback. Being able to perform routine activities during brain-training would likely increase user adherence to longer therapy sessions. In the future, we plan to verify these findings by conducting experiments on ADHD-patients.**

***Index Terms*— neurofeedback, brain training, haptic devices, vibrotactile feedback, biofeedback.**

I. INTRODUCTION

Neurofeedback (NF) is a type of biofeedback in which the neural activity of a user's brain is recorded in real-time and fed back to them in an understandable form [1]. Research has shown that humans can learn to self-regulate their brain activity and behaviour consciously (called brain training) by receiving such biofeedback in a closed loop [2], as shown in Fig. 1. NF therapies are commonly used to treat various neurological disorders, such as Attention Deficit Hyperactivity Disorder (ADHD) [3], and in other non-clinical applications such as relaxation training [2].

The current practice of administering NF uses the users' visual and/or auditory channel(s) to feedback the neural activity information to them. For example, the auditory channel has been used to convey NF in mindfulness training [4]. Auditory and visual channels have been used together to convey NF in post-stroke memory rehabilitation [5]. However, the use of auditory feedback (*i.e.*, the auditory channel) has been reported to cause anxiety and distraction [4]. Due to this and the auditory channel's sensitivity to environmental distractions, such as noise, audio NF has not gained much popularity among researchers. On the other hand, the visual channel is the most commonly-used means to provide NF in current therapeutic treatments where the users' brain activity is displayed back to them in the form of color-changing graphs [5] or video games [3], [6], [7]. The visual channel offers a number of advantages over the auditory channel such as enhanced user engagement and the ability to display neural activity in a variety of forms (*e.g.*, graphs and video games).

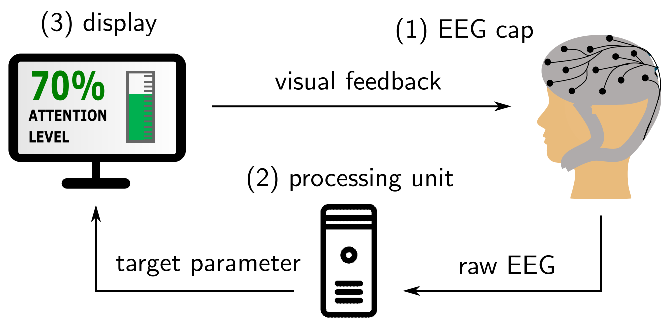

Fig. 1. The commonly-used brain-training solutions generally consist of three parts: (1) Electroencephalogram (EEG) acquisition where EEG is recorded, amplified, and sent to a processing unit; (2) a processing unit in which the raw EEG is translated into a target parameter (*e.g.*, attention level); and (3) a screen where the parameter is fed back to the user in different forms, such as a video game.

However, as visual feedback requires constant eye-contact and focus on the displayed information, it is known to cause mental fatigue [8], excessive boredom [9], and restricted mobility during the prolonged therapy sessions. This in turn leads to a reduced performance and low adherence rate [10]. Making visual NF therapies mobile through a smart phone [11], for example, may help increase the users' mobility while receiving the therapy. However, challenges related to the need for constant eye-contact may still cause boredom, mental fatigue, and a reduced performance. In addition, the visual channel can be easily preoccupied with environmental distractions, resulting in poor performance and low adherence rate [12], [13].

To address the problems mentioned above, we propose to convey the NF through the users' haptic channel. We hypothesize that haptic NF may improve the performance by increasing user engagement and adherence rate due to its intuitiveness, smaller cognitive load, and ability to be administered on-the-go. Haptics has already been investigated in brain computer interface (BCI) systems for motor imagery (MI) tasks. For example, Cincotti *et al.* [14] showed that haptic feedback performed better than visual feedback when users performed a visual task (*e.g.*, memorizing colors) while trying to control the BCI. Other studies have reported improved performance in MI tasks when haptic and visual

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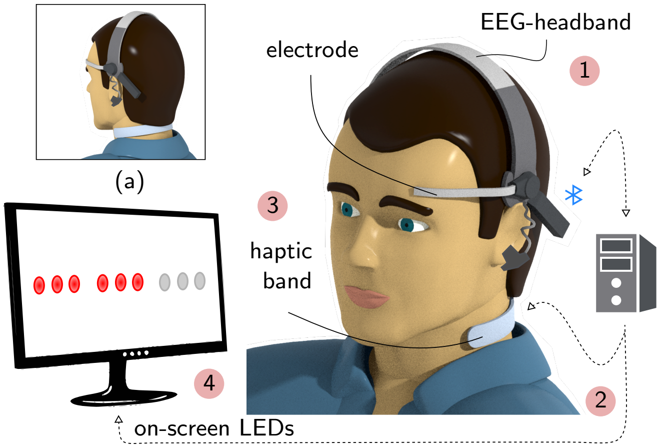

Fig. 2. The proposed brain-training system to deliver haptic and/or visual NF: (1) a wearable EEG device to record the brain signals, (2) a computing device (*e.g.*, portable microprocessor), (3) a haptic band to provide vibrotactile feedback around the user's neck, and (4) a monitor with on-screen LEDs for visual feedback. (a) shows a rear-view of the user wearing the haptic and EEG devices.

feedback were used together [15], [16]. However, the use of haptics in closed-loop brain training and neuropsychological treatments has not been investigated yet.

We, therefore, investigate the effectiveness of haptic vs. visual NF for brain training by developing a NF system that provides the users' EEG activity in the form of visual feedback (on-screen LEDs) and haptic feedback (vibrotactile sensation on the neck) through a novel wearable haptic device, as shown in Fig. 2. The system can convey the *attention level* (AL) of the users in three different modes: (a) visual-only, (b) haptics-only, and (c) visual-and-haptics combined. The users' AL and *completion time* (CT) during a brain training task were measured by conducting two user studies (Study-I & II). In addition to the brain-training performance examined in Study-I , Study-II investigated the user performance when they were simultaneously engaged in a secondary task (playing a shape-sorting game as shown in Fig. 5). The secondary task was introduced to assess the suitability of haptic and visual NF for performing brain training while the users are engaged in their routine life activities, such as commuting or doing household chores.

The specific contributions of this work include: (i) introduction and investigation of haptics as a means to perform closed-loop brain training, (ii) design and implementation of a novel wearable haptic NF system, (iii) comparison of the user performance for three different NF modes in brain training, and (iv) extending the possibility of delivering NF to mobile users with higher engagement, which is expected to increase the performance and adherence rate of NF therapies.

II. PROPOSED NEUROFEEDBACK SYSTEM

The proposed NF system, as shown in Fig. 2, is comprised of four main parts: an EEG acquisition unit, a processing unit, a haptic feedback unit, and a visual feedback unit.

A. EEG Acquisition Unit

To record the users' EEG, we used a commercial head-mounted EEG device (MindWave Mobile 2), which has been used in several similar existing studies (*e.g*, [3], [17]). The device has a single dry-electrode that reads the EEG from the frontal lobe of the brain. This location has been used in previous works to estimate the level of human attention [18], [19]. The EEG is recorded at a sampling rate of 512 Hz with a 16-bit resolution level and is sent to a computer (running MATLAB) using serial communication via built-in Bluetooth. Ground-referencing is done by attaching an electrode to the user's left ear lobe.

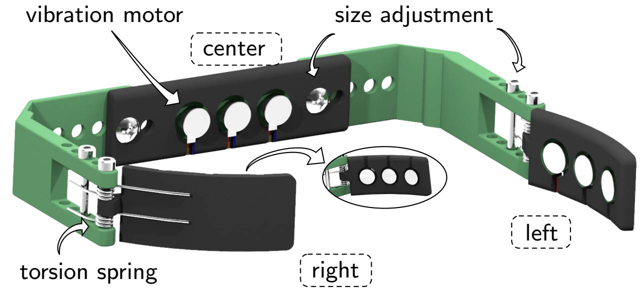

Fig. 3. The wearable haptic band has three clusters of vibration motors (left, center, and right) that are controlled based on the users' AL as determined by their EEG. Adjustment screws and torsion springs are used to ensure the device fits to different neck sizes.

B. Processing Unit

A low pass filter (with a cut-off frequency of 50 Hz), similar to [19], is applied on the raw EEG. Then, Fast Fourier Transform (FFT) is applied to the signal with windows of 1 second (512 data points). Each window has a 0.5 second (256 data points) overlap with each adjacent window. As a result, based on the frequency range, the signal is divided into 5 wave-bands: Delta (δ): [0.5, 3] Hz, Theta (θ): [3, 8] Hz, Alpha (α): [8, 12] Hz, Beta (β): [12, 30] Hz, and Gamma (γ): [30, 50] Hz. Considering the existing works ([18]–[20]), we decided to use β/α to gauge users' AL. A high α generally indicates a resting state of mind while a high β is associated with more intense thinking [19]. We mapped the β/α ratio to a scale of 0-9 by assigning the maximum observed ratio for a user to 9 and mapping the range linearly from 0. This range was decided to match our feedback modes that are explained in Sec. II-C and II-D. Similar to [3], the normalization for each individual is done using the Color Stroop test with 20 attempts. In this game, the name of a color is displayed in a different color. The maximum attention value is obtained by observing the user's maximum β/α ratio during the correct attempts.

C. Haptic Feedback Unit

The haptic feedback is provided to the users through a compact, light-weight, and custom-designed wearable device (Fig. 3), which is powered using four 2.85 Ah AA batteries connected in series and can function for about 6.5 hours without a recharge. We selected vibrotactile feedback due to its smaller form factor and ability to quickly alert the users in response to external events [21]. In addition, the following points were considered while designing the haptic device:

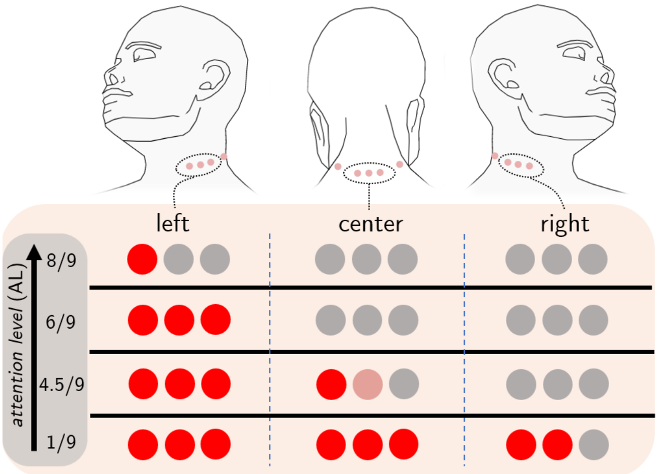

Fig. 4. The diagram represents three on-screen LED clusters (left, center, right) and their corresponding motor clusters on a user's neck. Each cluster contains three LEDs/motors. Depending on the user's attention level (shown on the left), each LED/motor can be in one of the three following states: *maximum*, *half*, and *off*. For the motors, these states can be customized for each user by selecting either 100% (50%) or 70% (35%) (of the motor nominal intensity) as *maximum* (*half*).

1) Haptic-delivery Location: We selected the user's neck to provide the haptic feedback because it is proximal to the user's head where the EEG device is mounted. Also, the neck is particularly sensitive to vibrotactile stimuli and can be easily used to convey meaningful information [22].

2) Actuator Placement: Different parts of the human neck have different levels of perception for vibration-location discrimination. Marrow *et al.* [23] concluded that the anterior side of the neck has a relatively low perception ability. M. F. Nolan [24] measured the average two-point discrimination for cutaneous stimuli on the neck as 35.2 mm by doing experiments on 43 healthy adults. Considering this, we decided to exclude the anterior portion of the neck and arrange the motors into three clusters, each with three vibrotactile units. The device length can be easily adjusted using the adjustment screws (Fig. 3). The center-to-center distance between each neighboring cluster varies from 7–10 cm based on the user's neck circumference (32 and 37 cm are average neck circumferences for females and males, respectively [25]). This ensures a minimum distance of 38 mm between the closest motors of each cluster for the smaller necks so that the users can discriminate between the different vibration locations properly. The user's ability to discriminate stimuli location using the device is experimentally confirmed for each user (see Sec. III-A).

3) Vibration Intensity: A maximum vibration frequency of 150 Hz (9000 rpm) is chosen based on the users' haptic perception around the neck area determined in [22], [23]. 8 mm coin-type eccentric rotating mass (ERM) motors (Jinlong Machinery & Electronics, Inc., China) are mounted on the 3-D printed parts of the haptic band to provide the vibrotactile stimuli. To minimize the interference of the actuators with each other, a layer of 2-mm thick silicon foam is used between each motor and the device. An Arduino Mega controls the motors individually using pulse-width modulation

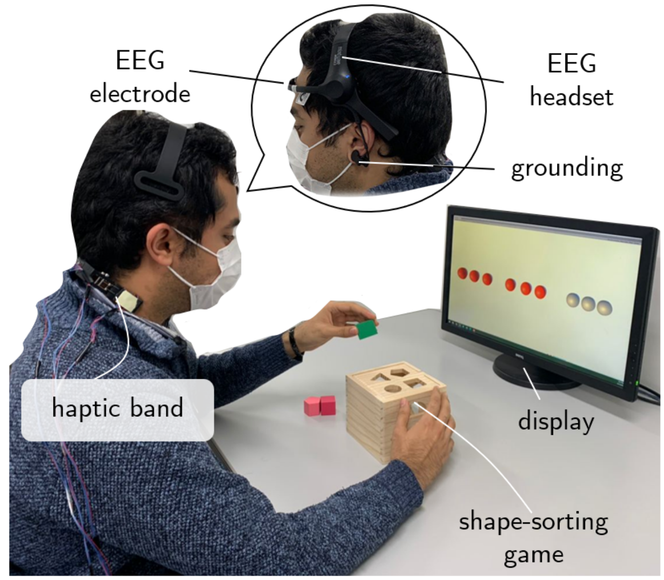

Fig. 5. Experimental setup: A user wears the haptic device around the neck and a head-mounted device to record EEG. The visual feedback is provided through a monitor by displaying on-screen LEDs. The user is instructed to switch-off at least 6 LEDs and/or motors, out of 9, by maintaining an attention level equal to 2/3 of their max. AL, for at least 5 seconds, in Study-I . In Study-II , the user performs a secondary task (shape-sorting game) in addition to the task performed in Study-I .

(PWM) based on the commands (wired serial communication) coming from a PC (MATLAB). The motors are driven with P2N2222A transistors and have three functional states: *maximum*, *half*, and *off* (explained in Sec. II-C.4). As the frequency and amplitude of ERM motors are inextricably linked, we use the term intensity to represent both.

4) Vibration Level Customization: In order to determine a suitable vibration intensity for the experiments, we customized the vibration level for each user. We conducted a pilot study to determine a set of two max. intensity levels that were distinguishable for all the subjects. We found that the users could not discriminate well when the intensity difference was smaller than 30% (of the maximum intensity). Therefore, we selected 100% (named *stronger*) and 70% (named *weaker*) as the candidates for *maximum* vibration state (used in the preliminary test Sec. III-A).

5) Feedback Delivery Method: The wearable device (haptic band, Fig. 3) conveys real-time NF, where each motor represents 1/9 of the user's attention (which was previously mapped to a range of 0-9). The number of vibrating motors is kept inversely proportional to the user's AL, as shown in Fig. 3. For example, if the user is 50% attentive, all the motors in the left cluster and the leftmost motor in the center cluster will vibrate at *maximum*, the middle motor in the center cluster will vibrate at *half*, and the rest will be *off*. If the user is 66% attentive (2/3 of their max. AL), all the motors on the left cluster will vibrate at *maximum* and the rest will be *off* (Fig. 4). The reason for keeping the inverse relationship between the number of active motors (LEDs during the visual feedback) and the user's AL is that vibration (red color of the LEDs) is perceived as warning/alert. Therefore, a lower AL should mean stronger feedback.

D. *Visual Feedback Unit*

Similar to the haptic feedback, visual feedback is provided to the users by using nine on-screen LEDs, grouped equally into three clusters. Like the vibration motors, each LED has three states (of brightness): *maximum*, *half*, and *off*. The LEDs are created using the Unity 3D game engine and are controlled via MATLAB. This analogous formation and control scheme is used to make the comparison between the visual and haptic NF as fair as possible.

III. USER STUDY

To experimentally evaluate the haptic NF and compare its effectiveness vis-a-vis with commonly-used visual NF, we conducted two user studies (Study-I & II) using the wearable haptic device described in Sec. II-C. Each user study consisted of three NF modes: (a) visual-only, (b) haptics-only, and (c) visual-and-haptics. 15 healthy subjects with no previous experience with BCI or NF training participated in each of the studies. For each participant, both studies were conducted in a random order on the same day in consecutive sessions, with a three-minute break in between. Participants understood and consented to the experimental protocols approved by the Institutional Review Board of the Department of Engineering, Kyoto University (No. 202013).

A. *Preliminary Test*

Before the user studies, a preliminary test (followed by a two-minute break to minimize the possible effects of the test on the user studies) was performed to customize the vibration intensity for each subject and assess their ability to correctly discriminate different vibration locations and intensity levels. Each subject sat comfortably on a chair, wearing the haptic band and the EEG headset. The haptic band's size was adjusted to ensure proper contact between the clusters and the subject's neck. Vibration level customization (see Sec. II-C.4) was performed by applying the *stronger* intensity (100% of the motor nominal intensity) on all motors for 30 seconds, and asking the subjects if they felt irritated. If the answer was *yes* (27% of the subjects), the *weaker* intensity (70% of the motor nominal intensity) was used as the *maximum* state of the motors. Otherwise, the *stronger* intensity was chosen as the *maximum*. This *maximum* intensity state for each subject was then used in Study-I & II .

For location discrimination, a vibration was randomly applied for 2 seconds using the left, right, and/or center clusters, either at *maximum* or *half* state. The subjects were asked to identify the active clusters in 20 trials and their response was recorded. For intensity discrimination, the vibration was applied for 2 seconds with two different intensities (*maximum* and *half*, in a random order) for a randomly selected motor in a cluster. The subjects were asked to identify the stronger intensity in a total of 20 trials.

B. *Study*-I

The objective of this study was to investigate and compare the effectiveness of the three different NF modes, (a) visual-only, (b) haptics-only, and (c) visual-and-haptics, in a brain training (attention training) task.

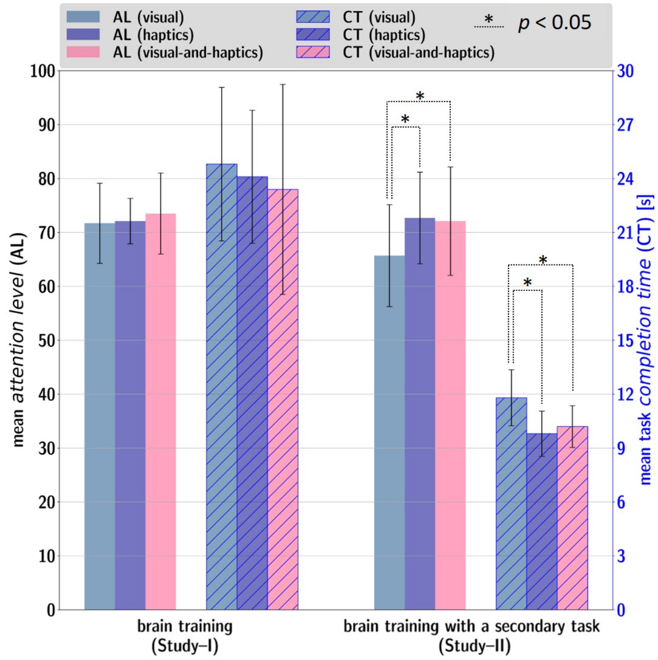

Fig. 6. The results of the participants' performance for Study-I (brain training without a secondary task) and Study-II (brain training with a secondary task) in terms of mean AL and CT for the three feedback modes: (a) visual-only, (b) haptics-only, and (c) visual-and-haptics. Error bars represent the standard deviation.

1) Setup: The experimental setup was identical to the one used in the preliminary test explained above. The chair height and distance of the screen providing the visual feedback were adjusted to each subject's comfort. Before the experiment, the subjects were explained the concept of NF for brain training, the proposed NF system, and the different feedback modes. AL normalization was then done as explained in Sec. II-B. Subjects did the brain-training task with each of the three modes separately (one minute each) in a trial session. They were allowed to perform additional trials to become familiar with the system, if needed. We instructed to avoid sudden head movements for smoother EEG recording.

2) Method: Each subject was asked to complete a brain-training task while receiving one of the three NF modes mentioned-above. The task required the subjects to reach at least 2/3 ($\approx 66\%$) of their maximum AL and maintain it for 5 seconds in the shortest possible time. The 5 second period was used to minimize the effect of noise and to ensure that the AL level was maintained consciously.

In the haptic feedback mode, the subject's goal was to keep at least 2/3 (6 out of 9) motors off for 5 seconds. While in the visual feedback mode, the subject's goal was to keep at least 2/3 (6 out of 9) LEDs switched-off for 5 seconds. In the combined visual-and-haptic mode, the subject's goal was to do both simultaneously. Since the LEDs and motors behave in exactly the same manner, the subject had the freedom to consider either (or both) of the feedback modes. The task was repeated three times for each NF mode (9 times in total, in a random order). AL and CT (excluding the 5-seconds period where subjects maintained their AL above 2/3 of their max. AL) were measured during each trial for all subjects. There

TABLE I

THE RESULTS OF THE SUBJECTS' (S1–S15) PERFORMANCE FOR STUDY-I (BRAIN TRAINING WITHOUT THE SECONDARY TASK) AND STUDY-II (BRAIN TRAINING WITH THE SECONDARY TASK) IN TERMS OF AL AND CT FOR THE THREE FEEDBACK MODES: (a) VISUAL-ONLY, (b) HAPTICS-ONLY, AND (c) VISUAL-AND-HAPTICS. THE RESULTS FOR VIBRATION LOCATION DISCRIMINATION (VLD) AND VIBRATION INTENSITY DISCRIMINATION (VID) OBTAINED FROM THE PRELIMINARY TEST ARE ALSO PRESENTED.

	Study-I						Study-II						Preliminary Test	
	Mean AL			Mean CT			Mean AL			Mean CT			VLD	VID
Feedback mode	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)		
S1	78.1	80.2	87.5	22.3	19.3	15.7	65.7	80.7	80.3	12.0	10.3	10.3	20	19
S2	77.1	75.2	79.2	19.0	19.0	16.0	71.3	85.0	82.0	14.0	12.7	11.0	17	18
S3	73.0	71.2	77.7	22.0	23.0	17.7	71.3	74.7	75.0	15.0	8.3	9.3	18	20
S4	65.4	69.8	72.3	28.7	26.3	22.7	56.0	68.0	73.7	12.0	10.3	11.3	20	19
S5	71.0	73.4	71.0	24.7	22.7	22.3	74.7	79.3	80.0	11.0	8.7	10.0	19	20
S6	75.3	73.4	78.9	18.3	17.3	17.0	78.0	86.3	86.7	13.0	11.7	13.3	19	17
S7	69.6	69.3	72.5	25.0	25.0	22.0	64.0	64.0	69.3	11.0	9.0	10.7	20	20
S8	81.5	71.3	79.9	22.3	23.3	20.0	73.0	72.9	75.3	9.3	8.3	8.9	19	19
S9	69.0	69.0	58.5	26.5	28.2	35.4	56.9	56.3	56.1	13.5	11.0	11.3	19	18
S10	72.5	70.0	68.9	21.3	22.1	24.2	68.5	71.2	70.3	10.9	9.0	8.9	20	17
S11	73.3	74.2	73.4	25.3	24.8	25.0	68.3	77.6	73.5	12.0	8.9	9.9	20	19
S12	49.9	62.3	59.8	34.6	30.3	32.1	41.2	61.3	46.5	11.2	9.1	9.2	19	19
S13	67.5	70.1	69.8	30.3	29.1	29.7	56.7	66.6	66.6	11.3	10.2	10.2	18	17
S14	75.8	75.7	76.0	24.8	24.7	23.9	70.8	73.6	73.2	11.8	10.1	10.0	19	19
S15	77.1	77.1	76.9	26.7	25.9	26.9	68.9	73.2	72.9	9.4	9.4	9.3	20	17
Mean	**71.7**	**72.1**	**73.5**	**24.8**	**24.1**	**23.4**	**65.7**	**72.7**	**72.1**	**11.8**	**9.8**	**10.2**	**19.1**	**18.5**
SD	7.43	4.22	7.51	4.27	3.71	5.84	9.46	8.49	10.06	1.56	1.26	1.16	0.91	1.12

was a 10-second pause between each repetition (trial).

C. *Study*-II

In this study, subjects' performance was evaluated while performing a secondary task (playing a shape-sorting game) in addition to the brain-training task used in Study-I. The secondary task was introduced to investigate the subjects' performance while receiving the NF in the three NF modes and simultaneously engaged in their routine life activities, such as doing household chores and commuting.

1) Setup: The experimental setup and procedure were identical to Study-I , except that the subjects played the shape-sorting game (the secondary task). They inserted four randomly-arranged shapes into the proper holes on a box (Fig. 5). The box and monitor were located such that they were both in the subject's field of view at the same time.

2) Method: The subjects were instructed to keep their AL as high as possible, by receiving one of the NF modes at a time, while playing the shape-sorting game. The task completed once the subject finished the secondary task. Similar to Study-I , this task was repeated three times for each feedback mode (9 times in total) in a random order.

At the end of Study-I and II , the subjects were asked to rate the comfort and ease of discriminating vibration levels and locations on a scale of 0-10: 0 meaning 'completely uncomfortable/very difficult' and 10 meaning 'completely comfortable/very easy'. They were also asked to rate whether visual or haptic NF was *more engaging* in their experience.

IV. RESULTS & DISCUSSION

Results of the preliminary test (Tab. I) showed that subjects could effectively discriminate both vibration location (average 19.1 out of 20; 95.5%) and intensity (average 18.5 out of 20; 92.5%).

The average CT and AL for all 15 subjects in Study-I and II are plotted in Fig. 6. The data of each individual subject is given in Tab. I. As indicated by the plot, in Study-I , the average AL and CT were nearly identical for the three NF modes, with only slight improvements for modes involving haptics. As there were more than two groups, we used one-way repeated measures ANOVA with Bonferroni post hoc to test for significance. For both AT and CT, no significant difference was found between the different modes in Study-I . This indicates that haptics can be a worthwhile alternative to the visual NF. While the subjects' performance was similar in general, there were subjects that exhibited better AL for a particular NF mode (*e.g.*, S8 with visual, and S12 with haptics). This indicates the need to deliver a customized NF (visual, haptics, or both) in clinical applications.

The results of Study-II (with a secondary task) showed a significant AL improvement, on average, for modes with haptics: 10.6% and 9.7% improvement for modes (b) and (c), respectively, when compared to visual-only mode (a). Also, modes with haptics (b & c) showed improved CT for all the subjects by 17% and 13.5%, respectively. These improvements were expected as the secondary task would cause distraction and partial occupancy of the subjects' visual channel, making it more difficult for them to finish the task quickly while simultaneously holding a high AL.

The ANOVA test for AL and CT for modes (a) and (b), as well as (a) and (c), showed a significant difference (p-values <0.05, Fig. 6), meaning that haptics successfully improved subjects' performance (AL and CT) while they were performing a secondary task. No significant difference was observed between modes (b) and (c), indicating that the subjects used haptic NF more than visual when presented together in mode (c) due to the mentioned occupancy of the visual channel. Considering the performances of S8 and S9, we can see a higher AL for mode (a) is achieved at the cost of higher (worse) CT. This shows the superiority and necessity of the haptic mode for NF delivery when users are engaged in other activities such as simple chores or commutes. In Study-I the subjects performed better with visual-and-haptic NF (mode (c)) compared to haptics-only (mode (b)) (improved AL and CT by 1.9% and 3%, respectively). However, haptics-only NF was slightly better in Study-II (AL and CT improved by 0.9% and 3.9%, respectively). This indicates the vulnerability of the visual channel to external distractions.

Duration of the preliminary test (2–3 minutes) was relatively shorter compared to the main user study ($\approx$ 15 minutes). In addition, a two-minute break was provided to diminish any negative effects (*e.g.,* sensory deterioration) of the preliminary test on the users' performance. It is important to note that the results showed no meaningful difference between the performance of subjects who received visual-only mode after the preliminary test, and the others who started the user study by receiving modes involving haptic feedback.

The questionnaire results showed that the subjects rated the vibration feedback as 'relatively comfortable' with an average score of 7.3/10 (SD = 1.54). Also, it was 'relatively easy' (7.0/10; SD = 1.58) for them to discriminate different vibration locations and intensity levels. 11/15 subjects rated haptics as *more engaging* than visual NF, which signifies the potential of haptics in making NF therapies less boring and, in turn, leading to increased adherence rate. After establishing the effectiveness of haptic NF, we will investigate the effects of different haptic stimuli on the subjects' EEG during brain training procedures, which has been previously done (*e.g.*, [26]) for applications other than NF.

V. Conclusion

This paper proposed haptics as an alternative means to provide neurofeedback (NF) in brain-training applications and help overcome some of the critical limitations, such as fatigue, boredom, and restricted mobility, faced by the current method of administering NF through the users' visual channel. We investigated the effectiveness of haptic vs. visual NF by conducting two user studies. A custom-designed NF delivery system including a novel wearable haptic device was developed. The system provided NF in three different modes: (a) visual-only, (b) haptics-only, and (c) visual-and-haptics together. The experimental results showed that the subjects' performance in a brain training task was comparable for the three NF modes. However, when a secondary task was involved, modes with haptics clearly outperformed the visual-only NF. This indicates the potential of the haptic NF to complement (or even replace) the commonly-used visual channel in brain training therapies. In the future, we will conduct user experiments involving ADHD-patients to verify these potentially important findings.

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