WONDER - Enhancing VR Training With Electrical Muscle Stimulation

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ABSTRACT

Training employees on workplace procedures in virtual environments (VEs) is becoming popular since it reduces cost and risks. Although haptic enhancements with force feedback make such VEs more realistic and increase performance. Such enhancements are only available for 'spatial' scenarios. One potential enhancement for low-cost VEs is electrical muscle stimulation (EMS), but it remains open how EMS can be used to support trainees. Therefore we present WONDER: A virtual training environment with an EMS feedback enhancing layer. In an initial study, we show the feasibility of the approach and that it can successfully support trainees in remembering workflows. We test feedback that supports participants by pushing their hand towards a button or pulling their hand away from it. Participants preferred a combination of both feedback types.

KEYWORDS

Electrical Muscle Stimulation (EMS), VE Training, Haptic Feedback, Kinesthetic/Force Feedback

CHI'19 Extended Abstracts, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5971-9/19/05.
https://doi.org/10.1145/3290607.3312780

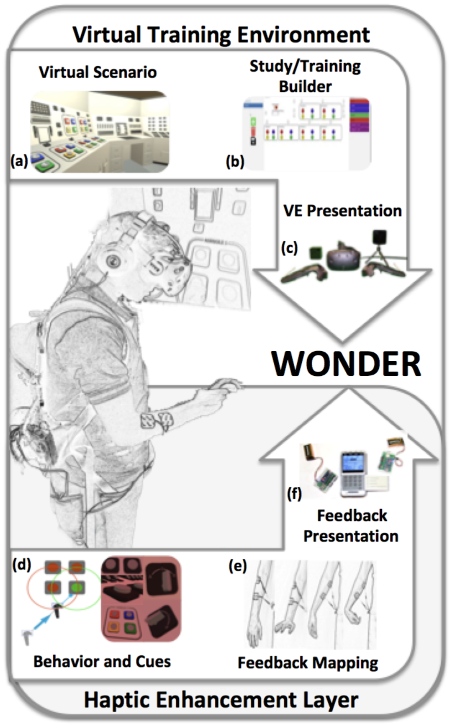

Figure 1: WONDER a virtual training environment that is enhanced with haptic feedback. It consists of six main components that belong to the virtual training environment (a-c) or to the haptic enhancement layer (d-f): The Virtual Scenario (a), the Study/Training Builder (b), the VE Presentation (c),Feedback Behavior and Cues (d), the Feedback Mapping (e), the Feedback Presentation (f).

[1]WONDER: https://github.com/hapticans/wonder

INTRODUCTION

Almost every workplace provides training to educate employees on proper procedures and practices. These trainings now often involve virtual environments (VEs) especially for working with sensitive or dangerous equipment. Training in VEs can help reduce both the risks and costs of training [7].

Training in VEs is an active research field across multiple disciplines, and much effort has focused on making training VEs as realistic as possible. For example, training processes could be improved by including haptic feedback in VEs [3, 10], but these approaches are used in "spatial" scenarios such as in flight simulators [3] or surgery training [10]. Most low-fidelity training VEs do provide high visual and tracking resolution but are still limited in providing force feedback.

Recently, electrical muscle stimulation (EMS) has become a popular way to simulate haptic feedback in VEs, to provide feedback for virtual tools, objects, or walls [4, 6] and to increases the performance of VR tasks [9]. Further, EMS feedback can also be used to identify hidden affordance [5] or to help locate targets [2]. However, it still remains open how EMS can be used as kinesthetic/force feedback in training VEs. In particular, how can EMS technology be used to give the trainee cues or hints that they are on the right track to solving a problem?

In our work, we first investigate how EMS-based haptic feedback can influences the learning process in VE training. As such, we developed WONDER: An approach and it's prototypical implementation [1] of a virtual training scenario that is enhanced with EMS as haptic feedback. Our approach provides the *virtual training environment* and *haptic feedback enhancement* layer (Figure 1). In the training environment, the scenarios and training the sequences are defined and presented to users e.g. through head-mounted displays (HMDs). The haptic feedback enhancement defines the feedback behavior depending on the environment (such as the feedback for controls), how the users muscles are used to generate the force feedback and how the feedback is applied to the user. In an initial user study we evaluated our approach and the use of EMS in a concrete training scenario. We investigated whether EMS feedback can present simple cues that can affect learning of interaction sequences on a control panel. The contribution of this work is a) an approach to provide and study haptic feedback for VE training using EMS, b) an open source prototype of a training environment for control panels and c) an initial investigation of learning with EMS feedback in a concrete scenario.

CONCEPT

To study the use of haptic feedback in training scenarios we developed WONDER. WONDER aims to wrap and enhance such VE training by providing a layer that allows haptic (feedback) enhancement (Figure 1). In addition, WONDER allows researcher to design and to create scenarios and interaction sequences to test the feedback. It consists of six main components that belong to the virtual training environment (a-c) or to the haptic enhancement layer (d-f) (see Figure 1).

The *Virtual Scenario* (a) describes the context of the training, including the modeled environment, the controls and scenario behavior [1]. For example, the scenario could be a virtual cockpit containing controls and requiring defined behaviors. The *Study/Training Builder* (b) defines sequences of interactions the learner needs to proceed. For example, it could describe a sequence of buttons and switches a worker needs to activate to follow a work procedure. *VE Presentation* (c) includes the technology used to present the scenario and run the study; this could be the HMDs, tracking system, controllers and PC. Also, it contains the technical implementation and the logging of data such as the implementation of 3D model representing the scenario in Unity [2]. The *Feedback Behavior and Cues* (d) describe how parts of the virtual training environment are enhanced by haptic feedback. Thus, it describes how the feedback expands the visualization, e.g. of buttons or sliders, and if the object itself has resistance, such as a minimum force that is needed to push a button down ([6]). Additionally, it describes cues and hints to support the learner during the training procedures. Such support could be a hint towards the next instruction if the user is still on the right track, but it could also indicate if the learner's decision has a large impact on the scenario, such as opening a valve that releases contaminated water. The *Feedback Mapping* (e) describes how the user's body should respond in a particular situation. For example, if a button should 'attract' or encourage a user to press it, the user's body will be kindly pushed towards the button. In a more complex scenario, learner would need to produce additional force to make a decision (eg, move a lever) that has a large impact on the system. Moreover, technology specific aspects for feedback are also defined, for example electrode placements and the EMS parameters of each movement. The *Feedback Presentation* (f) describes the hardware and infrastructure needed to apply the feedback to the user. Moreover, the *Feedback Presentation* also defines the required software e.g. to calibrate users' movements and to play the movements back in the scenario.

[2]Unity 3D: https://unity3d.com

IMPLEMENTATION

We implemented our approach to evaluate the feasibility and to run user studies to get insights into how EMS could be used in learning scenarios. Our main goal was to understand how users can receive haptic cues before making a decision in a workflow. The cue should communicate whether the step the user is assumed to perform next will be right or wrong.

As the *virtual scenario* we define a control panel inspired by a nuclear power station from the 60s, but we generalized the controls so they could be used for any other control panel (Figure 2). We implemented six sub-panels (numbered) with four colored buttons (red, blue, yellow and green). The buttons had a base size of 11.4 x 11.4 cm and a cylindrical interactive (7cm diameter) area. Additionally, to add visual and auditory distractions we included a flashing noisy emergency alarm. We also developed a *Study/Training Builder* to configure different combinations of buttons on different areas of the control panel and sequences of different lengths. For the *VE Presentation* we implemented the

Figure 2: Virtual training console: Scenario of control panel inspired by a nuclear power station from the 60s.

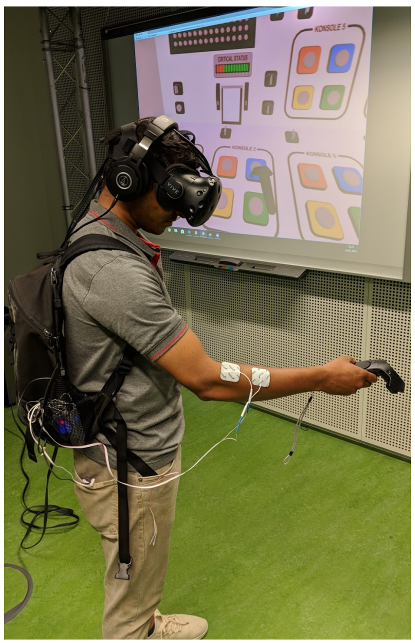

Figure 3: A user is running a training set while receiving haptic cues through EMS.

scenario in Unity 3D and SteamVR using an HTC Vive. In addition, we tracked the user's hand with the HTC Vive controller to measure when to apply the feedback.

Our feedback enhancing layer was designed as follows. With the *Feedback Behavior and Cues*, we were manly focused on buttons that need to be pressed down to activate. The haptic (feedback) cues should communicate to the user in advance if the next button will be correct or incorrect. We implemented a simple movement prediction function based on the speed angle of the user's hand movement. If the hand is predicted to be closer than 20cm to a wrong button, while not being close to a correct button, feedback is triggered. Between 20cm and 10cm away the feedback intensity increases in 5 steps from 60% to 100% of the calibrated intensity. Distances smaller than 10cm trigger 100% feedback. We implemented two types of feedback cues i) *preventing* and ii) *encouraging*. The preventing feedback (pull-feedback) should protect the user from pressing the wrong button, and the encouraging feedback (push-feedback) should push the user toward a correct button. For the *Feedback Design* we used electrical muscle stimulation to generate force feedback. Based on [8] we chose the *extensor digitorum* muscle to lift the hand to prevent the user from pushing the button and the *flexor digitorum profundus* muscle to push the hand towards the button. Such as, we calibrated the feedback for each user individually. The feedback was calibrated in a way that actuation can be seen visually, but it is still small enough to prevent the user's muscles from cramping. For the *EMS Presentation* we used the "Let Your Body Move" Toolkit [8] with an STIM-PRO x9+ to generate the EMS pulse. The feedback for the movements in the virtual environment was implemented in a Unity Script and sent to the toolkit. Our implementation makes it easy to define and test training sequences in VEs with a set of controls and cues that prevent the user from making a wrong decisions and can push the user toward the right decision (Figure 3).

INITIAL USER STUDY

To evaluate haptic cues through EMS in training scenarios we set up an initial with-in subject lab study with 8 participants (18-28 years, 2 of then where females). As conditions, we had two independent variables (feedback condition x sequences). All our participants were right handed, one had previous experience with VE, and one had experienced EMS before. We designed four feedback conditions: (1) no 'haptic' feedback, (2) preventing feedback for incorrect buttons, (3) encouraging feedback for correct buttons, and (4) both encouraging feedback and preventing feedback. As sequences, we used a random orders of buttons across all panels with lengths three, five and seven panel / button combinations. The order of the conditions was randomized. In total each user performed 12 tasks. Before each task the user had up to one minute to remember the sequence that was shown on 15" screen (e.g. Console 6 blue, Console 1 red, ect.). After the learning phase, the user was asked to perform / activate the buttons in the VE. Direct after each the sequence was entered in the VE the participant also had to write down the performed sequence on paper. The timing and the success of sequence

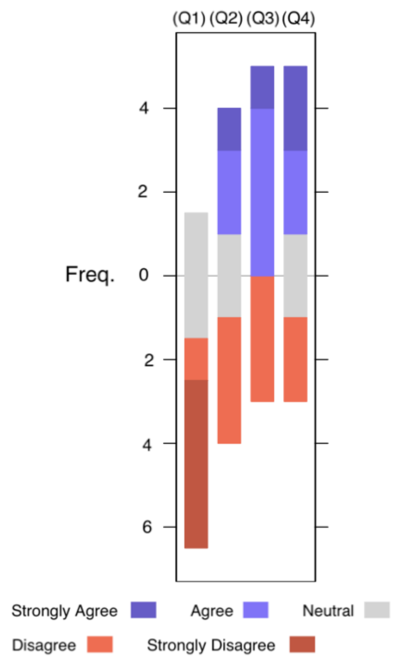

Figure 4: Results of the questionnaire: (Q1) Was the EMS uncomfortable? (Q2) Did the EMS-push supports you? (Q3) Did the EMS-pull supports you? And, (Q4) Did the EMS-push+pull supports you?

was logged. To simulate a stressful situation, we distract the participant's audio and visual channel by a red flashing alarm light in the VE scenario and hearing alarm noises through the headphones. After the participant completed all tasks, we asked them to fill in a questionnaire for demographic information and further insights into how the user felt about the provided cues. The experimental design was approved by our local ethics board.

Procedure: We recruited participants through social media. After welcoming participants, we informed them about the purpose of the study and asked them to sign a consent form. After calibrating the EMS (the stimulation intensity and the placement of the electrodes), we equipped them with the VE HMD, and gave as much time as they needed to get familiar with the VE scenario and the EMS feedback. When the participant indicated they were comfortable in the environment, they received the first sequence of buttons to remember and started the task. After all tasks were performed, the questionnaire was filled and the participant was debriefed.

RESULTS

The eight participants performed 96 tasks overall, seven tasks were not successful and overall 11 errors (wrong buttons pressed) were made. Regarding the three-button length sequences, all participants successfully repeated all button colors and subpanels sequences immediately after each session. For the five-buttons length sequences, one participant failed to successfully repeat the sequence in the condition with no additional haptic feedback. In the seven-buttons length sequences, five (out of eight) participants failed (in total 9 errors / wrong buttons) to successfully repeat the task in the condition with no additional haptic feedback, and one failed to repeat the task in the condition with encouraging haptic feedback. There were no learning effect between the feedback conditions.

In addition, we asked whether the EMS feedback was perceived as uncomfortable: all participants were neutral or disagreed (Figure 4 Q1). Participants felt that all EMS feedback methods supported them during the tasks (Figure 4 Q2-4). The combination of both feedback was ranked best. Non of the participants reported about motion sicknesses.

DISCUSSION

The quantitative results show that users made fewer errors when they used additional EMS feedback for longer sequences when they needed to repeat the sequences immediately after the training session. This indicates that participants do not simply just rely on the feedback without trying to remember the sequences and not just following the feedback. Regarding different haptic feedback conditions, there were only small differences between conditions, but participants preferred, the combination of encouraging and intervention feedback towards or away from a button was preferred.

ONGOING WORK

Our user study is a first step toward investigating EMS feedback in enhanced learning scenarios. The WONDER approach makes it easy to run studies in this field, and it allows operators the ability to adopt additional types of feedback methods such as vibration or other mechanical actors [4]. Also, it can help researchers explore how to use EMS feedback in training scenarios. We will looking into long term-learning effects and investigate if our findings are consistent after several training sets or after different time intervals. We will also investigate more complex scenarios with longer sequences, we will look into where the user needs to process knowledge, and explore the contexts of particular scenarios. Additionally, further input controllers such as sliders or dials will be included in our future implementations of WONDER for cases where the user needs to input discreet values or consider thresholds. Finally, we will investigate participants behaviour in critical situations when they might need to override and contradict the feedback. A possible research question could be: how much force is need to let them rest, rethink or repeal the decision in a particular work-flow?

CONCLUSION

Here we present WONDER, an approach for enhancing virtual training environments with haptic feedback through EMS. In an initial study, our findings indicate that EMS-based haptic cues support the trainee when performing work flows under noisy and stressfull conditions. Our approach can be easily adapted to future studies with different conditions and parameters set.

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