



ARL-TR-9045 • SEP 2020



# Using Eye Tracking and Electroencephalography (EEG) for Visual Search Experimentation in Virtual Environments: A Data Guide

by Bianca Dalangin, Ashley Oiknine, Jessica Villarreal, Angela Jeter, Stephen Gordon, Russell A Cohen Hoffing, Steven Thurman, Robert Smith, Leah Enders, Heather Roy, and Jonathan Touryan

Approved for public release; distribution is unlimited.

## **NOTICES**

### **Disclaimers**

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.



# Using Eye Tracking and Electroencephalography (EEG) for Visual Search Experimentation in Virtual Environments: A Data Guide

**Bianca Dalangin, Jessica Villarreal, Angela Jeter, Robert Smith,  
Leah Enders, and Stephen Gordon**  
*DCS Corporation*

**Ashley Oiknine**  
*DCS Corporation*  
*UC Santa Barbara*

**Russell A Cohen Hoffing, Steven Thurman, Heather Roy,  
and Jonathan Touryan**  
*Human Research Engineering Directorate, CCDC Army Research Laboratory*

| REPORT DOCUMENTATION PAGE   |                                    |   | Form Approved<br>OMB No. 0704-0188      |   |  |
|---|------------------------------------|---|---|---|--|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.<br><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b>  |                                    |   |   |   |  |
| <b>1. REPORT DATE (DD-MM-YYYY)</b><br>September 2020  |                                    | <b>2. REPORT TYPE</b><br>Technical Report |   | <b>3. DATES COVERED (From - To)</b><br>November 2019–March 2020 |  |
| <b>4. TITLE AND SUBTITLE</b><br>Using Eye Tracking and Electroencephalography (EEG) for Visual Search Experimentation in Virtual Environments: A Data Guide   |                                    |   |   | <b>5a. CONTRACT NUMBER</b>                                      |  |
|   |                                    |   |   | <b>5b. GRANT NUMBER</b>   |  |
|   |                                    |   |   | <b>5c. PROGRAM ELEMENT NUMBER</b>                               |  |
| <b>6. AUTHOR(S)</b><br>Bianca Dalangin, Ashley Oiknine, Jessica Villarreal, Angela Jeter, Stephen Gordon, Russell A Cohen Hoffing, Steven Thurman, Robert Smith, Leah Enders, Heather Roy, and Jonathan Touryan   |                                    |   |   | <b>5d. PROJECT NUMBER</b>                                       |  |
|   |                                    |   |   | <b>5e. TASK NUMBER</b>  |  |
|   |                                    |   |   | <b>5f. WORK UNIT NUMBER</b>                                     |  |
| <b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b><br>CCDC Army Research Laboratory<br>ATTN: FCDD-RLH-FC<br>Aberdeen Proving Ground, MD 21005  |                                    |   |   | <b>8. PERFORMING ORGANIZATION REPORT NUMBER</b><br>ARL-TR-9045  |  |
| <b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  |                                    |   |   | <b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>                         |  |
|   |                                    |   |   | <b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>                   |  |
| <b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b><br>Approved for public release; distribution is unlimited.   |                                    |   |   |   |  |
| <b>13. SUPPLEMENTARY NOTES</b><br>ORCID ID(s): Jonathan Touryan, 0000-0001-7343-7869; Steven Thurman, 0000-0003-3962-8447   |                                    |   |   |   |  |
| <b>14. ABSTRACT</b><br>Electroencephalography (EEG) and eye-tracking technologies have each been essential tools within the perceptual sciences community for many years. A growing number of studies now combine these two measurement technologies to elucidate the neural processes that underlie free viewing visual search. However, the majority employ a relatively passive approach (static imagery, prescribed motion, or video stimuli). In our everyday interaction with the natural world, we navigate our environment actively seeking and using task-relevant visual information. For this reason, vision researchers increasingly utilize virtual reality (VR), which offers interactive, realistic visual environments while maintaining experimental control. However, combining simultaneous measures of gaze position and neural activity within a VR environment remains a significant challenge. Here, we describe a data set in which participants freely navigate a virtual environment and search for targets while gaze position and EEG are synchronously recorded. This data guide summarizes the materials, methods, task specifications, and processing techniques used to provide sufficient context to interpret the data set while concisely summarizing our research objectives. Our aim is to bring together these data specifications in one cohesive document to increase data analysis efficacy, foster collaboration, and capture lessons learned for researchers using virtual environments for experimentation. |                                    |   |   |   |  |
| <b>15. SUBJECT TERMS</b><br>visual search, electroencephalography, EEG, eye tracking, virtual environment, situational awareness  |                                    |   |   |   |  |
| <b>16. SECURITY CLASSIFICATION OF:</b>  |                                    |   | <b>17. LIMITATION OF ABSTRACT</b><br>UU | <b>18. NUMBER OF PAGES</b><br>57                                | <b>19a. NAME OF RESPONSIBLE PERSON</b><br>Bianca Dalangin          |
| <b>a. REPORT</b><br>Unclassified  | <b>b. ABSTRACT</b><br>Unclassified | <b>c. THIS PAGE</b><br>Unclassified       |   |   | <b>19b. TELEPHONE NUMBER (Include area code)</b><br>(805) 509-1733 |

## Contents

---

|   |            |
|---|------------|
| <b>List of Figures</b>  | <b>vii</b> |
| <b>List of Tables</b>   | <b>vii</b> |
| <b>1. Introduction</b>  | <b>1</b>   |
| <b>2. HID Overview</b>  | <b>1</b>   |
| 2.1 Background  | 1          |
| 2.2 Experimental Design   | 1          |
| 2.3 Materials   | 2          |
| 2.3.1 Equipment for Data Collection                                 | 2          |
| 2.3.2 Physiological Measures  | 3          |
| 2.4 Data Collection Location  | 3          |
| 2.5 Eligibility Criteria  | 4          |
| 2.5.1 Online Prescreen  | 4          |
| 2.5.2 In-person-Vision Acuity and Color Vision Test                 | 4          |
| 2.6 Procedure   | 5          |
| <b>3. Prescreen Questionnaire: Items, Descriptions, and Scoring</b> | <b>7</b>   |
| 3.1 Demographics  | 7          |
| 3.1.1 Description   | 7          |
| 3.1.2 Items   | 8          |
| 3.2 Motion Sickness Questionnaire                                   | 8          |
| 3.2.1 Description   | 8          |
| 3.2.2 Reliability/Validity  | 9          |
| 3.2.3 Scoring Instructions  | 9          |
| 3.2.4 Questionnaire Instructions and Items                          | 10         |
| 3.3 Game Use Inventory  | 10         |
| 3.3.1 Description   | 10         |
| 3.3.2 Questionnaire Instructions and Items                          | 10         |
| 3.4 Handedness  | 12         |
| 3.4.1 Description   | 12         |

|           |   |           |
|-----------|---|-----------|
| 3.4.2     | Reliability/Validity  | 12        |
| 3.4.3     | Scoring Instructions  | 12        |
| 3.4.4     | Questionnaire Instructions and Items                              | 13        |
| <b>4.</b> | <b>In-Person Questionnaires: Items, Descriptions, and Scoring</b> | <b>13</b> |
| 4.1       | PTSD Checklist (PCL-C/M)  | 13        |
| 4.1.1     | Description   | 13        |
| 4.1.2     | Reliability/Validity  | 13        |
| 4.1.3     | Scoring Instructions  | 14        |
| 4.1.4     | Questionnaire Instructions and Items                              | 14        |
| 4.2       | Simulator Sickness Questionnaire                                  | 15        |
| 4.2.1     | Description   | 15        |
| 4.2.2     | Reliability/Validity  | 15        |
| 4.2.3     | Scoring Instructions  | 15        |
| 4.2.4     | Questionnaire Instructions and Items                              | 16        |
| 4.3       | Presence Questionnaire V4   | 16        |
| 4.3.1     | Description   | 16        |
| 4.3.2     | Reliability/Validity  | 16        |
| 4.3.3     | Subscales   | 16        |
| 4.3.4     | Scoring Instructions  | 17        |
| 4.3.5     | Questionnaire Instructions and Items                              | 17        |
| 4.4       | Presence Questionnaire  | 19        |
| 4.4.1     | Description   | 19        |
| 4.4.2     | Reliability/Validity  | 19        |
| 4.4.3     | Scoring Instructions  | 19        |
| 4.4.4     | Questionnaire Instructions and Items                              | 19        |
| 4.5       | Exit Questions  | 20        |
| 4.5.1     | Description   | 20        |
| 4.5.2     | Questionnaire Instructions and Items                              | 20        |
| <b>5.</b> | <b>Visual Search Tasks</b>  | <b>21</b> |
| 5.1       | Eye-Tracking Calibration  | 21        |
| 5.1.1     | Descriptions  | 21        |
| 5.1.2     | Constructs for Analysis   | 21        |
| 5.2       | Castle and Fountain Classification                                | 21        |
| 5.2.1     | Descriptions  | 21        |

|                    |  |           |
|--------------------|--|-----------|
| 5.2.2              | Constructs for Analysis                                  | 22        |
| 5.3                | Training   | 22        |
| 5.3.1              | Descriptions   | 22        |
| 5.3.2              | Constructs for Analysis                                  | 23        |
| 5.4                | HID Live   | 23        |
| 5.4.1              | Descriptions   | 23        |
| 5.4.2              | Auditory Math Task                                       | 24        |
| 5.4.3              | Constructs for Analysis                                  | 24        |
| 5.5                | Castle and Fountain Recall                               | 24        |
| <b>6.</b>          | <b>Naming Conventions/Label Conventions</b>              | <b>25</b> |
| 6.1                | PSID: Prescreen ID                                       | 25        |
| 6.2                | SSID: Participant in Lab Subject ID                      | 25        |
| 6.3                | Conditions   | 26        |
| 6.4                | C3DS   | 26        |
| <b>7.</b>          | <b>Generated Data (Analysis)</b>                         | <b>27</b> |
| 7.1                | JPGs   | 27        |
| 7.2                | Saliency Maps  | 27        |
| 7.3                | Corrected Eye Tracker                                    | 29        |
| 7.4                | Deep Learning Outputs                                    | 29        |
| 7.5                | Luminance  | 30        |
| 7.6                | Lux  | 31        |
| <b>8.</b>          | <b>Conclusion</b>  | <b>31</b> |
| <b>9.</b>          | <b>References</b>  | <b>32</b> |
| <b>Appendix A.</b> | <b>Human Interest Detector (HID) Data Specifications</b> | <b>34</b> |
| A.1                | File Pathway   | 35        |
| A.2                | File Types   | 36        |
| A.2.1              | JavaScript Object Notation (JSON)                        | 36        |
| A.2.2              | Extensible Data Format (XDF)                             | 36        |
| A.2.3              | Extensible Markup Language (XML)                         | 36        |
| A.3                | File Descriptions  | 36        |

|   |           |
|---|-----------|
| A.4 Live XDF Stream Channel Labels                  | 41        |
| A.5 Live Raycast Channel Labels                     | 43        |
| A.6 Live Camera Transform Channel Labels            | 43        |
| <b>Appendix B. Computer Screen Settings</b>         | <b>44</b> |
| <b>List of Symbols, Abbreviations, and Acronyms</b> | <b>46</b> |
| <b>Distribution List</b>                            | <b>48</b> |



## List of Figures

---

|        |  |    |
|--------|--|----|
| Fig. 1 | A comparison among the four target objects used in HID Live .....  | 2  |
| Fig. 2 | Example of an Ishihara plate.....  | 4  |
| Fig. 3 | Example of a Snellen chart .....   | 5  |
| Fig. 4 | Participant’s view of the Castle and Fountain task. This is an image of a fountain. ....   | 22 |
| Fig. 5 | Participant’s view of HID Live.....  | 23 |
| Fig. 6 | Participant’s view of the castle and fountain recall task.....   | 25 |
| Fig. 7 | Twelve saliency models calculated on one frame of the HID Live task.....   | 29 |
| Fig. 8 | Luminance measurements ( $y$ -axis) in candelas per meter squared ( $\text{cd}/\text{m}^2$ ) as a function of red (left), green (middle), and blue (right) color intensity over the entire intensity space from 0–255 (normalized from 0 to 1 on the $x$ -axis). The black dotted line is the model fit of an exponential function to the data, and the associated gamma parameters were red = 2.24, green = 2.23, blue = 2.22. By design, a typical LCD monitor has gamma values of around 2.2, which is consistent with these measurements. .... | 30 |

## List of Tables

---

|           |   |    |
|-----------|---|----|
| Table 1   | A summary of target objects by specificity (i.e., number of models) and size..... | 2  |
| Table 2   | Equipment used for HID.....   | 3  |
| Table 3   | Eligibility criteria asked during the prescreen .....                             | 4  |
| Table 4   | Procedure of the HID study .....  | 6  |
| Table 5   | MSSQ items (child) .....  | 10 |
| Table 6   | MSSQ items (adult) .....  | 10 |
| Table 7   | Handedness items.....   | 13 |
| Table 8   | Presence subscales and their corresponding question items.....                    | 18 |
| Table 9   | What each digit in the SSID represents .....                                      | 26 |
| Table B-1 | Computer screen settings .....  | 45 |

## 1. Introduction

---

This document captures a high-level overview of the Human Interest Detector (HID) project for those interested in understanding the context and materials used to collect and preprocess the study data. The initial sections provide a general summary of the HID project including its background, procedure(s), equipment specifications, and data collection process. The later sections summarize available data from each questionnaire and task as well as describe the processing techniques used to understand the context of such data. Contextual information, frequently asked questions, and an Appendix that contains other data specifications can be found near the end of the guide. **Please use the navigation pane for ease of navigation.**

## 2. HID Overview

---

### 2.1 Background

---

The overarching HID study aim was to examine physiological markers (i.e., electroencephalography [EEG], heart rate [HR], eye tracking) of situational awareness (SA), specifically target detection, via a search task embedded in a virtual and more naturalistic 3-D virtual environment. The HID protocol was approved by the US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory (ARL) Human Research Protection Program (HRPP).

### 2.2 Experimental Design

---

This was a between-subjects design in which the independent variable was the target objects participants were asked to count in a visual search task (see Section 5.4 *HID Live* for more information about the visual search task). Since the virtual environment was the same for each participant, all participants were exposed to all the same target objects, but were asked to focus on different target objects depending on their assigned experimental condition. Participants were randomly assigned to one out of four target object conditions (1 – Motorcycle, 2 – Humvee, 3 – Furniture, 4 – Aircraft). In addition to the target objects, the HID Live environment also contained nontargets that were used as distractors. Figure 1 shows a comparison among the four target objects used in HID Live.

For each object category there are a fixed number of target “assets” and a varying number of asset models (e.g., could have one model copied many times vs. unique models).



**Fig. 1 A comparison among the four target objects used in HID Live**

Targets may be further broken down by specificity and size (Table 1). Specificity was defined as whether the object is based on a single object model (e.g., Aircraft model A) or a variety of models (Aircraft model A, Aircraft model B).

**Table 1 A summary of target objects by specificity (i.e., number of models) and size**

| Size         | Specific   | General                              |
|--------------|------------|--------------------------------------|
| <i>Small</i> | Motorcycle | Furniture (table, chair, etc.)       |
| <i>Large</i> | Humvee     | Aircraft (biplane, helicopter, etc.) |

In addition to the main task of interest (HID Live), participants completed various tasks and questionnaires while experimenters collected eye-tracking data, EEG data, and virtual environment (VE) data detailed in the remaining sections.

Data collection occurred throughout December 2019–March 2020. Around 400 participants in the Los Angeles area attempted the prescreening questionnaire. From this pool of participants, 50 eligible participants completed the in-person study by coming into the lab. Due to circumstances surrounding COVID-19, data collection was placed on hold. Future iterations may continue at CCDC Army Research Laboratory West (California), Joint Base San Antonio (JBSA) (Texas), and Aberdeen Proving Ground (APG) (Maryland) that builds on lessons learned from this data set. For more information on data availability per sample size, please contact the HID Data Guide point of contact (POC) (Bianca Dalangin) for more real-time updates.

## 2.3 Materials

### 2.3.1 Equipment for Data Collection

Table 2 shows the equipment used for HID.

**Table 2 Equipment used for HID**

| <b>Item</b>                             | <b>Description</b>           |
|---|------------------------------|
| EEG                                     | Biosemi ActiView, 64-channel |
| Tablet used for online in-person survey | Windows Surface Pro 3 Tablet |
| Eye tracker                             | Tobii Pro Spectrum (300 Hz)  |
| Desktop for visual tasks                | Dell desktop monitor (LCD)   |
| Mouse and keyboard                      | Dell (wired)                 |
| Speakers (for sound)                    | Real-Tek audio speakers      |
| PC                                      | Corsair One                  |

### **2.3.2 Physiological Measures**

Physiological measures included in this study were EEG, eye tracking, electrooculogram (EOG), and HR.

Note: For more specific information on which physiological data were collected as well as resolution and refresh rate, please see [\*Appendix A. HID Data Specifications\*](#).

#### ***Platforms***

Online questionnaires (i.e., prescreener and in-lab) were administered using the online survey software Qualtrics. The HID program was built using Unity 2018.3.13f1 and C#. Some data were saved using the C# binding for the lab streaming layer ([LSL](#)) and [LabRecorder](#). The rest of the data were saved to common-separated value (.csv) and JavaScript Object Notation (JSON) files.

### **2.4 Data Collection Location**

Data collection occurred at the ARL West research facilities located in Los Angeles, California. Participants volunteered using various third-party platforms (e.g., Facebook, Craigslist) and completed an online prescreening that determined their eligibility. Eligible participants were invited to complete the study in person for approximately 2.5 h (see Section 2.5 [Eligibility Criteria](#) for more information on eligibility). Future research with similar experimental designs may be conducted at other sites such as JBSA and APG.

The ARL West laboratory space is in a publicly accessible campus on a secured floor in a secured suite. The lab space has a sound-controlled recording booth used for testing called the whisper room. After participants were fitted with the physiological equipment, participants were led into the whisper room to complete the questionnaires and tasks. The experimenter sat just outside the whisper room observing with a mirrored experimenter monitor.

## 2.5 Eligibility Criteria

---

### 2.5.1 Online Prescreen

Table 3 shows the eligibility criteria asked during the prescreen.

**Table 3 Eligibility criteria asked during the prescreen**

|   |  |
|---|--|
| Fluency in English (self-report)  | No brain injury / brain trauma (self-report)       |
| Years & over (self-report)  | No heart problems (self-report)                    |
| Normal hearing (self-report)  | Not pregnant (self-report)                         |
| Normal color vision and corrected to normal vision acuity with contacts (self-report) | No susceptibility to motion sickness (self-report) |

### 2.5.2 In-person-Vision Acuity and Color Vision Test

#### 2.5.2.1 Ishihara (14-plate)

##### *Description/Scoring*

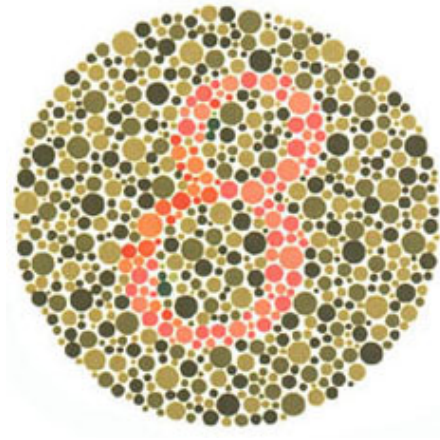
Eligible participants should read every single image correctly. Figure 2 shows an example Ishihara plate.

##### *Reliability/Validity*

Internal consistency reliability was found to be 0.92 on a retest (Salvia and Ysseldyke 1971).

##### *Question Type:*

Question: “I will present you with some images and ask you to tell me what you see. For example, the answer to the sample prompt is 12.”



**Fig. 2 Example of an Ishihara plate**

### 2.5.2.2 Snellen Chart

#### *Description/Scoring*

This is an eligibility criterion that tests people’s visual acuity by asking them to stand 20 ft away from the chart and read the 20/40 line with no more than one mistake. Figure 3 shows an example of a Snellen chart.

#### *Reliability/Validity*

The reliability coefficient was found to be 0.94 (Lovie-Kitchin 1988).

#### *Question Type:*

Question: “I am going to point to a line on this chart and I would like you to read it aloud to me from left to right.”

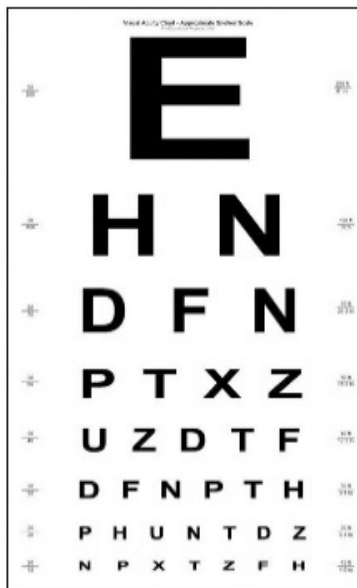


Fig. 3 Example of a Snellen chart

## 2.6 Procedure

---

Table 4 is an outline of the prescreen and in-person procedure.

**Table 4 Procedure of the HID study**

| <b>Section</b>   | <b>Time</b> | <b>Description</b>  |
|--|-------------|---|
| <b>Prescreen Qs: Demographics</b>  | 10          | N/A   |
| <b>Prescreen Qs: <a href="#">Motion Sickness Susceptibility Questionnaire-Short</a></b> (Golding 2006) | 2           | Measures history with sickness associated with transportation in childhood and adulthood.                             |
| <b>Prescreen Qs: <a href="#">Game Use Inventory</a></b>  | 1           | HRED-developed Game-Use survey to explore an individual's game habits.  |
| <b>Prescreen Qs: <a href="#">Edinburgh Handedness Questionnaire</a></b> (Oldfield 1971)                | 2           | Measure to classify handedness (left handed, right handed, ambidextrous) in an individual.                            |
| <b>In-Person Screening: <a href="#">Ishihara (14-plate)</a></b>  | 5           | Task and eligibility requirement used to measure colorblindness (must read all plates with 1 incorrect at most).      |
| <b>In-Person Screening: <a href="#">Visual Acuity</a></b> (Hetherington 1954)                          | 4           | Task and eligibility requirement used to measure visual acuity (20:40 vision or better).                              |
| <b>In-Person Screening: <a href="#">Eye Tracking Calibration Test</a></b>                              | 15          | Using the eye-tracker to find the optimal position for eye tracking.  |
| <b>Physiological Setup</b>   | 25          | EEG set up, debugging EEG offset values, and <b>repeating eye tracking calibration</b>                                |
| <b>Pre Task Questionnaire: <a href="#">PTSD Checklist (PCL-C/M)</a></b> (Weather et al. 1993)          | 2           | A self-report measure consisting of DSM-IV symptoms of post-traumatic stress disorder (PTSD).                         |
| <b>Pre Task Questionnaire: <a href="#">Simulator Sickness 1 (SSQ)</a></b> (Kennedy et al. 1993)        | 3           | A published measure used to quantify simulator sickness and subsets including nausea, oculomotor, and disorientation. |
| <b><a href="#">Castles and Fountains Task</a></b>  | 20          | In this first task, participants do a go/no-go task that asks them to respond to a target stimulus.                   |
| <b>Physiological Setup: Recalibrate eye tracker</b>  | 2           | Using the eye tracker to find the optimal position for eye tracking.  |
| <b><a href="#">Virtual Environment Training Mini Task</a></b>  | 12          | Task that familiarizes participants with a virtual environment, teaching them controls, etc.                          |
| <b>Post Task Questionnaire: <a href="#">Simulator Sickness 2 (SSQ)</a></b> (Kennedy et al. 1993)       | 3           | A published measure used to quantify simulator sickness and subsets including nausea, oculomotor, and disorientation. |
| <b>Post Task Questionnaire: <a href="#">Presence questionnaire</a></b> (Witmer et al. 2005)            | 4           | A set of questions that measure total presence.   |

**Table 4 Procedure of the HID study (continued)**

| <b>Section</b>   | <b>Time</b> | <b>Description</b>  |
|--|-------------|---|
| <b>Post Task Questionnaire:</b> <a href="#">Slater and Usoh Presence</a> (Usoh et al. 2000)      | 1           | A set of questions that measures presence.  |
| <b>Physiological Setup:</b> Recalibrate eye tracker  | 2           | Using the eye tracker to find the optimal position for eye tracking.  |
| <b><a href="#">HID Live Search and Auditory Math Task</a></b>                                    | 20          | Given at most 20 min, participants navigate through a virtual environment to mentally count targets. At approximately 8 min into the task, a series of 3-4 numbers are read aloud, asking participants to report the sum aloud while moving and counting targets. |
| <b>Post Task Questionnaire:</b> No. of Counted Targets   | 1           | Asks participants the number of target objects they counted.  |
| <b>Post Task Questionnaire:</b> <a href="#">Simulator Sickness 3 (SSQ)</a> (Kennedy et al. 1993) | 3           | A published measure used to quantify simulator sickness and subsets including nausea, oculomotor, and disorientation.   |
| <b>Post Task Questionnaire:</b> <a href="#">Presence Questionnaire V4</a> (Witmer et al. 2005)   | 4           | A set of questions that measure total presence.   |
| <b>Post Task Questionnaire:</b> <a href="#">Slater and Usoh Presence</a> (Usoh et al. 2000)      | 1           | A set of questions that measure presence.   |
| <b>Physiological Set Up:</b> Recalibrate eye tracker   | 2           | Using the eye tracker to find the optimal position for eye tracking.  |
| <b><a href="#">Castles and Fountain Recall Task</a></b>  | 15          | Participants are given a few screens with an array of images and asked to click on the images that they recognized from the initial Castle and Fountains task.  |
| <b><a href="#">Exit Questionnaire</a></b>  | 10          | A set of questions that ask about participant's experience and feelings doing the experiment.   |

### **3. Prescreen Questionnaire: Items, Descriptions, and Scoring**

#### **3.1 Demographics**

##### **3.1.1 Description**

These 15 items were used to evaluate participant eligibility prior to an invitation to come in to the lab.



### 3.1.2 Items

The following are the items listed on the prescreen questionnaire:

- 1) Gender:
- 2) Age:
- 3) Education level: \_\_\_\_\_
- 4) Ethnicity: \_\_\_\_\_
- 5) Race: \_\_\_\_\_
- 6) MOS Military Occupational Specialty: \_\_\_\_\_
- 7) Are you fluent in English? Y / N
- 8) Do you have normal hearing? Y / N
- 9) Handedness: right, left, ambidextrous
- 10) Do you have normal or corrected to normal vision? Y / N
- 11) Are you color blind? Y / N
- 12) Have you experienced any significant brain trauma or brain injuries? Y / N
- 13) Do you have any heart problems? Y / N
- 14) Are you pregnant? Y / N
- 15) Do you easily get motion sick from exploring virtual environments on a desktop monitor? Y / N

## 3.2 Motion Sickness Questionnaire

---

### 3.2.1 Description

The Golding (2006) Motion Sickness Susceptibility Questionnaire (MSSQ-Short) measures the motion sickness in an individual caused by various forms of transportation. There are two identical parts, each relating to their *childhood* experiences before the age of 12 and as an *adult* within the last 10 years, respectively. There are 18 total questions, 9 per part of the questionnaire (Golding 2006). From this measure, one can calculate the motion sickness susceptibility as a child (MSA), motion sickness susceptibility as an adult (MSB), and total motion sickness susceptibility.

### 3.2.2 Reliability/Validity

Internal reliability is determined in the following way: Cronbach's alpha 0.87; test-retest reliability around  $r = 0.9$ ; Part A (child) with Part B (adult)  $r = 0.68$ . MSSQ-Short provides reliability with an efficient compromise between length (reduced time cost) and validity (predicted motion susceptibility) (Golding 2006, p. 237).

### 3.2.3 Scoring Instructions

For this continuous measure, participants are to rate each item on a 5-point rating scale from "Not Applicable Never Traveled", "Never Felt Sick", "Rarely Felt Sick", "Sometimes Felt Sick", and "Frequently Felt Sick" indicating the degree of sickness they have experienced from the motions listed.

*MSA (Q1-9, child):*

- **First, calculate the total sickness scores:** Sum of responses to part A
  - Not applicable / Never Traveled = 0 (t)
  - Never felt sick = 0
  - Rarely felt sick = 1
  - Sometimes felt sick = 2
  - Frequently felt sick = 3

Next, use this formula to calculate the MSA:

$MSA = [(total\ sickness\ score) \times (9)/(9 - (\# \text{ of times that an item was not applicable/never traveled (i.e., t) in part A})]$ .

*MSB (Q10-18, adult):*

- Use the same scoring and formula but only with data from part B.

*Total motion sickness susceptibility:*

- Raw score: (MSA + MSB)

*Motion sickness susceptibility percentile:*

Another option is to calculate the percentile score. This is not recorded in the data processing sheet.

Percentile score: To calculate the percentile score, use the following polynomial formula:

- (y = percentile; x = raw score)
- $y = (5.116)(x) + (-0.055)(x)^2 + (-0.001)(x)^3 + (1.0714752e-005)(x)^4$

### 3.2.4 Questionnaire Instructions and Items

The following instructions are taken from the questionnaire. Tables 5 and 6 list the MSSQ items for children and adults, respectively.

“This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. (Sickness here means feeling queasy or nauseated or actually vomiting.) For your childhood experience only (before 12 years of age), for each of the following types of transport or entertainment, please indicate how often you felt sick or nauseated.”

**Table 5 MSSQ items (child)**

|                  |                              |                            |
|------------------|------------------------------|----------------------------|
| Cars             | Aircraft                     | Swings in playgrounds      |
| Buses or coaches | Small boats                  | Roundabouts in playgrounds |
| Trains           | Ships, e.g., channel ferries | Big dippers, funfair rides |

“For your experience over the last 10 years (approximately), please indicate how often you felt sick or nauseated for each of the following types of transport or entertainment.”

**Table 6 MSSQ items (adult)**

|                  |                              |                            |
|------------------|------------------------------|----------------------------|
| Cars             | Aircraft                     | Swings in playgrounds      |
| Buses or coaches | Small boats                  | Roundabouts in playgrounds |
| Trains           | Ships, e.g., channel ferries | Big dippers, funfair rides |

## 3.3 Game Use Inventory

### 3.3.1 Description

ARL’s Human Research and Engineering Directorate (HRED) adapted a questionnaire that has been used in previous study protocol 17-017. The Gaming Use Inventory is a six-item, self-report questionnaire utilizing dichotomous, ratio, and ranking questions. It measures the participant’s familiarity with game-like elements, game preferences, and game habits currently and over time.

### 3.3.2 Questionnaire Instructions and Items

**Please Note:** In these questions, “video game” refers to *any* computer (e.g., PC), console (e.g., PlayStation), handheld device (i.e., mobile phone or Nintendo DS), or social media (e.g., Candy Crush) game.

- 1) Do you currently consider yourself to be an active video game player?
  - a) Yes
  - b) No

- 2) During the average **week** how many hours do you **currently** spend playing video games?
- a) Less than 2 hours
  - b) 2 – 7 hours
  - c) 8 – 14 hours
  - d) 15 – 21 hours
  - e) More than 21 hours
- 3) During the average **week** how many hours **would you like to** spend playing video games?
- a) Less than 2 hours
  - b) 2 – 7 hours
  - c) 8 – 14 hours
  - d) 15 – 21 hours
  - e) More than 21 hours
- 4) If you have any video game playing experience, at what age did you first start to play?
- \_\_\_\_\_ Years
- \_\_\_\_\_ N/A
- 5) Please rank order the following platforms in the order of your preference for playing electronic games on each platform using the following scale: “**1**, prefer to play the **most**” to “**4**, prefer to play the **least**”. Note: If you do not use a platform enough to have a preference, place a **0** by that platform.
- \_\_\_\_\_ Computer (e.g., PC/Mac/laptop)
- \_\_\_\_\_ Video gaming console (e.g., PlayStation)
- \_\_\_\_\_ Mobile or other touch-screen device (e.g., smartphone)
- \_\_\_\_\_ Dedicated handheld device (e.g., Gameboy DS)
- \_\_\_\_\_ Place an X here if you have no preferences at all
- 6) Please rank order the following genres in the order of the one you prefer to play the most using the following scale: “**1**, prefer to play the **most**” to “**4**, prefer to play the **least**”. Note: If you do not play this modality regularly enough to have a preference, place a **0** in each.
- \_\_\_\_\_ First-person shooter
- \_\_\_\_\_ Action or Fighting
- \_\_\_\_\_ Driving or Racing
- \_\_\_\_\_ Sports
- \_\_\_\_\_ Other genre(s) \_\_\_\_\_

## 3.4 Handedness

---

### 3.4.1 Description

The Edinburgh Handed Questionnaire (Oldfield 1971) measures an individual's hand dominance in performing everyday tasks along a continuous scale (single lateral index) for right, left, and ambidextrous people. This measure includes 10 items that are rated along a 5-point scale with the responses of "Left Only", "Left", "Indifferent", "Right", and "Right Only". The items present a task name and prompt participants to indicate which hand they would prefer to complete the task. One indicating using their left or right hand for the task, and two indicating when the preference is so strong the individual would not use the other hand unless forced. The 10-item inventory has been used in various clinical fields as a screener (Robinson 2013). From this measure, one can calculate the total Handedness score and the laterality quotient creating categorical variables (Robinson 2013).

### 3.4.2 Reliability/Validity

This measure was reported to have a high internal consistency (coefficient alpha) of  $\alpha = 0.95$  (Veale 2013).

### 3.4.3 Scoring Instructions

*Handedness score:*

- 1) Score right-hand total code participant responses as follows: 1 = 0, 2 = 0, 3 = 1, 4 = 1, 5 = 2
- 2) Score left-hand total code participant responses as follows: 1 = 2, 2 = 2, 3 = 1, 4 = 0, 5 = 0
- 3) Use the following format:

$$[(Total\ Right - Total\ Left) / (Total\ Right + Total\ Left)] \times 100 = Handedness$$

*Laterality Quotient:* Use the Handedness score to classify an individual's handedness.

The interpretation of results is as follows:

Left-handed: Handedness score less than -40.

Ambidextrous: Handedness score is between -41 to +39.

Right-handed: Handedness score greater than +40.

### 3.4.4 Questionnaire Instructions and Items

The following instructions are taken from the questionnaire. Table 7 lists the handedness items.

“Please indicate your preference with a one (1) in using your right or left hand in the following tasks.

Where the preference is so strong you would never use the other hand unless absolutely forced to, select two (2). Some of the activities require both hands. In these cases, the part of the task or object for which hand preference is wanted is indicated in the parentheses.”

Table 7 Handedness items

|         |          |                      |                    |                          |
|---------|----------|----------------------|--------------------|--------------------------|
| Writing | Throwing | Toothbrush           | Spoon              | Striking a match (match) |
| Drawing | Scissors | Knife (without fork) | Broom (upper hand) | Opening a box (lid)      |

## 4. In-Person Questionnaires: Items, Descriptions, and Scoring

### 4.1 PTSD Checklist (PCL-C/M)

#### 4.1.1 Description

Although there are two types of questionnaires (PCL-M [military] and PCL-C [civilian]), the PCL-C was used for this study to apply to all populations. The PCL-C is a 17-item, self-report measure assessing symptoms of PTSD consistent with the Diagnostic and Statistical Manual (DSM-IV). The PCL-C was derived from the PCL-military version (Weather et al. 1993). The civilian version is identical to the military version, except that it inquires about a “stressful experience from the past” as opposed to a specific military trauma. This continuous measure asks about symptoms in relation to generic “stressful experiences” and can be used with any population. The measure may also be scored as a binary variable, indicating the presence of PTSD or not. This measure is used for screening for PTSD, making provisional diagnoses of PTSD, or for monitoring symptom changes during and after treatment. For the purpose of the HID study, the PCL-C was strictly used for research purposes only.

#### 4.1.2 Reliability/Validity

The PCL-C/M was found to have a retest reliability of  $r = 0.96$ , an excellent internal consistency ranging from  $\alpha = 0.93$ – $0.97$ , and strong convergent validity (Weather et al. 1993).

### 4.1.3 Scoring Instructions

There are many reliable and valid ways to score this scale; here we provide two.

A **total symptom severity score** (range = 17–85) can be obtained by summing the scores from each of the 17 items that have response options ranging from the following:

Not at all = 1    A little bit = 2    Moderately = 3    Quite a bit = 4    Extremely = 5

To classify individuals as meeting criteria for PTSD according to the PCL-C, individuals should have the following:

- At least **one** response of 3 or higher in DSM-IV B criteria (PCL-C items 1–5)
- At least **three** responses of 3 or higher in DSM-IV C criteria (PCL-C items 6–12)
- At least **two** responses of 3 or higher in DSM-IV D criteria (PCL-C items 13–17)

In which responses 1–2 (below “moderately”) is classified as nonsymptomatic and responses 3–5 (moderately or above) is classified as symptomatic.

### 4.1.4 Questionnaire Instructions and Items

The following instructions are taken from the questionnaire.

“Instruction to patient: The following is a list of problems and complaints that veterans sometimes have in response to stressful life experiences. Please read each one carefully, indicate how much you have been bothered by that problem *in the last month*.

Not at all (1) A little bit (2) Moderately (3) Quite a bit (4) Extremely (5)

1. Repeated, disturbing *memories, thoughts, or images* of a stressful experience from the past?
2. Repeated, disturbing *dreams* of a stressful experience from the past?
3. Suddenly *acting or feeling* as if a stressful experience *were happening* again (as if you were reliving it)?
4. Feeling *very upset* when *something reminded* you of a stressful experience from the past?
5. Having *physical reactions* (e.g., heart pounding, trouble breathing, or sweating) when *something reminded* you of a stressful experience from the past?

6. Avoid *thinking about* or *talking about* a stressful experience from the past or avoid *having feelings* related to it?
7. Avoid *activities* or *situations* because they *remind you* of a stressful experience from the past?
8. Trouble *remembering important parts* of a stressful experience from the past?
9. Loss of *interest in things that you used to enjoy*?
10. Feeling *distant* or *cut off* from other people?
11. Feeling *emotionally numb* or being unable to have loving feelings for those close to you?
12. Feeling as if your *future* will somehow be *cut short*?
13. Trouble *falling* or *staying asleep*?
14. Feeling *irritable* or having *angry outbursts*?
15. Having *difficulty concentrating*?
16. Being “*super alert*” or watchful on guard?
17. Feeling *jumpy* or easily startled?”

## **4.2 Simulator Sickness Questionnaire**

---

### **4.2.1 Description**

The Simulator Sickness Questionnaire (Kennedy et al. 1993) measures total simulator sickness and parts of simulator sickness such as nausea, oculomotor, and disorientation in an individual. The 16-item continuous measure is rated on a 4-point scale (0 – *None*, 1 – *Slight*, 2 – *Moderate*, 3 – *Severe*), and is asked three times throughout the study (see Section 2.6 [Procedure](#)).

### **4.2.2 Reliability/Validity**

No scale dimensionality, reliability, or validation information is available.

### **4.2.3 Scoring Instructions**

This measure allows one to calculate total simulator sickness, as well as nausea (N), oculomotor (O), and disorientation (D).

*Nausea Score*: Sum the scores of questions that have N, then multiply by 9.54.

*Oculomotor Score*: Sum the scores of questions that have O, then multiply by 7.58.



*Disorientation Score*: Sum the scores of questions that have D, then multiply by 13.92.

*Total Simulator Sickness*:  $([Nausea\ Score/9.54] + [Oculomotor\ Score/7.58] + [Disorientation\ Score/13.92]) \times 3.74$ .

#### **4.2.4 Questionnaire Instructions and Items**

The following instructions are taken from the questionnaire.

“Rate your experience of the following (i.e., right now I feel):

- |                              |                                   |
|------------------------------|-----------------------------------|
| 1. General discomfort (N,O)  | 9. Difficulty concentrating (N,O) |
| 2. Fatigue (O)               | 10. Fullness of head (D)          |
| 3. Headache (O)              | 11. Blurred vision (O,D)          |
| 4. Eyestrain (O)             | 12. Dizzy (eyes open) (D)         |
| 5. Difficulty focusing (O,D) | 13. Dizzy (eyes closed) (D)       |
| 6. Increased salivation (N)  | 14. Vertigo (D)                   |
| 7. Sweating (N)              | 15. Stomach awareness (N)         |
| 8. Nausea (N, D)             | 16. Burping (N)”                  |

### **4.3 Presence Questionnaire V4**

---

#### **4.3.1 Description**

On the Presence Questionnaire (PQ), participants can rate their involvement with the VE along a 7-point scale anchored at “not at all”, “somewhat”, and “completely” (Witmer and Singer 1998). This continuous questionnaire is asked twice (see Section 2.6 [Procedure](#)).

#### **4.3.2 Reliability/Validity**

The Presence Questionnaire is one of the most accepted and widely used questionnaires in the presence literature. The reported internal reliability for this measure is  $\alpha = 0.81$  (Witmer and Singer 1998).

#### **4.3.3 Subscales**

These subscales are involvement, sensory fidelity, adaptation/immersion, and interface quality. Internal consistency reliability coefficients (Cronbach’s alpha) revealed alpha values of 0.89, 0.84, 0.80, and 0.57 for each factor of involvement, sensory fidelity, adaptation/immersion, and interface quality, respectively (Witmer et al. 2005).

#### **4.3.4 Scoring Instructions**

The following are the scoring instructions:

- 1) To calculate total presence, sum the scores together. Questions 19, 22, and 23 are reverse-scored.
- 2) To calculate each subsection, sum the scores of the questions that correspond to the section.

#### **4.3.5 Questionnaire Instructions and Items**

The following instructions are taken from the questionnaire. Table 8 lists the presence subscales and their corresponding question items.

- 1) “How much were you able to control events?
- 2) How responsive was the environment to actions that you initiated (or performed)?
- 3) How natural did your interactions with the environment seem?
- 4) How much did the visual aspects of the environment involve you?
- 5) How much did the auditory aspects of the environment involve you?
- 6) How natural was the mechanism which controlled movement through the environment?
- 7) How compelling was your sense of objects moving through space?
- 8) How much did your experiences in the virtual environment seem consistent with your real world experiences?
- 9) Were you able to anticipate what would happen next in response to the actions that you performed?
- 10) How completely were you able to actively survey or search the environment using vision?
- 11) How well could you identify sounds?
- 12) How well could you localize sounds?
- 13) How well could you actively survey or search the virtual environment using touch?
- 14) How compelling was your sense of moving around inside the virtual environment?

- 15) How closely were you able to examine objects?
- 16) How well could you examine objects from multiple viewpoints?
- 17) How well could you move or manipulate objects in the virtual environment?
- 18) How involved were you in the virtual environment experience?
- 19) How much delay did you experience between your actions and expected outcomes?
- 20) How quickly did you adjust to the virtual environment experience?
- 21) How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?
- 22) How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?
- 23) How much did the control devices interfere with the performance of assigned tasks or with other activities?
- 24) How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?
- 25) How completely were your senses engaged in this experience?
- 26) How easy was it to identify objects through physical interaction; like touching an object, walking over a surface, or bumping into a wall or object?
- 27) Were there moments during the virtual environment experience when you felt completely focused on the task or environment?
- 28) How easily did you adjust to the control devices used to interact with the virtual environment?
- 29) Was the information provided through different senses in the virtual environment (e.g., vision, hearing, touch) consistent?"

**Table 8      Presence subscales and their corresponding question items**

| <b>Subscale</b>             | <b>Corresponding question items</b>                   |
|-----------------------------|---|
| AdaptationImmersionPresence | Adaptation/Immersion – 9, 20, 21, 24, 25, 30, 31, 32  |
| InterfaceQualityPresence    | Interface Quality – 19R, 22R, 23R                     |
| InvolvementPresence         | Involvement – 1, 2, 3, 4, 6, 7, 8, 10, 14, 17, 18, 29 |
| SensoryFidelityPresence     | Sensory Fidelity – 5, 11, 12, 13, 15, 16              |
| OverallPresence             | Take the sum of all questions                         |

## 4.4 Presence Questionnaire

---

### 4.4.1 Description

This widely used measure by Usoh et al. (2000) measures presence and is asked twice (see Section 2.6 [Procedure](#)). Presence consists of measuring the sense of being in a VE, and the VE being the dominant reality and a place. The six-item set uses a 7-point semantic differential scale that are question-specific (see Section 4.4.4 *Questionnaire Instructions and Items*).

### 4.4.2 Reliability/Validity

The validity of this scale is concurrently supported in relation to other measures of presence. The presence questionnaire of this study has been used and received much attention in research regarding presence.

### 4.4.3 Scoring Instructions

The presence score can be calculated as adding the number of items that had a score 6 or 7 and dividing it by the total number of items; a higher number corresponds to the person having higher presence.

### 4.4.4 Questionnaire Instructions and Items

The following instructions are taken from the questionnaire:

- 1) “Please rate your sense of being in the virtual environment, on the following scale from 1 to 7, where 7 represents your normal experience of being in a place. I had a sense of “being there” in the virtual environment: *(1 – Not at all, 7 – Very much)*
- 2) To what extent were there times during the experience when the virtual environment was the reality for you? There were times during the experience when the virtual environment was the reality for me... *(1 – At no time, 7 – Almost all the time)*
- 3) When you think back about your experience, do you think of the virtual environment more as images that you saw, or more as somewhere that you visited? The virtual environment seems to me to be more like... *(1 – Images that I saw, 7 – Somewhere that I visited)*
- 4) During the time of the experience, which was strongest on the whole, your sense of being in the virtual environment, or of being elsewhere? I had a stronger sense of... *(1 – Being elsewhere, 7 – Being in the virtual environment)*

- 5) Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By ‘structure of the memory’ consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in color, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements. I think of the virtual environment as a place in a way similar to other places that I’ve been today... (1 – *Not at all*, 7 – *Very Much so*)
- 6) During the time of the experience, did you often think to yourself that you were actually in the virtual environment? During the experience I often thought that I was really standing in the virtual environment... (1 – *Not very often*, 7 – *Very much so*)”

## **4.5 Exit Questions**

---

### **4.5.1 Description**

A set of questions that are used to understand the overall feelings of all of the tasks and strategies used during the tasks.

### **4.5.2 Questionnaire Instructions and Items**

The following instructions are taken from the questionnaire:

- 1) “What was the most difficult part of this task? Why? (free response)
- 2) Was there anything unclear, odd, or strange? (free response)
- 3) Did you use any strategies during the task? (yes/no)
- 4) Please describe the strategy you used. (free response)
- 5) How confident were you in your ability to recall objects you saw in the environment? (1-9 scale; 1 – *not confident at all*, 9 – *extremely confident*)”

## 5. Visual Search Tasks

---

### 5.1 Eye-Tracking Calibration

---

#### 5.1.1 Descriptions

Calibration for the eye trackers was conducted before physiological setup and again before every component task, resulting in a total of five calibrations per participant throughout the testing session. During calibrations, participants were instructed to look at a calibration dot until it “explodes” (see Section 2.3.1 [Equipment](#) for more information on eye-tracking system).

#### 5.1.2 Constructs for Analysis

The following were the constructs for analysis:

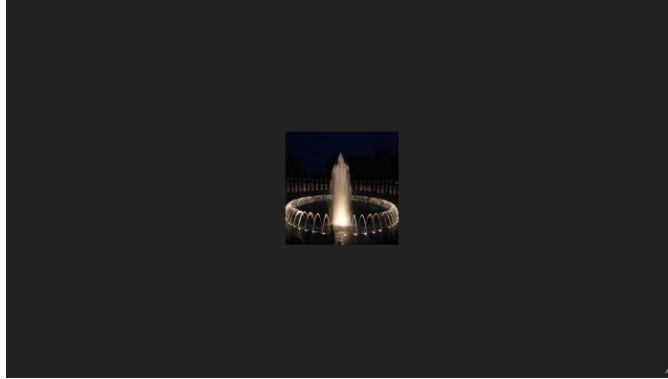
- Gaze error
- Gaze variance

### 5.2 Castle and Fountain Classification

---

#### 5.2.1 Descriptions

In this rapid serial visual presentation (RSVP) task, subjects were presented with a series of images on a screen, either of a castle or a fountain, and participants are asked to press the spacebar if the displayed image was a fountain. Images were presented asynchronously with InterStimulus Interval (ISI) uniformly distributed between 1–4 s. Images are displayed for 250 ms. Three consecutive blocks of approximately 5 min were performed for a total of approximately 15 min to complete the task, plus breaks. The Recall task is intended to provide a measure of stimulus encoding from the RSVP to determine if the neural state and signatures at the time of stimulus presentation are predictive of subsequent recall and, thus, presumably stronger encoding; participants were prompted with a recall task (see Section 5.5 [Castle and Fountain Recall](#) for more information). Participants who completed this task are exposed to all 390 images (312 castles and 78 fountains), and 130 trials per block. Figure 4 shows an example image from this test.



**Fig. 4** Participant's view of the Castle and Fountain task. This is an image of a fountain.

### **5.2.2 Constructs for Analysis**

Castles and Fountains task example metrics are the following:

- False alarm rate: responding to a nontarget as though it was a target stimulus.
- Correct rejection rate: correctly withholding response to a nontarget stimulus.
- Hit rate: correctly responding to a target stimulus.
- Response time: time to respond to stimulus
- Total "points": sum of correct hits to a target stimulus

The RSVP task is intended to provide the following:

- 1) Baseline measures of the participant's P300 neural response to visual stimuli
- 2) Baseline measures of the participant's reaction time to visual stimuli
- 3) Feed subsequent analyses on stimulus processing as a function of onset predictability

## **5.3 Training**

---

### **5.3.1 Descriptions**

Subjects navigated the VE using the W (forward), A (left), S (backwards), and D (right) keys (see the instructional quote that follows) on the computer keyboard for navigating through the HID environment. Participants were further instructed to use the computer mouse to change their camera view in the environment. The objective is to continue along a path until they reach a bull's-eye target in a house.

This task takes about 3–5 min. The purpose of this task is to familiarize the participants with navigating the environment and controls. The instructions are as follows:

“You will now have some practice on how to navigate in the virtual world. You will use the keys W, A, S, and D to move around the world and the mouse to control the camera. Your task is to move down the path until you reach the bulls eye target in the house. When you reach the house, stand on the target to complete the training. Do you have any questions?”

### 5.3.2 Constructs for Analysis

The purpose of the Training task was twofold:

- 1) As a familiarization period for the participants to interact with the virtual environment
- 2) As a potential baseline for cognitive state assessment

## 5.4 HID Live

---

### 5.4.1 Descriptions

Participants navigated a VE with the assistance of navigation cues (i.e., trail blazes placed on trees) to visually search and maintain a mental count of a specific type of target objects depending on the random assignment to experimental condition (Fig. 5; for more information on the conditions, see Section 2.2 [Experimental Design](#)). Movement was performed using the W, A, S, and D keys on the keyboard to navigate and the mouse to control the camera view. Participants were instructed to visually search for a specific type of object and to keep a mental count of the number of occurrences of the target object for which they were assigned. After the task, the participants reported their total target object count in an online survey.



Fig. 5 Participant’s view of HID Live



### **5.4.2 Auditory Math Task**

An auditory math problem was administered at the 8-min mark of exploration. Three separate sets of numbers were given during the task and each set consisted of a series of 3–4 numbers between 0–9, followed by a tone. After the tone and after each set, participants reported the sum of the series of numbers aloud to the experimenter, while moving through the environment (for a total of three responses). Participants were instructed to continue counting the number of target objects while performing the math task. Numbers were aurally presented at random intervals between 3.0–4.0 s. Between each set of numbers there is a break at random intervals between approximately 8.0–30.0 s.

### **5.4.3 Constructs for Analysis**

The HID Live task was intended to provide the following:

- 1) An applied framework for investigating the ocular and neural underpinnings of visual search and SA, including but not limited to the following:
  - a) Number, frequency, and duration of fixations on target versus nontarget stimuli
  - b) Variance in behavior as a function of stimulus properties (e.g., some targets are larger/smaller than others)
  - c) Impact that cognitive state manipulations, such as during the math task, have on behavior
  - d) Integration/synchronization of virtual world information with neural state and behavior (i.e., information can be sampled, and resampled, solely at the participant's discretion/leisure)
- 2) Trail blazes are intended to provide a common target stimulus to all groups.

## **5.5 Castle and Fountain Recall**

---

Subjects were presented with a grid of images and asked to click on the images that they recognized from the Castles and Fountains task. Fifty percent of the images were previously viewed, prior to the HID Live task and the remaining were new images. All targets (i.e., fountains, from the Castle and Fountain classification) were presented. Participants were free to scroll through subsequent pages of images to make selections (Fig. 6). There was no time limit on this task.



**Table 9 What each digit in the SSID represents**

| <b>W</b>   | <b>XX-</b>  | <b>Y</b>   | <b>Z</b>  |
|--|---|--|---|
| <i>FIRST DIGIT. Foundational amendments to the protocol require a different first digit, with more recent data having the highest serial number:</i> | <i>SECOND AND THIRD DIGIT. Is the “serial” number of participants”</i>        | <i>FOURTH DIGIT (AFTER THE DASH). the condition (see the Conditions section)</i> | <i>FIFTH DIGIT (To be used ONLY by JBSA to distinguish data collection site</i> |
| <i>1 - Pilot data</i>  | <i>This answers: “How early/ late in data collection was this collected?”</i> | <i>This answers: “What was the participant’s condition (target)?”</i>            | <i>1 = JBSA</i>   |
| <i>2 - Test data</i>   |   |  | <i>0 or n/a = Los Angeles</i>   |
| <i>3 - Consent Form signed data</i>  | <i>“What number participant was this?”</i>                                    |  | <i>This answers: “Where was this data collected?”</i>                           |
| <i>4 - Data that adds re-calibrated eye-tracking data in between tasks;</i>  |   |  |   |
| <i>5 - Ran executable that contained the “newer” condition the furniture and aircraft condition</i>  |   |  |   |
| <i>This answers: “Was this a debug or consented participant?”</i>  |   |  |   |
| <i>“What version of the experimental manual was used?”</i>   |   |  |   |

For example, for subject 324-2, the participant is the 24th person to come into the lab overall and is in the Humvee condition.

### 6.3 Conditions

Conditions in HID vary by which object target they are asked to mentally count while navigating a VE (see Section 5.4 *HID Live*). It is indicated by the fourth number in an SSID (e.g., 453-3). The numbers correspond as follows: 1 – *Motorcycle*, 2 – *Humvee*, 3 – *Furniture* 4 – *Aircraft*. Each participant gets to see all the object targets in HID live but they are randomly assigned to only *one* object target. For more information on the conditions, please see Section 2.2 [Experimental Design](#).

### 6.4 C3DS

The Cognition and Neuroergonomics Collaborative Technology Alliance (CaN CTA) Data Consortium Data Server (C3DS) is managed by DCS and provides secure data storage. Each folder in the C3DS system gives information about each participant. The filename is labeled “subject\_”, followed by a “P” (pilot), “S”

(subject), or “T” (test), and the participant’s four digit SSID (without the dash). This is followed by an underscore and a random string of characters. To get more information on file pathways and file types, please see [Appendix A: HID Data Specifications](#).

## 7. Generated Data (Analysis)

---

### 7.1 JPGs

---

During HID Live, the position of the camera is recorded. This information is stored in the XDF file as well as a separate .csv file. During postprocessing, images are created (i.e., JPGs and/or PNGs) for each position of the camera. Therefore, during post-processing, we can re-create and record a high-resolution image of the information displayed on the main monitor at any point during the HID Live run. However, atmospheric (i.e., clouds) and exact foliage position cannot be precisely replicated during the image-generation process. The image-generation tool is called the Snapshot Generator.

Image sequences for most subjects have been generated, resampled to 12 Hz, and encoded in MP4 movie format for further analysis. MP4 encoding does introduce small artifacts to the source PNG images, but Bland Altman analysis determined that over 95% of differences in pixel intensity between source PNG images and mp4 encoded images fell within a range of 13, which corresponds to 5% of the total range of red, green, blue (RGB) intensities (which range from 0–255). There was no significant bias in the mean difference between the PNG pixel intensities and the encoded MP4 intensities (i.e., the difference was not different from 0). Importantly, downsampling the image sequence from 120 Hz (monitor refresh rate) to 12 Hz, together with MP4 encoding, achieved a near 100-fold decrease in the storage space required to store the snapshots (from around 200 GB per subject to around 2 GB per subject).

### 7.2 Saliency Maps

---

Using the JPGs we have computed saliency maps from the pixel data using the following previously published approaches:

- **DeepFeat:** Mahdi A, Qin J, Crosby G. DeepFeat: a bottom-up and top-down saliency model based on deep features of convolutional neural networks. *IEEE Transactions on Cognitive and Developmental Systems*. 2020;12:54–63.

- **BMS**: Zhang J and Sclaroff S. Saliency detection: a Boolean map approach. In: Proceedings of the IEEE International Conference on Computer Vision; 2013. pp. 153–160.
- **DeepGazeII**: Kummerer M, Wallis TSA, Gatys LA, Bethge M. Understanding low-and high-level contributions to fixation prediction. In: Proceedings of the IEEE International Conference on Computer Vision; 2017. pp. 4789–4798.
- **ICF**: Kummerer M, Wallis TSA, Gatys LA, Bethge M. Understanding low-and high-level contributions to fixation prediction. In: Proceedings of the IEEE International Conference on Computer Vision; 2017. pp. 4789–4798.
- **CORS**: Rueopas W, Leelhapantu S, Chalidabhongse TH. A corner-based saliency model. In: 2016 13th International Joint Conference on Computer Science and Software Engineering (JCSSE); 2016. pp. 1–6. IEEE.
- **SDS**: Li Y and Mou X. Saliency detection based on structural dissimilarity induced by image quality assessment model. Journal of Electronic Imaging. 2019;28(2):023025.
- **SALICON**: Huang X, Shen C, Boix X, Zhao Q. Salicon: reducing the semantic gap in saliency prediction by adapting deep neural networks. In: Proceedings of the IEEE International Conference on Computer Vision; 2015. pp. 262–270.
- **CASNet2**: Fan S, Shen Z, Jiang M, Koenig BL, Xu J, Kankanhalli MS, Zhao Q. Emotional attention: A study of image sentiment and visual attention. In: Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition; 2018. pp. 7521–7531.
- **TASEDNet**: Min K and Corso JJ. TASED-Net: Temporally-Aggregating Spatial Encoder-Decoder Network for video saliency detection. In: Proceedings of the IEEE International Conference on Computer Vision; 2019. pp. 2394–2403.
- **STRA-Net**: Lai Q, Wang W, Sun H, Shen J. Video saliency prediction using spatiotemporal residual attentive networks. IEEE Transactions on Image Processing. 2019;29:1113–1126.
- **DeepVS**: Jiang L, Xu M, Liu T, Qiao M, Wang Z. Deepvs: A deep learning based video saliency prediction approach. In: Proceedings of the European Conference on Computer Vision (ECCV); 2018. pp. 602–617.

- **SALEMA**: Panagiotis L, Mohedano E, Nieto JJ, McGuinness K, Giro-i-Nieto X, O’Connor NE. Simple vs complex temporal recurrences for video saliency prediction. BMVC; 2019.

Due to computational constraints, the saliency maps have only been computed for detected fixations (Fig. 7).

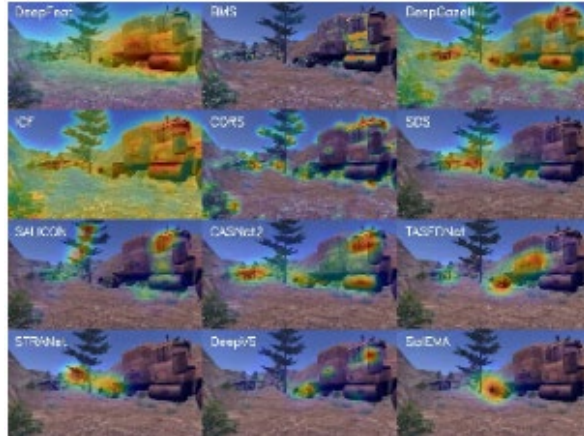


Fig. 7 Twelve saliency models calculated on one frame of the HID Live task

### 7.3 Corrected Eye Tracker

---

The Tobii Pro Spectrum can lose track of the eye position for a number of reasons. These data samples are recorded as a NaN in the Tobii stream. There are two primary reasons for this loss: 1) very brief (i.e., a couple of samples) drops in the data due to a number of Tobii-specific issues and 2) larger drops (i.e., order of seconds or more) in the data due to the participant moving in/out of the view box for the Tobii. While we cannot completely restore the missing data, we have implemented a technique to map the recorded EOG data from the BioSemi to the Tobii to correct/repair/replace missing data. We have visually inspected the results but have not formally presented or published on the method. This is intended to be used as is, and caveats apply.

### 7.4 Deep Learning Outputs

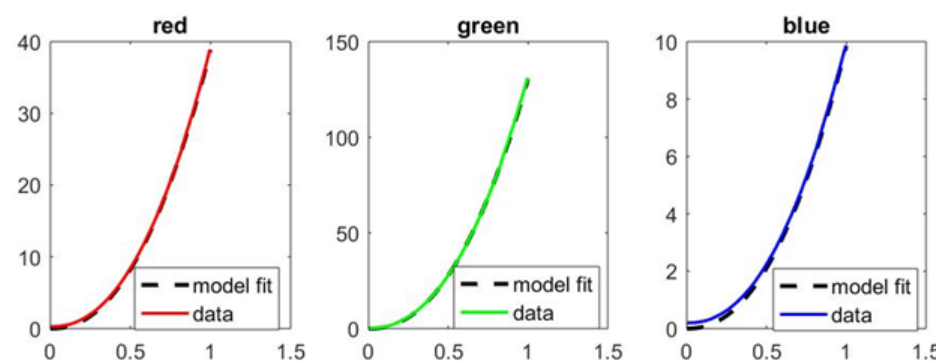
---

We have precomputed deep learning outputs for the data using the EEGNet deep learning tool and pretrained models, as published in (Solon et al. 2019). We are providing these, on a sample-by-sample basis for the EEG data with a downsample rate of 128 Hz.

## 7.5 Luminance

Luminance is of interest for the effect on pupil size data with regards to using this data type for human state estimation. Currently, luminance values are not available and instead a surrogate measure of luminance from converted RGB channel values is being used. It is possible to approximate screen luminance from the distribution of RGB values in the scene on each frame of the HID Live experiment (Fig. 8). This is accomplished by regenerating snapshots of each frame of the experiment (see Section 7.1 *JPGs* for more details). These snapshots are then used as covariates for models (Knapen et al. 2016; Korn and Bach, 2016) to parse out the effect of luminance to create a measure that more accurately estimates the cognitive component of the pupil size.

We have also used a photospectrometer in the whisper room to measure luminance ( $\text{cd}/\text{m}^2$ ) across the spectrum of each RGB color channel with the same computer screen settings and lighting environment used during the actual study. We then fit luminance measurements from each color channel (ranging from 0–255 in steps of 16) with an exponential function to derive a gamma value. This is the typical approach for “gamma-correcting” a monitor to linearize the color lookup table (clut). Indeed, the gamma parameters we derived from the study screen monitor was in the range of 2.2, which by design is typical for most modern day LCD monitors (red gamma = 2.24, green gamma = 2.23, blue gamma = 2.22). While this study did not employ the inverse gamma function during stimulus rendition on the screen to linearize the images shown to subjects in real time, these values may be useful in post-hoc analysis to translate RGB triplet values into approximate luminance values. To see computer screen settings for this project, please see *Appendix B. Computer Screen Settings*.



**Fig. 8** Luminance measurements ( $y$ -axis) in candelas per meter squared ( $\text{cd}/\text{m}^2$ ) as a function of red (left), green (middle), and blue (right) color intensity over the entire intensity space from 0–255 (normalized from 0 to 1 on the  $x$ -axis). The black dotted line is the model fit of an exponential function to the data, and the associated gamma parameters were red = 2.24, green = 2.23, blue = 2.22. By design, a typical LCD monitor has gamma values of around 2.2, which is consistent with these measurements.

Note: In addition to saliency and luminance, a number of other stimulus features may be calculated in coming months/years. These include, but are not limited to, optic flow and spatial frequency.

## 7.6 Lux

---

Lux is the measure of light levels in a room. This may be important to take into account for pupil size measurements since pupil size adapts to the light levels in the experimental testing area. In the current data set, lights in the testing area were replaced starting with SSID 580-3 and onward. The lux measurement before this implementation was 150 lx; however, no lux measurement was recorded after this implementation due to abrupt COVID-19 circumstances. This information will be updated as soon as possible (for inquiries related to lux, please contact the HID Data Guide POC [[Bianca Dalangin](#)]).

To see computer screen settings for this project, please see *[Appendix B. Computer Screen Settings](#)*.

## 8. Conclusion

---

---

In this guide, we have described a data set for the analysis of physiological (e.g., eye movement and brain activity), state (e.g., PTSD), and behavior (e.g., task performance) variables related to visual search during an active navigation of a VE as well as to a baseline recall task. This guide contains a sufficient level of detailed information for analysis of the corresponding data, including demographics, questionnaires, stimuli, task, and physiological time-series. As the research community continues to find ways to leverage existing data sets, we aim to facilitate transparency to enable increased collaboration and long-term impact by continuously maintaining this data guide and the lessons it contains. Specifically, as the Army looks to more academic and industry partners, such documents are invaluable to developing a common operating picture for understanding and interpreting Army research priorities. Establishing and maintaining this document to reflect data specifications is critical to the usability and longevity of this work.



## 9. References

---

- Golding JF. Predicting individual differences in motion sickness susceptibility by questionnaire. *Personality and Individual Differences*. 2006;41(2):237–248. doi: <https://doi.org/10.1016/j.paid.2006.01.012>.
- Hetherington R. The Snellen chart as a test of visual acuity. *Psychologische Forschung*. 1954;24:349–357. doi: <https://doi.org/10.1007/BF00422033>.
- Kennedy RS, Lane NE, Berbaum KS, Lilienthal MG. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*. 1993;3(3):203–220. doi: [https://doi.org/10.1207/s15327108ijap0303\\_3](https://doi.org/10.1207/s15327108ijap0303_3).
- Knapen T, de Gee JW, Brascamp J, Nuiten S, Hoppenbrouwers S, Theeuwes J. Cognitive and ocular factors jointly determine pupil responses under equiluminance. *PLoS ONE*. 2016;11(5). doi:10.1371/journal.pone.0155574.
- Korn CW, Bach DR. A solid frame for the window on cognition: modelling event-related pupil responses. *J Vis*. 2016;16(3). doi:10.1167/16.3.28.
- Lovie-Kitchin JE. Validity and reliability of visual acuity measurements. *Ophthalmic and Physiological Optics*. 1988;8(4):363–370. doi:<https://doi.org/10.1111/j.1475-1313.1988.tb01170.x>.
- Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*. 1971;9(1):97–113.
- Robinson J. Edinburgh handedness inventory. (Volkmar FR, ed.) *Encyclopedia of autism spectrum disorders*. Springer; 2013. doi:<https://doi.org/10.1007/978-1-4419-1698-3>
- Salvia J, Ysseldyke J. An analysis of the reliability and validity of the Ishihara color plates with mentally retarded males. *Perceptual and Motor Skills*. 1971;33:243–246. doi:<https://doi.org/10.2466/pms.1971.33.1.243>
- Solon AJ, Lawhern VJ, Touryan J, McDaniel JR, Ries AJ, Gordon SM. Decoding P300 variability using convolutional neural networks. *Front Hum Neurosci*. 2019;201. doi:10.3389/fnhum.
- Usuh M, Catena E, Arman S, Slater M. Using presence questionnaires in reality. *Presence: Teleoperators & Virtual Environments*. 2000;9(5):497–503. doi:<https://doi.org/10.1162/105474600566989>.

- Veale JF. Edinburgh handedness inventory - short form: a revised version based on confirmatory factor analysis. *Laterality: Asymmetries of Body, Brain and Cognition*. 2013;19(2):164–177. doi: 10.1080/1357650X.2013.783045.
- Weather F, Litz B, Herman DS, Huska JA, Keane TM. The PTSD Checklist (PCL): Reliability, validity, and diagnostic utility. Annual Convention of the International Society for Traumatic Stress Studies; 1993; San Antonio, TX.
- Witmer BG, Singer MJ. Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*. 1998;7(3):225–240. doi:<https://doi.org/10.1162/105474698565686>.
- Witmer BG, Jerome CJ, Singer MJ. The factor structure of the presence questionnaire. *Presence: Teleoperators & Virtual Environments*. 2005;14(3):298–312.

## **Appendix A. Human Interest Detector (HID) Data Specifications**

---

---

This section is a guide on how to interpret data from the visual search tasks. The directory structure is organized by participant.

## A.1 File Pathway

---

HID\_Live \ LA \

**Checked:** contains subject data that has passed basic quality control measures.

**Raw:** contains subject data as it was collected and that is awaiting quality control.

Note: In both Checked and Raw, folders contain all the files and subfolders available for each participant, indicated by subject ID (SSID).

**Reports:** contains data quality reports organized by subject.

In each participant folder, the following files and subfolders will be available:

### Baseline:

Baseline\_config.json  
experiment\_metadata.json  
Images.zip  
lab\_recorder\_generated\_config.cfg  
subject \*\_\*-\*-\*-.xdf (Baseline)

### Live:

camera\_transform.csv  
experiment\_metadata.json  
lab\_recorder\_generated\_config.cfg  
raycasts.csv  
subject \*\_\*-\*-\*-.xdf (Live)  
visual\_search\_object\_definitions.json

### Recall:

experiment\_metadata.json  
Images.zip  
lab\_recorder\_generated\_config.cfg  
subject \*\_\*-\*-\*-.xdf (Recall)

### Training:

camera\_transform.csv  
experiment\_metadata.json  
lab\_recorder\_generated\_config.cfg

raycasts.csv  
subject\_\*\*-\*\*-\*\*-\*.xdf (Training)

experiment\_metadata.json  
eye\_tracker\_calibration\_data.xml  
eye\_tracker\_config\_data.json  
system\_metadata.json

## A.2 File Types

---

### A.2.1 JavaScript Object Notation (JSON)

Metadata storage format. Parsers exist in all languages.

Relevant links:

- [Json grammar/overview](#)
- [Python3 Json parser](#)
- [Python2 Json parser](#)
- [Matlab Json parser \(built-in function\)](#)

### A.2.2 Extensible Data Format (XDF)

Data storage format used for storing LSL streams. Parsers exist in Matlab and Python.

See the XDF Github for more details.

Relevant links:

- [XDF Github](#)

### A.2.3 Extensible Markup Language (XML)

Tobii calibration data format. Parsers exist in all languages.

## A.3 File Descriptions

---

This section provides more detail on each file.

- `lab_recorder_generated_config.cfg`  
**File Type:** Custom text file format  
**Overview:** This file is generated and used as the configuration for starting Lab recorder. No relevant information is stored for research in this file.

- experiment\_metadata.json  
**File Type:** JSON  
**Overview:**  
**List of Useful Fields with Descriptions**  
 experiment\_name: Name of the current experiment (Baseline, Live, etc.)  
 subject\_id: generated ID of subject  
 start\_utc\_timestamp: start time of the experiment, expressed as the Coordinated Universal Time (UTC)  
 start\_local\_timestamp: local start time of the experiment  
 experimenter\_notes: text that was added by the experimenter at the start of the experiment  
 stop\_utc\_timestamp: stop time of the experiment, expressed as UTC  
 stop\_local\_timestamp: local stop time of the experiment
- eye\_tracker\_calibration\_data.xml  
**File Type:** XML  
**Overview:** Contains the Tobii calibrations data from the start of the experiment. We currently cannot parse this as it is in a proprietary format. Also, most of the subjects recalibrated during the experiment and those recalibrations are not recorded. This file should not be used in analysis.
- eye\_tracker\_config\_data.json  
**File Type:** JSON  
**Overview:**  
**List of Useful Fields with Descriptions**  
 GazeOutputFrequency: sampling rate in Hz of the eye tracker  
 DisplayArea:  
 TrackBox:
- system\_metadata.json  
**File Type:** JSON  
**Overview:**  
**List of Useful Fields with Descriptions**  
 screen: data related to the monitor  
 screen.height: height of the screen in pixels  
 screen.width: width of the screen in pixels  
 screen.dpi: dots per inch (DPI) of screen  
 system: general system data
- Images.zip  
**File Type:** Zip  
**Overview:** Zip file of the images used in the Recall and Baseline tasks

- `baseline_config.json`  
**File Type:** [JSON](#)  
**Overview:** Configuration used for the Baseline tasks.  
**List of Useful Fields with Descriptions**  
CrossHairDurationMin: minimum duration of the crosshair between images in seconds.  
CrossHairDurationMax: maximum duration the crosshair between images in seconds.  
ImageDuration: How long the image lasts on the screen in seconds.  
Blocks: How many times a break for the subject appears in the experiment.
- `visual_search_object_definitions.json`  
**File Type:** [JSON](#)  
**Overview:** Names and parameters for all objects in HID Unity environment. Has object IDs, names, and tags. Has object location and hit-box information. Note: some objects have multiple components and hit-boxes (see stream info).  
**Data Structure**  
VisualSearchTags: {3x1 cell}  
Screenshots: []  
GameTag: 'Humvee'  
Name: 'Humvee\_14'  
ObjectID: 8844  
UUID: '2207b7b3f379b114eb4655c0097cc6bc'  
FullSerialization: 1  
ShouldHeatMap: 1  
BoxColliders: [1x1 struct]  
AssociatedStreams: []
- `camera_transform.csv`  
**File Type:** `.csv`  
**Overview:** Contains a camera transforms (position, rotation) linked back to a raycast  
**List of Useful Fields with Descriptions**  
position\_x/position\_y/position\_z: position (x,y,z) in meters  
rotation\_x/rotation\_y/rotation\_z: euler rotation (x,y,z)  
count: links transform to raycast
- `raycasts.csv`  
**File Type:** `.csv`  
**Overview:** Contains raycasts for Subject's gaze points. Raycasts are 1-1 with VALID gaze points.

### List of Useful Fields with Descriptions

uuid: Uuid of the object the raycast hit

origin\_x/origin\_y/origin\_z: position(x,y,z) where the raycast started

direction\_x/direction\_y/direction\_z: euler direction(x,y,z) of the raycast

gaze\_data\_count: a link back to the gaze point that was used for this raycast

- subject\_\*\*-\*\*-\*.xdf (Baseline)

**File Type:** [XDF](#)

**Overview:** Contains all time-series data from the subject, including: task info, keyboard input, EEG, eye tracking (see stream info).

#### List of Streams with Channel Info

Number of Streams: 5

1. Stimulus (Markers) from CORSAIRONE

Channels: 5, Sample Rate: 0, Format: string, Samples: 1566

2. Tobii (Gaze) from CORSAIRONE

Channels: 33, Sample Rate: 300, Format: double64, Samples: 394278

3. BioSemi (EEG) from CORSAIRONE

Channels: 89, Sample Rate: 2048, Format: float32, Samples: 2801686

4. Response (Markers) from CORSAIRONE

Channels: 1, Sample Rate: 0, Format: int16, Samples: 75

5. Keyboard (Markers) from CORSAIRONE

Channels: 1, Sample Rate: 0, Format: string, Samples: 160

- subject\_\*\*-\*\*-\*.xdf (Live)

**File Type:** [XDF](#)

**Overview:** Contains all time-series data from the subject, including: task info, keyboard input, EEG, eye tracking (see stream info).

#### List of Streams with Channel Info

Number of Streams: 6

1. Keyboard (Markers) from CORSAIRONE

Channels: 1, Sample Rate: 0, Format: string, Samples: 16

2. Subject (Transform) from CORSAIRONE

Channels: 7, Sample Rate: 0, Format: float32, Samples: 93955

3. BioSemi (EEG) from CORSAIRONE

Channels: 89, Sample Rate: 2048, Format: float32, Samples: 1607672

4. Math\_Task (Markers) from CORSAIRONE

Channels: 1, Sample Rate: 0, Format: string, Samples: 44



- 5. Tobii (Gaze) from CORSAIRONE  
Channels: 33, Sample Rate: 300, Format: double64, Samples: 233434
- 6. Trail\_Blaze (Markers) from CORSAIRONE  
Channels: 1, Sample Rate: 0, Format: string, Samples: 19
- subject\_\*\*-\*\*-\*\*.xdf (Recall)
  - File Type:** [XDF](#)
  - Overview:** Contains all time-series data from the subject, including: task info, keyboard input, EEG, eye tracking (see stream info).
  - List of Streams with Channel Info**
  - Number of Streams: 7
  - 1. Selection (Markers) from CORSAIRONE  
Channels: 5, Sample Rate: 0, Format: string, Samples: 52
  - 2. Stimulus (Markers) from CORSAIRONE  
Channels: 6, Sample Rate: 0, Format: string, Samples: 936
  - 3. Keyboard (Markers) from CORSAIRONE  
Channels: 1, Sample Rate: 0, Format: string, Samples: 4
  - 4. Tobii (Gaze) from CORSAIRONE  
Channels: 33, Sample Rate: 300, Format: double64, Samples: 82023
  - 5. BioSemi (EEG) from CORSAIRONE  
Channels: 89, Sample Rate: 2048, Format: float32, Samples: 1215547
  - 6. MouseButtons (Markers) from CORSAIRONE  
Channels: 1, Sample Rate: 0, Format: string, Samples: 157
  - 7. MousePosition (Position) from CORSAIRONE  
Channels: 2, Sample Rate: 0, Format: float32, Samples: 11190
- subject\_\*\*-\*\*-\*\*.xdf (Training)
  - File Type:** [XDF](#)
  - Overview:** Contains all time-series data from the subject, including: task info, keyboard input, EEG, eye tracking (see stream info).

## A.4 Live XDF Stream Channel Labels

---

Note: The stream numbers/sequence are arbitrary.

Number of Streams: 6

- 1) Keyboard (Markers) from CORSAIRONE

Channels: 1, Sample Rate: 0, Format: string, Samples: 16

- 2) Subject (Transform) from CORSAIRONE

Channels: 7, Sample Rate: 0, Format: float32, Samples: 93955

|                        |                        |                   |
|------------------------|------------------------|-------------------|
| Channel 1 - position_x | Channel 4 - rotation_x | Channel 7 - Count |
| Channel 2 - position_y | Channel 5 - rotation_y |                   |
| Channel 3 - position_z | Channel 6 - rotation_z |                   |

- 3) BioSemi (EEG) from CORSAIRONE

Channels: 89, Sample Rate: 2048, Format: float32, Samples: 1607672

|                   |                  |                    |
|-------------------|------------------|--------------------|
| Channel 1 - Trig1 | Channel 31 - A30 | Channel 61 - B28   |
| Channel 2 - A1    | Channel 32 - A31 | Channel 62 - B29   |
| Channel 3 - A2    | Channel 33 - A32 | Channel 63 - B30   |
| Channel 4 - A3    | Channel 34 - B1  | Channel 64 - B31   |
| Channel 5 - A4    | Channel 35 - B2  | Channel 65 - B32   |
| Channel 6 - A5    | Channel 36 - B3  | Channel 66 - EX1   |
| Channel 7 - A6    | Channel 37 - B4  | Channel 67 - EX2   |
| Channel 8 - A7    | Channel 38 - B5  | Channel 68 - EX3   |
| Channel 9 - A8    | Channel 39 - B6  | Channel 69 - EX4   |
| Channel 10 - A9   | Channel 40 - B7  | Channel 70 - EX5   |
| Channel 11 - A10  | Channel 41 - B8  | Channel 71 - EX6   |
| Channel 12 - A11  | Channel 42 - B9  | Channel 72 - EX7   |
| Channel 13 - A12  | Channel 43 - B10 | Channel 73 - EX8   |
| Channel 14 - A13  | Channel 44 - B11 | Channel 74 - AUX1  |
| Channel 15 - A14  | Channel 45 - B12 | Channel 75 - AUX2  |
| Channel 16 - A15  | Channel 46 - B13 | Channel 76 - AUX3  |
| Channel 17 - A16  | Channel 47 - B14 | Channel 77 - AUX4  |
| Channel 18 - A17  | Channel 48 - B15 | Channel 78 - AUX5  |
| Channel 19 - A18  | Channel 49 - B16 | Channel 79 - AUX6  |
| Channel 20 - A19  | Channel 50 - B17 | Channel 80 - AUX7  |
| Channel 21 - A20  | Channel 51 - B18 | Channel 81 - AUX8  |
| Channel 22 - A21  | Channel 52 - B19 | Channel 82 - AUX9  |
| Channel 23 - A22  | Channel 53 - B20 | Channel 83 - AUX10 |
| Channel 24 - A23  | Channel 54 - B21 | Channel 84 - AUX11 |

|                  |                  |                    |
|------------------|------------------|--------------------|
| Channel 25 - A24 | Channel 55 - B22 | Channel 85 - AUX12 |
| Channel 26 - A25 | Channel 56 - B23 | Channel 86 - AUX13 |
| Channel 27 - A26 | Channel 57 - B24 | Channel 87 - AUX14 |
| Channel 28 - A27 | Channel 58 - B25 | Channel 88 - AUX15 |
| Channel 29 - A28 | Channel 59 - B26 | Channel 89 - AUX16 |
| Channel 30 - A29 | Channel 60 - B27 |                    |

External Channels (EX/EXG):

|                          |                       |
|--------------------------|-----------------------|
| EX1 (66) = Right Mastoid | EX5 (70) = LeogVbelow |
| EX2 (67) = Left Mastoid  | EX6 (71) = LeogVabove |
| EX3 (68) = ReogH         | EX7 (72) = EKG        |
| EX4 (69) = LeogH         |                       |

4) Math\_Task (Markers) from CORSAIRONE

Channels: 1, Sample Rate: 0, Format: string, Samples: 44

Channel 1 - Math\_Task\_Event

5) Tobii (Gaze) from CORSAIRONE

Channels: 33, Sample Rate: 300, Format: double64, Samples: 233434

Channel 1 - Eyetracker\_Timestamp

Channel 2 - System\_Timestamp

Channel 3 - LeftEye\_GazeOrigin\_PositionInUserCoordinates\_X

Channel 4 - LeftEye\_GazeOrigin\_PositionInUserCoordinates\_Y

Channel 5 - LeftEye\_GazeOrigin\_PositionInUserCoordinates\_Z

Channel 6 - RightEye\_GazeOrigin\_PositionInUserCoordinates\_X

Channel 7 - RightEye\_GazeOrigin\_PositionInUserCoordinates\_Y

Channel 8 - RightEye\_GazeOrigin\_PositionInUserCoordinates\_Z

Channel 9 - LeftEye\_GazeOrigin\_PositionInTrackBoxCoordinates\_X

Channel 10 - LeftEye\_GazeOrigin\_PositionInTrackBoxCoordinates\_Y

Channel 11 - LeftEye\_GazeOrigin\_PositionInTrackBoxCoordinates\_Z

Channel 12 - RightEye\_GazeOrigin\_PositionInTrackBoxCoordinates\_X

Channel 13 - RightEye\_GazeOrigin\_PositionInTrackBoxCoordinates\_Y

Channel 14 - RightEye\_GazeOrigin\_PositionInTrackBoxCoordinates\_Z

Channel 15 - LeftEye\_GazePoint\_PositionInUserCoordinates\_X

Channel 16 - LeftEye\_GazePoint\_PositionInUserCoordinates\_Y

Channel 17 - LeftEye\_GazePoint\_PositionInUserCoordinates\_Z

Channel 18 - RightEye\_GazePoint\_PositionInUserCoordinates\_X

Channel 19 - RightEye\_GazePoint\_PositionInUserCoordinates\_Y

Channel 20 - RightEye\_GazePoint\_PositionInUserCoordinates\_Z

Channel 21 - LeftEye\_GazePoint\_PositionOnDisplayArea\_X  
Channel 22 - LeftEye\_GazePoint\_PositionOnDisplayArea\_Y  
Channel 23 - RightEye\_GazePoint\_PositionOnDisplayArea\_X  
Channel 24 - RightEye\_GazePoint\_PositionOnDisplayArea\_Y  
Channel 25 - LeftEye\_Pupil\_PupilDiameter  
Channel 26 - RightEye\_Pupil\_PupilDiameter  
Channel 27 - LeftEye\_GazeOrigin\_Validity  
Channel 28 - RightEye\_GazeOrigin\_Validity  
Channel 29 - LeftEye\_GazePoint\_Validity  
Channel 30 - RightEye\_GazePoint\_Validity  
Channel 31 - LeftEye\_Pupil\_Validity  
Channel 32 - RightEye\_Pupil\_Validity  
Channel 33 - Gaze\_Data\_Count

6) Trail\_Blaze (Markers) from CORSAIRONE

Channels: 1, Sample Rate: 0, Format: string, Samples: 19

Channel 1 - Trail\_Blaze\_Activated

#### **A.5 Live Raycast Channel Labels**

---

Columns: 10

'origin\_x'

'origin\_y'

'origin\_z'

'direction\_x'

'direction\_y'

'direction\_z'

'point\_x'

'point\_y'

'point\_z'

'gaze\_data\_count'

#### **A.6 Live Camera Transform Channel Labels**

---

Columns: 7

'position\_x'

'position\_y'

'position\_z'

'rotation\_x'

'rotation\_y'

'rotation\_z'

'Count'

## **Appendix B. Computer Screen Settings**

---

---

Table B-1 lists the computer screen settings.

**Table B-1 Computer screen settings**

|  |   |  |
|--|---|--|
| <p><b>Screen settings</b><br/>         Color Mode – User 1<br/>         Overdrive – Standard<br/>         Hue – 0<br/>         Saturation - 0<br/>         Brightness – 93<br/>         Contrast – 50<br/>         Temperature – 6500 K<br/>         Gamma – 2.2<br/> <b>Input Signal – 1080p</b><br/>         fH – 67.6 kHz<br/>         fV – 60.1 Hz<br/>         fD - 148.2 MHz</p> | <p><b>Signal (HDMI)</b><br/>         Picture Expansion – Aspect Ratio<br/>         Sharpness – 0<br/>         Input Color Format - RGB<br/>         Input Range – Auto<br/>         Sound Source – HDMI<br/>         Menu Rotation – 0°<br/>         Power Save – On<br/>         Power Indicator – On<br/>         Information (HDMI)<br/>         Usage Time (h) – 1400</p> | <p><b>EcoView Settings</b><br/>         Auto EcoView – Off<br/>         EcoView Optimizer 2 – Off<br/>         Power Reduction – 2 W<br/>         CO2 Reduction - 1 g<br/>         Eco Performance Level – Level 1</p> |
|--|---|--|

## List of Symbols, Abbreviations, and Acronyms

---

|         |   |
|---------|---|
| 3-D     | three-dimensional   |
| APG     | Aberdeen Proving Ground   |
| ARL     | Army Research Laboratory  |
| C3DS    | CaN CTA Data Consortium Data Server                             |
| CaN CTA | Cognition and Neuroergonomics Collaborative Technology Alliance |
| CCDC    | US Army Combat Capabilities Development Command                 |
| .csv    | comma-separated value   |
| D       | disorientation  |
| DSM-IV  | Diagnostic and Statistical Manual                               |
| EEG     | electroencephalography  |
| EOG     | electrooculogram  |
| HID     | Human Interest Detector   |
| HR      | heart rate  |
| HRED    | Human Research and Engineering Directorate                      |
| HRPP    | Human Research Protection Program                               |
| ISI     | InterStimulus Interval  |
| JBSA    | Joint Base San Antonio  |
| JSON    | JavaScript Object Notation                                      |
| LCD     | liquid-crystal display  |
| LSL     | lab streaming layer   |
| MOS     | Military Occupational Specialty                                 |
| MSA     | motion sickness susceptibility as a child                       |
| MSB     | motion sickness susceptibility as an adult                      |
| MSSQ    | Motion Sickness Susceptibility Questionnaire                    |
| N       | nausea  |
| O       | oculomotor  |

|      |                                  |
|------|----------------------------------|
| PC   | personal computer                |
| POC  | point of contact                 |
| PQ   | Presence Questionnaire           |
| PSID | prescreen subject identification |
| PTSD | post-traumatic stress disorder   |
| RGB  | red, green, blue                 |
| RSVP | rapid serial visual presentation |
| SA   | situational awareness            |
| SSID | session subject identification   |
| VE   | virtual environment              |
| VR   | virtual reality                  |
| XDF  | Extensible Data Format           |
| XML  | Extensible Markup Language       |



1 DEFENSE TECHNICAL  
(PDF) INFORMATION CTR  
DTIC OCA

1 CCDC ARL  
(PDF) FCDD RLD DCI  
TECH LIB

1 CCDC ARL  
(PDF) FCDD RLH B  
T DAVIS  
BLDG 5400 RM C242  
REDSTONE ARSENAL AL  
35898-7290

1 CCDC ARL  
(PDF) FCDD HSI  
J THOMAS  
6662 GUNNER CIRCLE  
ABERDEEN PROVING  
GROUND MD  
21005-5201

1 USAF 711 HPW  
(PDF) 711 HPW/RH K GEISS  
2698 G ST BLDG 190  
WRIGHT PATTERSON AFB OH  
45433-7604

1 USN ONR  
(PDF) ONR CODE 341 J TANGNEY  
875 N RANDOLPH STREET  
BLDG 87  
ARLINGTON VA 22203-1986

1 USA NSRDEC  
(PDF) RDNS D D TAMILIO  
10 GENERAL GREENE AVE  
NATICK MA 01760-2642

1 OSD OUSD ATL  
(PDF) HPT&B B PETRO  
4800 MARK CENTER DRIVE  
SUITE 17E08  
ALEXANDRIA VA 22350

ABERDEEN PROVING GROUND

23 CCDC ARL  
(PDF) FCDD RLH  
J LANE  
Y CHEN  
P FRANASZCZUK  
A MARATHE  
K MCDOWELL  
K OIE  
FCDD RLH F  
J GASTON (A)  
FCDD RLH FA  
A DECOSTANZA  
L ENDERS  
A JETER  
J VILLARREAL  
FCDD RLH FB  
D BOOTHE (A)  
R COHEN HOFFING  
B DALANGIN  
A OIKNINE  
H ROY  
S THURMAN  
FCDD RLH FC  
K COX (A)  
J TOURYAN  
S GORDON  
R SMITH  
FCDD RLH FD  
A FOOTS (A)  
FCDD RLH FE  
D HEADLEY