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平成29年度　生体医歯工学共同研究実施報告書

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生体医歯工学共同研究拠点　研究所長会議　議長　殿

共同研究代表者
所属機関 University of Ontario Institute of Technology (UOIT)
職　　名 Associate Professor
氏　　名 Bill Kapralos　　　　　印
勤務先所在地 〒L1H 7K4
2000 Simcoe Street North, Oshawa,
Ontario L1H 7K4, Canada
電話番号 +1-905-721-8668 x2882
FAX番号 +1-905-721-3167
E-mailアドレス : Bill.Kapralos@uoit.ca

下記により、共同研究の実施報告を致します。

記

研究題目	（和） （英）Examining the effect of sound on haptic fidelity perception in virtual environments
研究領域	1. 生体材料に関する基礎・応用研究 2. 生体工学に関する基礎・応用研究 3. 生体機能分子に関する基礎・応用研究 [✓ 4.] 化学・電気・機械・材料工学の生体応用研究
研究期間	平成 29 年 4 月 17 日 ～ 平成 30 年 3 月 31 日

研究組織

氏　名	所属機関・部局等	職　名	役割分担
Bill Kapralos	Faculty of Business and Information Technology, University of Ontario Institute of Technology, Canada	Associate Professor	Leader
Michael Jenkin	Department of Electrical Engineering and Computer Science, Lassonde School of Engineering, York University, Canada	Professor	Participant
Robert Allison	Department of Electrical Engineering and Computer Science, Lassonde School of Engineering, York University, Canada	Associate Professor	Participant
Julita Vassileva	Computer Science Department, University of Saskatchewan, Canada	Professor	Participant
Hirokazu Taki	Faculty of Systems Engineering,	Professor	Participant

	Wakayama University, Japan		
Hidetoshi Nonaka	Graduate School of Information Science and Technology, Hokkaido University, Japan	Professor	Participant
Karen Collins	Canadian Centre of Arts and Technology at the University of Waterloo, Canada	Associate Professor	Participant
Adam Dubrowski	Divisions of Emergency Medicine and Pediatrics, Faculty of Medicine, Memorial University, Canada	Associate Professor	Participant
Noriyuki Matsuda	Faculty of Systems Engineering, Wakayama University, Japan	Associate Professor	Participant
Magdalina Todorova	Department of Computer Science, Faculty of Mathematics and Informatics, Sofia University, Bulgaria	Associate Professor	Participant
Michael Vynnycky	Division of Metals Casting, Department of Material Science Engineering, Royal Institute of Technology, Sweden	Head of Division	Participant
Patrick Hung	Faculty of Business and Information Technology, University of Ontario Institute of Technology, Canada	Associate Professor	Participant
Miguel Vargas Martin	Faculty of Business and Information Technology, University of Ontario Institute of Technology, Canada	Associate Professor	Participant
Andrew Hogue	Faculty of Business and Information Technology, University of Ontario Institute of Technology, Canada	Associate Professor	Participant
Sanshiro Sakai	Faculty of Informatics, Shizuoka University, Japan	Professor	Participant
Hiroshi Inokawa	Research Institute of Electronics, Shizuoka University, Japan	Professor	Participant
Kamen Kanev	Faculty of Informatics, Shizuoka University, Japan	Professor	Participant
Alvaro Joffre Uribe	Multimedia and Industrial Engineering, Nueva Garanada Mil. University	Assistant Professor	Participant
Robert Shewaga	Faculty of Business and Information Technology, University of Ontario Institute of Technology, Canada	Graduate Student	Participant
Robert Codd-Downey	Department of Electrical Engineering and Computer Science, Lassonde School of Engineering, York University, Canada	Graduate Student	Participant

生体医歯工学共同研究拠点内対応教員	（共同研究をした教員名を記載） Hiroshi Inokawa, Professor Research Institute of Electronics, Shizuoka University, Japan

研究成果

Introduction

The simulation of the sense of touch falls under the field of haptics which collectively refers to machine touch and human-machine touch interactions and includes all aspects of information acquisition and object manipulation through touch by humans, machines, or a combination of the two within real, virtual, or teleoperated scenarios [1]. Haptic feedback plays an important role in our daily interactions [2]. The sense of touch allows us to interact with objects, and in conjunction with other senses (e.g., sight and hearing), the sense of touch provides multimodal feedback to better accomplish a variety of tasks [3]. Since the birth of virtual reality [4], research has focused on stimulating the senses and increasing our interactions with computer-generated worlds, through the use of a variety of input/output technologies including head mounted displays [5], 3D sound [6], smell sprays [7], and electro-mechanical devices to provide haptic feedback [8]. However, early virtual reality (VR) input/output devices were bulky and cost-prohibitive thus limiting their use and application to research institutions and industry [3]. In the real world, senses interact with one another and alter each other's processing and ultimately perception. Our prior work that has examined the effect of sound on visual fidelity perception has shown a strong influence of sound on the visual scene (e.g., see [2]). However, very little prior work has considered multi-modal interactions with the other senses, particularly the sense of touch. Here, we build upon our prior work by considering the effect of sound on haptic fidelity perception. More specifically, what effect does sound have on the perception of touch, and more importantly, can sound lead to an increase in the perception of haptic (touch) fidelity in a virtual environment? Our goal is to determine whether sound can be used to increase the perception of haptic fidelity inherent in low-end consumer-level haptic devices to allow the use of such devices (coupled with the appropriate auditory cues) in applications that require higher fidelity at a fraction of the associated cost.

Within the scope of this Collaborative Research Project, we have conducted an experiment that has examined the effect of sound on haptic fidelity perception within the context of a virtual drilling task (virtual drilling through a block of wood). This scenario was selected as haptic feedback plays an important role during drilling, providing the user with information regarding the drilling process (e.g., how far the drill bit has traveled, whether the drill bit is moving through the material or is stuck, and whether something is wrong with the device or the drill bit). Furthermore, drilling is a fundamental component of various medical procedures including dental bone surgery [9], endoscopic endonasal drilling [10], dental implant surgery [11], orthopedic surgery (e.g., temporal bone surgery, knee replacement and to create a hole for screw insertion to fix bone fractures) [14] [12], and needle insertion [13] amongst many others. Although preliminary, our results do indicate that sound can influence haptic fidelity perception albeit, greater work remains.

Experimental Procedure

Overview: The Unity3D game engine was used to develop the virtual drilling scenario (graphical user interface and the virtual environment). Haptic feedback was generated with the Novint Falcon, a consumer level, a low-fidelity haptic device that provides three degrees-of-freedom (3DOF) and force feedback over the three coordinate axes upon contact with virtual objects. The device's actuators allow touch feedback and it can be programmed relative to the configured mechanical properties of the virtual object. The Novint Falcon has a workspace of 10.6 cm^3 with a maximum force of 8.9 N, a resolution of 400 dpi, and an approximate cost of $250 USD. A graphical overview of the virtual drilling scenario architecture is provided in Fig. 1.

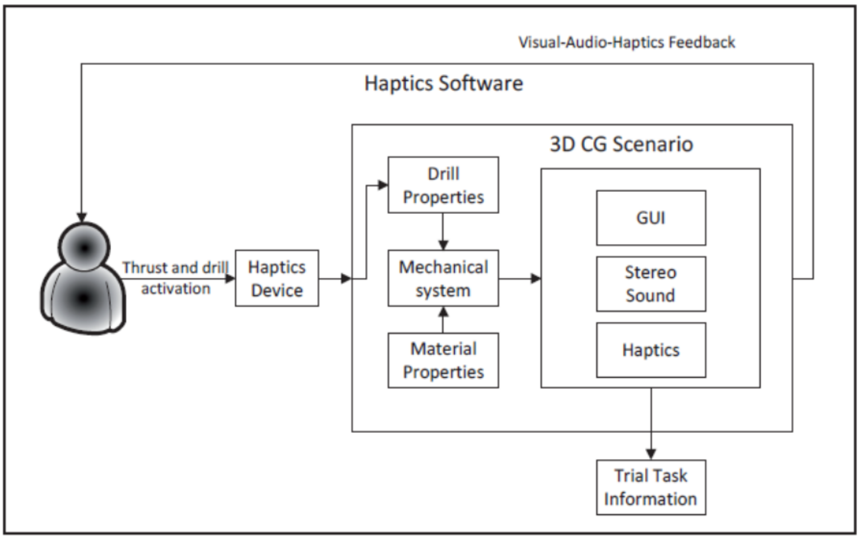

Fig. 1. Virtual drilling scenario system architecture.

The system is defined with respect to the drilling procedure and the interactions required to accomplish it. With respect to the drilling procedure, we identify the following parameters required by the system: i) drill speed, ii) type of drill bit, iii) drilling sounds, and iv) material (wood) mechanical properties. The system receives the user's input in the form of thrust movements towards/away from the (virtual) material being drilled and activation/deactivation of the (virtual) drill. The movement and button pressing status are sent to the haptic software which will respond accordingly based on the mechanical system (e.g., drill and material properties). A graphical user interface (GUI) provides visual feedback that includes visuals, sound, and haptics providing the user with cues regarding the drilling process and when the drilling task has been completed. Additionally, information (e.g., drilling depth, and user movements) regarding the drilling process is collected and stored.

The auditory stimuli consisted of five auditory sound condition that were either non-contextual (i.e., not related to the task) or contextual (i.e., related to the task). The four non-contextual conditions consisted of: i) no sound at all, ii) white noise, iii) classical music ("Sarabande" by Bach), and iv) heavy metal music ("Holy Wars" by Megadeth). The one contextual auditory condition consisted of i) drill sound while drilling through wood. The drilling sound comprised a recording of a drill drilling through wood. The recording was made in an Eckel audiometric room to limit any external noise (air condition "hums", etc.) and reverberation of the generated sounds within the environment, at a sampling rate of 44.1 kHz. The white noise sound was sampled at a rate of 44.1 kHz and band-pass filtered using a 256-point Hamming windowed finite impulse response (FIR) filter with low and high-frequency cut-off frequencies of 200 Hz and 10 kHz respectively. All auditory stimuli were presented to the participants with a pair of headphones.

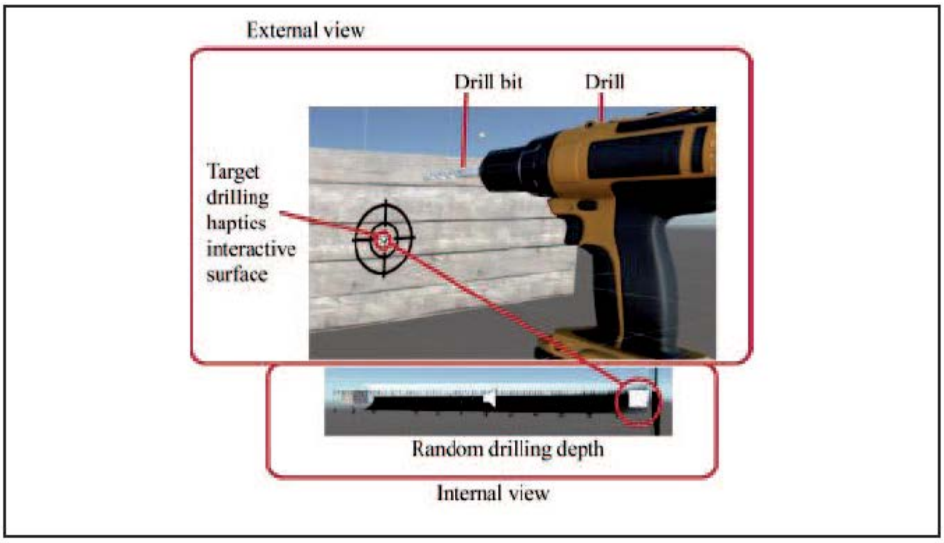

Fig. 2. Drilling scenario.

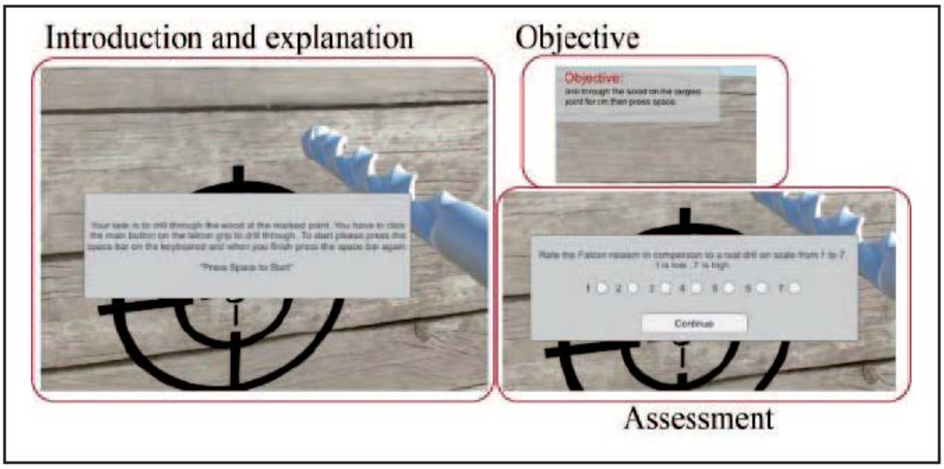

Fig. 3. Graphical user interface.

The virtual drilling scenario was comprised of various trials that required the participants to (virtually) drill through a piece of wood. Participants manipulated the Novint Falcon using its gripper and main button to drill. They were also provided with a visual target indicating the drilling point (Fig. 2). Once the task was completed, participants were presented with a dialogue box that asked them to rate the haptic fidelity (Fig 3). Each trial was repeated four times for a total of 20 trials whose order was randomized. The experiment took approximately 15 minutes to complete. Prior to starting the experiment participants were provided with a description of the experiment and asked to complete a brief demographic questionnaire that asked them their age range, gender, prior drilling experience, and whether they had any issues with their hearing). Finally, upon completion of all trials, participants were asked to rate the following two questions on a Likert scale ranging from 1 (not at all) to 7 (very much): i) whether they believed that sound influenced their perception of haptic fidelity, and ii) whether the sound played during the drilling process was important to them in completing the drilling task.

Results

Data collected from each participant included the haptic fidelity rating. As previously described, each trial was repeated four times; the average of these four repetitions was then analyzed. A summary of the results for haptic fidelity perception across each of the five auditory conditions is provided in Fig. 4. As shown, the responses varied only slightly. The maximum rating (5.6) corresponds to the “Drill Sound” (contextual) auditory condition whereby the sound corresponded to the task at hand. This of course is not surprising and is in-line with prior work that considered the effect of sound on visual fidelity perception and saw higher visual fidelity perception ratings when the sound corresponded (was contextual) to the visual scene (see [2]). The minimum (4.7) rating corresponds to the “Classic Music” auditory condition albeit the difference between the “Classic Music” auditory condition and the “Metal Music” (4.8), “No Sound” (4.9) and “White Noise” (4.9) conditions are negligible. It should also be noted that the differences are not statistically significant. Fig. 5 illustrates several examples of participants virtually drilling through wood during their participation in the experiment. Finally, responses to the two “exit questions” were as follows. With respect to the question asking whether sound influenced their perception of haptic fidelity, six (54.5%) chose “7”, three (27.3%) chose “6” and one (9.1%) chose “5” and “4”.

With respect to the question asking whether they believed that the sound played during the drilling process was important three (27.3%) chose “7”, five (45.5%) chose “6”, two (18.2%) chose “5”, and one (9.1%) chose “4”. Overall, the majority of the participants believe that sound is an important part of the drilling process and that it can influence their haptic fidelity. Additionally, participants expressed feeling different haptic feedback across the five audio scenarios, which can be seen from Fig. 4 box plot.

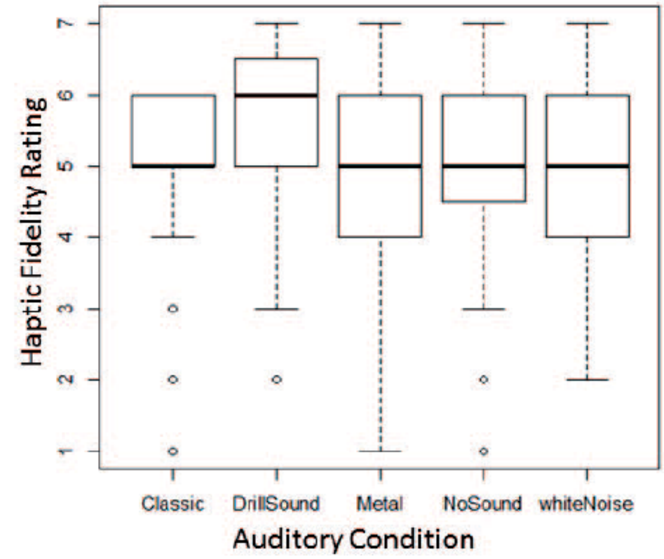

Fig. 4. Results. Haptic fidelity perception rating vs. auditory condition.

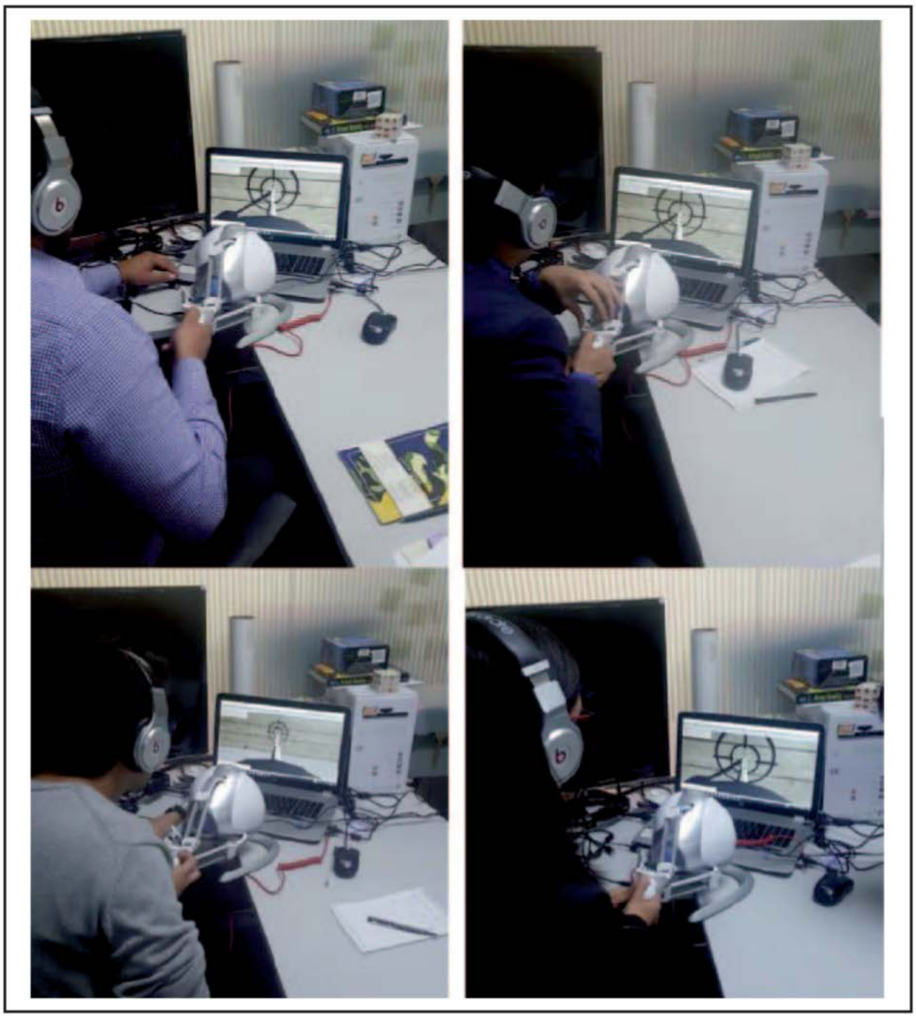

Fig. 5. Sample participants taking part in the experiment..

Conclusions

We have conducted an experiment that was motivated by prior work that saw a strong influence of sound on visual fidelity perception and the potential to, through the appropriate use of sound, allow lower-end (and less expensive) haptic devices to be used in place of higher fidelity yet cost prohibitive haptic devices. Although the results are preliminary and greater work remains, the results presented here do indicate that sound can potentially influence haptic fidelity perception and more specifically, a contextual sound that matches/corresponds to the task being performed should be included. Furthermore, participants generally strongly believed that sound is an important part of the drilling process and that it can influence haptic fidelity perception; all participants felt different haptic feedback while the mechanical model remained the same for the duration of the experiment. In addition, the experiment presented here has provided tremendous insight regarding the difficulties and potential problems to be encountered when conducting multimodal experiments that include haptic devices. There are many factors that must be considered including the measurement and modeling of the physical forces involved (here drilling through wood), and the potential issues associated with haptic devices, particularly lower-end devices (e.g., the potential need to re-calibrate the device during experimentation).

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Meetings/Presentations

1. Research Advancements in HCI: Environments and Perception (M.Jenkin, 2018.02.21, RIE 204)
2. Research Advancements in Fidelity Enhanced Virtual Environments (A.Quevedo, 2018.02.23, RIE 201)

使用した設備・資料・試料等	The work was carried out at multiple partner institutions. The development of the virtual drilling framework primarily took place at UOIT within Dr. Bill Kapralos’ Games and Media Entertainment Research Lab (GAMER Lab), a state-of-the-art, interdisciplinary research laboratory where faculty, visiting professors, and students (graduate and undergraduate alike) conduct research related to serious games, human factors, simulation, games for fitness and health, applied game design, augmented reality, stereo-vision gaming, and affective computing. The GAMER Lab is equipped with a variety of state-of-the-art equipment including stereoscopic displays, physiological monitoring equipment, tabletop computer, high-fidelity audio equipment, various input devices (including a haptic device), amongst others. The hardware and software required to complete the development of the auscultation app accessible within the GAMER Lab was made available to the project members and used to support this project. Once the virtual drilling framework has been developed, we have incorporated the haptic device (Novint Falcon). This was completed in the laboratory of Dr. Bill Kapralos who already had a Novint Falcon haptic device. The experiments that will examine the effect of sound on haptic fidelity perception were conducted in Dr. Kapralos’ GAMER Lab. However, by replicating the hardware at multiple institutions, it will allow, if needed, continuing experiments to be conducted at the Research Institute of Electronics and in Dr. Jenkin’s lab, too.

本研究成果に関連する論文発表状況

1. B. Kapralos, A. Uribe-Quevedo, and A. Dubrowski. Immersive technologies for medical education. In N. Lee (Ed.) Encyclopedia of Computer Graphics and Games, Springer International Publishing (to appear).
2. B. Kapralos, F. Moussa, K. Collins, and A. Dubrowski. Levels of fidelity and multimodal interactions. In P. Wouters and H. van Oostendorp (Eds.) Techniques to Improve the Effectiveness of Serious Games, Springer Advances in Game-based Learning Book Series, Ch. 5, pp. 79-101, 2017.
3. M. Melaisi, M. Nguyen, A. Uribe-Quevedo, and B. Kapralos. The effect of sound on haptic fidelity perception. In Proceedings of the IEEE Global Engineering Education Conference (EDUCON) 2017, April 25-28, 2017, Athens, Greece, pp. 709-712.

次年度の共同研究継続の有無	[✓ 有] ・ 無	拠点内対応教員とご相談の上ご記入ください。 継続の場合には次年度の研究計画をご記入願います。

次年度の研究計画（継続の場合）

In an effort to develop a greater understanding of the effect of sound on haptic fidelity perception, we will expand upon our prior work that examined the effect of sound on haptic fidelity perception with the addition of electroencephalogram (EEG) monitoring with the aim of correlating brain signals to haptic-sound interactions. More specifically, we will repeat the experiment described here whereby participants will drill through a block of wood (to two drilling depths, 3 cm, and 6 cm), in the presence of contextual sounds (those associated with the drilling process itself), and non-contextual sounds (those not associated with the drilling process). The contextual sounds will consist of: i) drilling in the air, and ii) drilling through wood. The non-contextual sounds will consist of i) classical music, ii) heavy metal music, iii) white noise, and iv) silence (no sound). Interactions will be limited to drilling through the block of wood to a pre-defined depth with the drill bit positioned at the appropriate starting position (e.g., no need to move and position the drill to the appropriate starting position). This will ensure participants focus solely on the drilling depth and thus limiting any potential confusion and/or frustration associated with aiming and moving the drill such that it aligned with the correct drilling position.

We will use the Emotiv Epoc EEG wireless neuroheadset as it is an affordable BCI that allows capturing brain data from 14 channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF42). Wireless EEG technology is a viable alternative for measuring subjectivity in evaluation scenarios. The Emotiv data acquisition frequency occurs within a 1-100 Hz threshold. There are five bands of normal EEG frequencies, and more specifically: i) delta, associated to deep sleep, dreamless state, immune system functions, and collective consciousness, ii) theta, associated with light sleep, meditation memory, vivid imagery), iii) alpha, associated with relaxation with eyes closed, creativity, visualization, super learning, iv) beta, associated to normal working state of consciousness, focus, alertness, learning, concentration, five physical senses, and v) gamma, associated to hyper-learning activity. The activity meaning associated with each sensor placement is presented as follows: AF3 - attention, AF4 - judgment, F7 - verbal expression, F8 - emotional expressions, F3 – motor planning, F4 - motor planning for left upper body, FC5 - right body controller, FC6 - left body controller, T7 - Verbal memory, T6 - emotional memory, P7 – verbal understanding, P8 - Emotional understanding and motivation, and finally O1 and O2 - visual processing. The Emotiv Epoc wireless feature allows the user to conduct activities without the discomfort and limitations of wired systems that could affect its mobility and natural movements. To process the Emotiv data, the Emotiv Testbench will be used in conjunction with the fast Fourier transform implemented in Matlab and the Matlab EEG Toolbox.

To better understand the participant’s perception of haptic fidelity, we analyzed the BCI data during the three stages (before, during, and after drilling). For each trial, we will analyze the BCI signals in the frequency domain for each of the 14 channels. We will then filter all the data using a band-pass filter and perform an Interdependent Component Analysis on the filtered data (to eliminate the segments of the signals that correspond to blinking and involuntary muscular movements) and then determine if there is a relation between the signals and the fidelity rating.