Integrating Methodology for Experimentation Using Commercial Off-the-Shelf Products for Haptic Cueing

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Abstract. Although haptic cueing is well researched, its effects on performance accuracy and workload are mixed (Hancock et al. 2013). As such, there is still a need to further develop our understanding of the effects of haptic cueing on performance and workload. The objective of this effort is to develop a cost-effective and non-invasive experimental methodology to investigate the effects of haptic cueing on unmanned aerial vehicle operator performance and workload utilizing commercial off-the-shelf products, specifically, Unity 3D™ - Game Engine and an Xbox 360™ controller.

Keywords: Haptic cueing · Performance · Workload · Usability

1 Introduction

For unmanned aerial vehicle (UAV) operators, searching displays for critical cues is an essential responsibility. As a result, research on a human's ability to visually search is well documented (Wolfe et al. 2005).

Research has shown that visual search can become progressively demanding when a large number of targets are present or in multitasking environments (Prewett et al. 2012). In addition, in environments where the number of targets is low but numerous distractors exist, humans are susceptible to a vigilance decrement (Hancock 2013; Warm 1984). As a result, research has shifted to investigate the effects of cueing to aid visual search, specifically haptic cueing, which are haptic signals that aid the attentional system in detecting signals.

Although haptic cueing is well researched, its effects on performance accuracy and workload are mixed (Hancock et al. 2013). Haptic cueing often results in improved response time but at a cost to accuracy. In addition, perceived workload ratings do not positively correlate with objective measures of workload (Mercado et al. 2014). As such, there is still a need to further develop our understanding of the effects of haptic cueing on performance and workload.

However, the cost of conducting research using haptic cueing aids is expensive. Haptic cueing devices such as a haptic belt or haptic car seat can cost thousands of dollars. In addition, many of the haptic cueing methods utilized in previous research are invasive. For example, Merlo et al. (2006) and Hancock et al. (2013) utilized a belt like

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device with eight vibrotactile actuators to provide participants with messages and haptic cueing, respectively. This belt like device was wrapped tightly around the participant's torso directly on their skin.

Van Erp and Van Veen (2004) utilized a vibrotactile display, consisting of eight vibrating factors that were mounted in a driver's seat to provide haptic cueing as part of a GPS system. Four factors were placed under each participant's thigh in a straight line from the front to the rear of the seat. In addition, Van Erp et al. (2007) utilized a 60-element tactile torso display to capture a pilot's attention in a hyper-gravity state. Similar to the belt-like device utilized by Hancock and colleagues, participants had the 60-element tactile torso display wrapped around their torso directly on their skin. Thus, there is a need to integrate a cost-effective and non-invasive experimental methodology to investigate the effects of haptic cueing on operator performance and workload.

This paper addresses the need for a cost-effective and non-invasive integration methodology for experimentation by utilizing commercial off-the-shelf (COTS) products, specifically, Unity 3D™ - Game Engine and an Xbox 360™ controller. It is important that this integration methodology be non-invasive because it may provide richer data. Specifically, a large portion of the potential participant pool (college students) is already familiar with using an Xbox 360 controller. Thus, they have experienced the Xbox 360 controller's haptic vibration. In addition, the participants will not have the factors connected to them. Thus, the factors will not distract the participants from their task. Familiarity and comfort are important for experimental methodology because an invasive apparatus can affect performance, workload, usability, and trust data (Hall 2001; Kendall 1983).

COTS systems are ubiquitous; however, utilizing COTS systems for research can be a difficult undertaking. The lack of source code availability can be a barrier when leveraging COTS systems for research. If researchers can overcome this barrier, COTS systems make for great research apparatus because of their large feature sets, ease of use, and cost-effectiveness (Hopkinson et al. 2003). Unity 3D is a low-cost, adaptable, cross-platform game engine aimed to create multiplatform 2D and 3D interactive experiences and games. This platform allows designers to build complete environments on personal computers, mobile devices, and websites (Creighton 2010). The Xbox 360 controller is a flexible device that users can connect to a computer via wire or wireless technology. This capability, along with its built-in vibrating motor, makes a great low-cost controller to pair with Unity 3D. Although this integration methodology for experimentation is generalizable to operators across many domains, we utilizing UAV operators as our framework. This allows us to be as detailed as possible in our integration methodology.

2 Integration Methodology for Experimentation

Research has been conducted to understand the benefits of haptic cueing in many settings, but investigating and measuring UAV operator performance and workload when they are provided with haptic cueing has been limited. Integrating a proper experimental methodology is essential to assess questions concerning how cost-effective and non-invasive haptic cueing influences an operator's performance and workload.

2.1 Equipment

The apparatus used to assemble the simulator include one laptop, one LCD monitor, and one Xbox 360 controller. These apparatus will be controlled by a purpose-created Unity 3D Game Engine that will synchronize the respective program and record response times and accuracy rates for each participant. The LCD monitor will be centered directly in front of the participant. All participants will be unaware of the cueing reliability, which will be set at 100 %, which is the optimal level for the mission. The middle of the LCD monitor will display an UAV traveling along a predetermined route. The top of the screen will display the UAV's speed. The left hand side of the screen will display the UAV's altitude, messages (similar to a chat room), and alerts (see Fig. 1).

Fig. 1. Display interface

Selection of the Xbox 360 Controller. The Xbox 360 controller was chosen as a cost-effective haptic cueing device because it provides great integration flexibility with existing cost-effective gaming engines, such as Unity 3D. The Xbox 360 contains two variable vibration motors at each end of the game controller that can be dually or individually activated for a given duration. The vibration in the motors can be adjusted for both frequency and intensity, which allows for multiple alert types during a task. The low cost, availability, and integration ease of these controls make the Xbox 360 controller an ideal haptic cueing device that can be easily deployable and tailored to various simulation platforms.

Integration of Xbox and Unity 3D. The simulator consisted of a windows laptop, an Xbox 360 controller, and gaming software called Unity 3D. The Xbox 360 controller is a legacy controller, which has been predominantly used by the gaming community along with the Xbox 360 game console. The online community support for both Unity 3D and the Xbox 360 controller is large, which allows developers a wide range of custom applications.

For this experiment, the Xbox 360 controller was integrated into the Unity 3D Game Engine using the XInputDotNet.dll, an open source C# wrapper around XInput. XInput served as a DirectX API that allowed the Xbox 360 controller to be used on the Windows computer. In order to execute the Xinput API, XInputDotNet.dll was included in the Unity 3D C# project so calls could be made to adjust each of the rumble packs in the controller. Cross communication between the Xbox 360 controller and Unity 3D was accomplished by mapping the controller inputs into Unity 3D to allow the user response through the Xbox 360 controller's joystick and buttons to be transferred to appropriate commands on the game scenario. Unity 3D Game Engine will collect the data and generate a CSV file for each participant, time stamping all of the Xbox controller inputs, along with when the participant received haptic cueing (for the haptic cueing scenario only).

2.2 Procedures

The experiment will be conducted in a controlled laboratory environment, free of competing noise or vibration. Before beginning any of the scenarios, the participant will be given a short briefing to explain their role in monitoring the UAV and sign the informed consent materials. The participant will be shown how to precisely increase/decrease altitude and airspeed and acknowledge messages from their commander and alerts. The participant will be informed to respond as quickly and accurately as possible. In addition, the participant will be informed as to the nature of each area of the display they have to monitor and how it relates to the overall mission. Lastly, the participant will be provided with a training scenario to become familiar with the mission and the haptic cueing of the Xbox 360 controller. The participant will not be made aware of any potential failures of the haptic cueing. However, in the present experiment, for the purpose of ecological validity, there will be no incorrect cueing information.

After completing the training, the participant will begin the experimental scenarios. The participant's primary job in each scenario is to make sure that the UAV does not fly into predefined no-fly zones. Their secondary task, which will be aided by haptic cueing during the cueing condition, will be to monitor the four sections of the LCD monitor mentioned earlier. The participants will have to monitor airspeed and altitude to make sure they are both within predetermined limits. If either moves out of those limits, the participant will have to adjust the UAV accordingly using the Xbox 360 controller. In the haptic cueing condition, the Xbox 360 controller will increasingly vibrate once the UAV is outside of its predefined speed or altitude. In regards to messaging, the participant will monitor the chat room for messages from their commander (the commander's chat name will be predefined). Once the participant notices a message from their commander, they will click an "acknowledge" button using the Xbox 360 controller. The alerts will work similarly to the messages. Once the participant notices an alert, they will click a separate "acknowledge" button using the Xbox 360 controller. For both the messages and alerts, during the haptic cueing condition, the Xbox 360 controller will vibrate simultaneously with the arrival of a message or alert. Each individual scenario will last approximately 10 min. Once the participant has completed each scenario, they will complete the NASA-Task Load Index (TLX; Hart and Staveland 1988), System Usability Scale (SUS: Brooke 1996), and the Experience-based Questionnaire for Usability Assessments Targeting Elaborations (EQUATE; Atkinson et al. in progress) for that specific scenario and then continue to the last scenario. After the participants complete the two scenarios they will be debriefed and allowed to depart the experiment.

3 Selecting Measures

The last step in integrating a methodology for experimentation is selection measures, as a proof of concept, which allow us to understand how cost-effective non-invasive haptic cueing influences an operator's performance and workload.

3.1 Independent Variables

The independent variables in this experiment will be the type of cueing (i.e., no cueing or haptic cueing) to support visual identification of stimuli changes (i.e., airspeed, altitude, messages from commander, aircraft system alerts) in the display and the type of haptic cueing (increasing vibration or steady vibration).

There will be 40 changes presented in each scenario, and they will be divided such that 10 changes per task type (monitor airspeed, attitude, messages, and aircraft system alerts) will occur. Changes will be presented at irregular intervals throughout each individual participant's series of trials so that for any single participant there will be no identifiable temporal pattern. In the haptic cueing condition the cueing will be presented simultaneously with the change in stimuli (i.e., decrease/increase in airspeed, decrease/increase in altitude, messages from commander, aircraft system alerts). However, the type of haptic cueing will vary. When the UAV is outside of the predefined airspeed and altitude limits, the haptic cueing vibration will increase steadily the further the UAV goes outside of the limits. In regards to messages and alerts, the haptic cueing will be a steady vibration. The issue of task difficulty and the potential for asymmetric transfer effects will be addressed in the following manner: First, the number of changes in stimuli will match previous studies (Hancock et al. 2013; Merlo and Hancock 2011), in which participants perceived that task as low/medium workload. In addition, the two scenarios will be counterbalanced across individual participant presentation. The participants will be divided into two groups that will undertake the sequence of different scenarios in differing testing orders (group 1 – scenario 1 then 2, group 2 –scenario 2 then 1).

3.2 Dependent Variables

The dependent variables will be objective measures of performance, experienced cognitive workload as assessed by the NASA-TLX, and perceived usability as assessed by the SUS and EQUATE. Objective measures of performance include response time and accuracy rate. Response time is defined as the latency between the onset of the change in stimuli (alert, airspeed outside of limits, etc.) and the subsequent corrective action. Accuracy rate will include: correct response (hit), response omissions (misses), and false alarms (incorrect action when there was no change in stimuli). The NASA-TLX measures a total weighted workload score based on six subscales: mental physical, and temporal demands, as well as effort, performance, and frustration. The SUS is a 10-question scale designed to measure users' overall feelings of usability (efficiency, efficacy, and satisfaction) with the interface and is scored on a 5-point Likert scale. The EQUATE measures usability based on 16 categories using a 5-point Likert scale.

4 Conclusion

The integration methodology for experimentation presented in this paper is intended to extend to any human-computer system involving human operators that provides haptic cueing. This novel approach, utilizing COTS products and focusing on a non-invasive experimental methodology, will afford more researchers the opportunity to contribute to haptic research and expand their knowledge base.

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