AFRL-RH-WP-TR-2020-0064

COG-PACK™ EYE/HEAD/GAZE/HEATMAP/3D DISPLAY DOCUMENTATION

2Lt Matt Rommel
Mr. Allen W. Dukes
Airman Biosciences Division

Mr. Ethan Blackford
Ball Aerospace & Technologies

May 2020
Interim Report

DISTRIBUTION A. Approved for public release.

AIR FORCE RESEARCH LABORATORY
711TH HUMAN PERFORMANCE WING,
AIRMAN SYSTEMS DIRECTORATE,
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

NOTICE AND SIGNATURE PAGE

Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data does not license the holder or any other person or corporation; or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

This report was cleared for public release by 88th Air Base Wing Public Affairs Office and is available to the general public including foreign nationals. Copies may be obtained from the Defense Technical Information Center (DTIC) (http://www.dtic.mil).

AFRL-RH-WP-TR-2020-0064 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

SOTO.ARMAN
DO.1262578328
Digitally signed by
SOTO.ARMANDO.1262578328
Date: 2020.08.17 16:47:02 -04'00'

ARMANDO SOTO
Work Unit Manager
Warfighter Interface Branch

MCKINLEY.RICHA
RD.A.1262239710
Digitally signed by
MCKINLEY.RICHARD.A.1262239710
Date: 2020.08.24 10:27:59 -04'00'

R. ANDY MCKINLEY, PhD
Core Research Area Lead
Cognitive Neuroscience Branch
Airman Biosciences Divisio

This report is published in the interest of scientific and technical information exchange, and its publication does not constitute the Government's approval or disapproval of its ideas or findings.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The 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, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this 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. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS**.

1. REPORT DATE ***(DD-MM-YY)*** 01-05-20	**2. REPORT TYPE** Interim	**3. DATES COVERED** ***(From - To)*** Jan 2019 to March 2020

4. TITLE AND SUBTITLE
COG-PACK™ EYE/HEAD/GAZE/HEATMAP/3D DISPLAY DOCUMENTATION

5a. CONTRACT NUMBER
FA8650-16-C-6610

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)
2Lt Matt Rommel*
Mr. Allen W. Dukes*
Mr. Ethan B. Blackford+

5d. PROJECT NUMBER
5329

5e. TASK NUMBER
08

5f. WORK UNIT NUMBER
H0KG (53290819)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ball Aerospace & Technologies+
2675 Presidential Drive, Fairborn, OH 45324

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Materiel Command*
Air Force Research Laboratory
711 Human Performance Wing
Airman Systems Directorate
Warfighter Interface Division
Applied Neuroscience Branch
Wright-Patterson AFB, OH 45433

Air Force Materiel Command**
Air Force Research Laboratory
711 Human Performance Wing
USAF School of Aerospace Medicine
Wright-Patterson AFB, OH 45433

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
711HPW/RHBC

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-RH-WP-TR-2020-0064

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release.

13. SUPPLEMENTARY NOTES 88ABW-2020-2580, cleared 13 August 2020

14. ABSTRACT

Viewing physiological signals can take many forms. Historically, electro-mechanical devices contained the elements required to display the waveforms. These devices used mechanically driven rolls of paper tape with pens to transcribe the waveforms of interest over time. A modern example that may be familiar to many is the polygraph machine. A polygraph machine typically displays blood pressure, pulse rate, respiration, and skin conductivity to the examiner. From these waveforms, the examiner then determines the validity of a test subject's statements.
Given the new emphasis on digital technologies and the rise of software-based solutions, many physiological devices still present the waveform data to a user as a strip-chart. These strip-charts are useful for many physiological data types, but not all. In some circumstances, three dimensional (3D) models may provide greater insight. For Eye, Head, and Gaze-based data-types, as well as a few additional derived types, creating and displaying a 3D world model may afford a more comprehensive view of a participant's interaction with task elements. Additionally, when presenting data in real-time from more open-ended experimental design constructs, further consideration in the presentation of these data can be constructed. This document discusses the approach taken in COG Pack™ to not only display those data-types but permits many additional controls and adjustments.

15. SUBJECT TERMS
COG Pack™, Eye, Head, Gaze, Heatmap, 3D Display, Documentation, Visualization

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT:**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** (Monitor)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Armando Soto
Unclassified	Unclassified	Unclassified	SAR	25	**19b. TELEPHONE NUMBER** *(Include Area Code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

COG PACK™
EYE/HEAD/GAZE/HEATMAP
3D DISPLAY DOCUMENTATION

Matt T. Rommel, Allen W. Dukes, Ethan B. Blackford

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

Viewing physiological signals can take many forms. Historically, electro-mechanical devices contained the elements required to display the waveforms. These devices used mechanically driven rolls of paper tape with pens to transcribe the waveforms of interest over time. A modern example that may be familiar to many is the polygraph machine. A polygraph machine typically displays blood pressure, pulse rate, respiration, and skin conductivity to the examiner. From these waveforms, the examiner then determines the validity of a test subject's statements.

Given the new emphasis on digital technologies and the rise of software-based solutions, many physiological devices still present the waveform data to a user as a strip-chart. These strip-charts are useful for many physiological data types, but not all. In some circumstances, three dimensional (3D) models may provide greater insight. For Eye, Head, and Gaze-based data-types, as well as a few additional derived types, creating and displaying a 3D world model may afford a more comprehensive view of a participant's interaction with task elements. Additionally, when presenting data in real-time from more open-ended experimental design constructs, further consideration in the presentation of these data can be constructed. This document discusses the approach taken in COG Pack™ to not only display those data-types but permits many additional controls and adjustments.

2.0 OVERVIEW

The configurable options are all displayed in a black tab on the top right of the screen several collapsible folders help group related controls. (Figure 1).

Camera - Manages the automatic positioning of the camera at one of its predefined locations.

Other - Oversees the following options: Gaze Line adjustment; Visibility of the reflective portion of the screens; Toggling the character's head model; Adjusting the screen-capture display opacity.

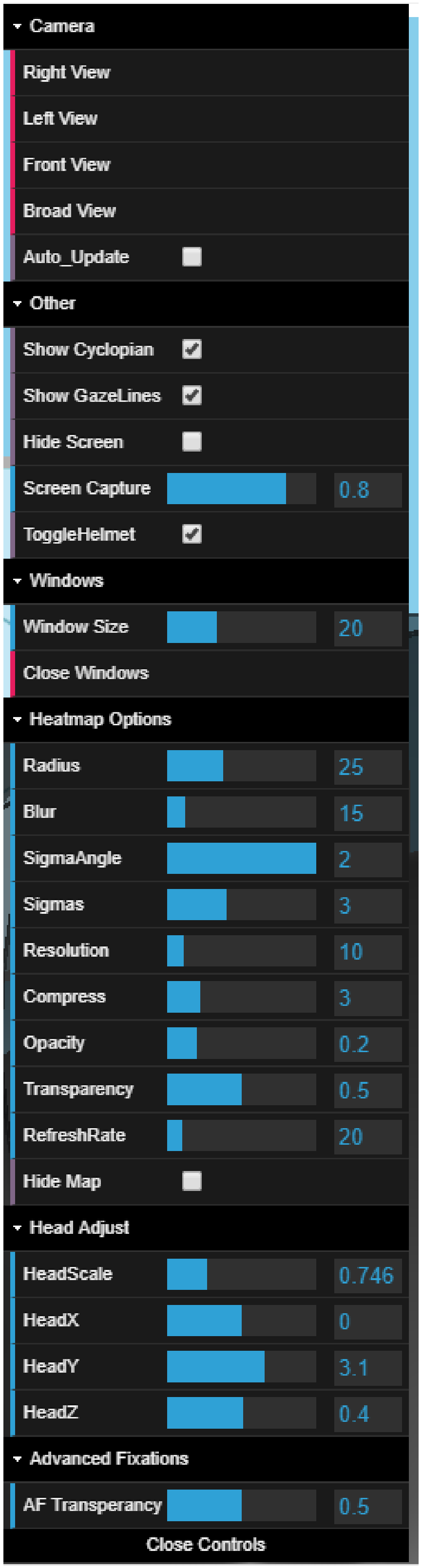
Windows - Controls the organization of the sub-windows in the upper left.

Heatmap - Maintains the settings for the real-time heatmap display.

Head Adjust - Manipulates the proportions of the head model.

Advanced Fixations – Manipulates the settings for the real-time advanced fixations display

The folders themselves (i.e., Camera, Box, Other) collapse if you click their name. This functionality provides the user with the ability to collapse a folder, decluttering the screen.



Camera
Right View
Left View
Front View
Broad View
Auto_Update ☐
Other
Show Cyclopian ☑
Show GazeLines ☑
Hide Screen ☐
Screen Capture 0.8
ToggleHelmet ☑
Windows
Window Size 20
Close Windows
Heatmap Options
Radius 25
Blur 15
SigmaAngle 2
Sigmas 3
Resolution 10
Compress 3
Opacity 0.2
Transparency 0.5
RefreshRate 20
Hide Map ☐
Head Adjust
HeadScale 0.746
HeadX 0
HeadY 3.1
HeadZ 0.4
Advanced Fixations
AF Transperancy 0.5
Close Controls

Figure 1. Configurable Options

3.0 METHODS, ASSUMPTIONS, AND PROCEDURES

3.1 Camera Controls

You can control the camera by clicking and dragging on the screen, or by selecting options in the Camera Folder. (Figure 2.)

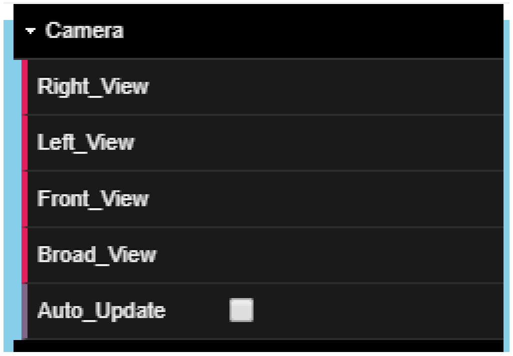


Figure 2. Camera Controls Sub-Window

3.1.1. Camera Mouse Controls

By default, the camera focuses on a particular point in space. **Clicking and dragging** the mouse on the screen causes the camera to rotate about its focal point in the direction of the mouse drag. **Scrolling the mouse** wheel zooms the camera towards or away from its focal point. **Holding Shift while clicking and dragging** changes the camera's focal point in the direction of the mouse drag.

Instead of trying to follow the above instructions, experiment with clicking and dragging, scrolling, and shift dragging about the screen to get an intuitive feel for camera manipulation.

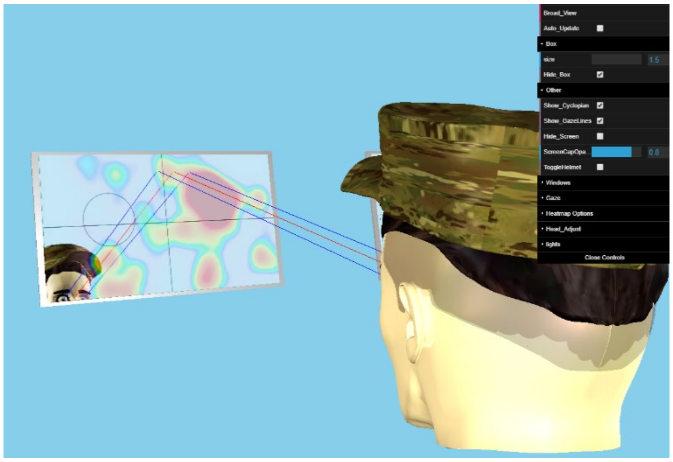
3.1.2. Front_View

The Front_View option first focuses the camera on the head. Then this option positions the camera in front of the head at a distance that allows the whole face to be visible. (Figure 3.)

Figure 3. Camera Controls: Front View Option

3.1.3. Left_View

The Left_View focuses the camera on the first screen in the world model. Next, it positions the camera slightly to the head model's left such that the screen, the head's profile, and the gaze vectors are all visible. (Figure 4.)



Auto_Update ☐
size 1.5
Hide_Box ☑
Show_Cyclopian ☑
Show_GazeLines ☑
Hide_Screen ☐
ScreenCapOpa... 0.8
ToggleHelmet ☐

Figure 4. Camera Controls: Left View Option

3.1.4. Right_View

The Right_View option focuses the camera on the first screen in the world model. Subsequently, the camera's position is adjusted slightly to the head model's right, such that the screen, the head's profile, and the gaze vectors are all visible. (Figure 5.)

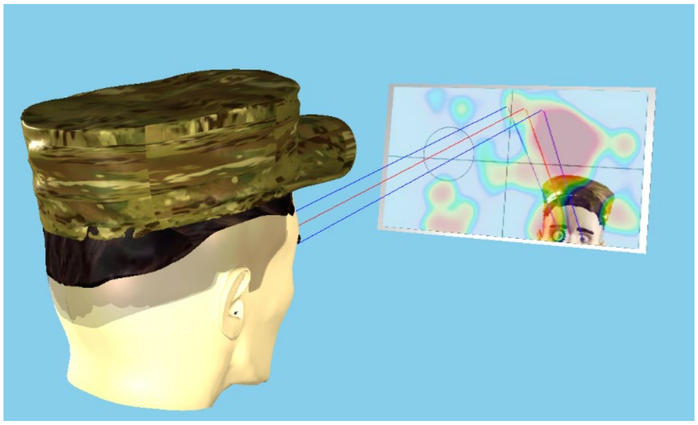


Figure 5. Camera Controls: Right View Option

3.1.5. Broad_View

The Broad_View option focuses the camera on the head, places the camera behind the screen, and hides the screen, such that the screen's heatmap, gaze vectors, and eye rotations are all visible. (Figure 6.)

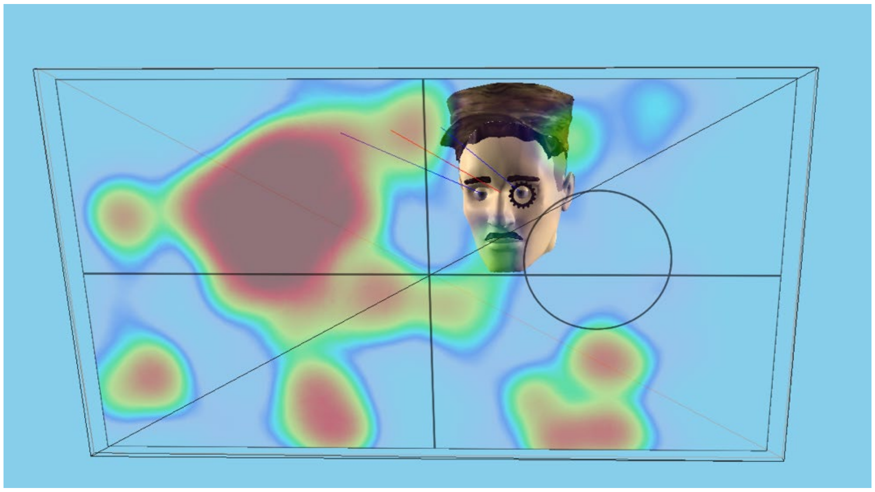


Figure 6. Camera Controls: Broad View Option

3.1.6. Auto_Update

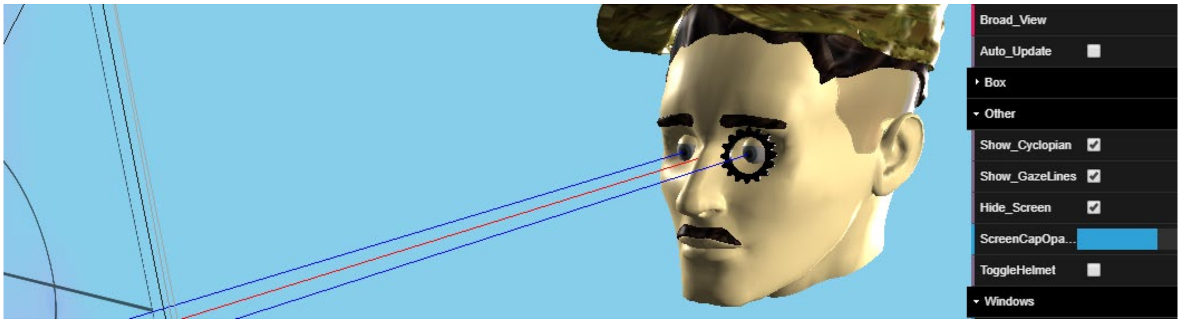
The Auto_Update checkbox, when enabled, automatically updates the camera position to the selected, pre-defined viewpoint each frame. This enables the camera to track head movement, but disables camera mouse controls.

The predefined viewpoints (front, right, left, and broad) work by positioning the camera a set distance from the head and then focusing the camera on the head or screen as applicable. Without Auto_Update enabled, the camera position will be set at a defined offset from the head's position at the moment that that particular viewpoint is chosen, but then the camera will stay at that place regardless of how the head moves. This gives you the freedom to then adjust the camera position with the mouse controls. With Auto_update enabled, however, the camera will snap back to the chosen viewpoint each frame, automatically recalculating the camera's position and focus, which will keep the camera at a set offset from the head as it moves. These automatic updates will disable camera mouse controls.

3.2 Other Controls

3.2.1. Show_Cyclopian and Show_GazeLines

These vectors convey where the operator is looking, stretching from his eyes and intersecting with an object. Figure 7 shows both vectors enabled (the default setting):

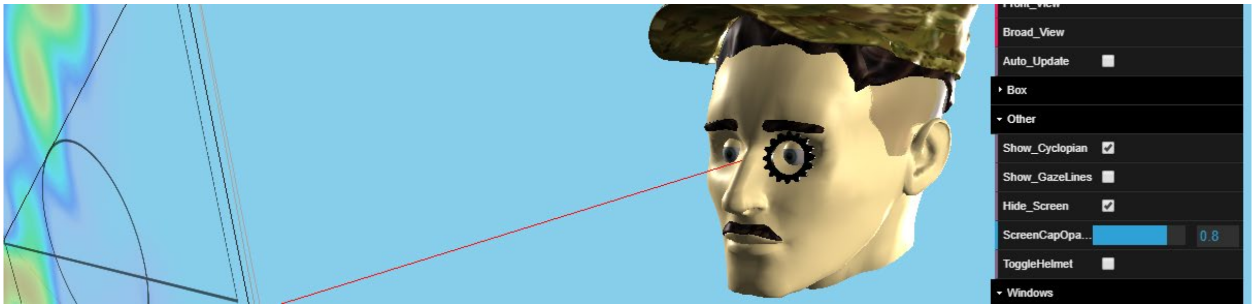


Auto_Update ☐
Show_Cyclopian ☑
Show_GazeLines ☑
Hide_Screen ☑
ScreenCapOpa...
ToggleHelmet ☐

Figure 7. Show Cyclopian and Gaze Lines

3.3 Show_Cyclopian

When enabled, the Show Cyclopian setting draws a vector originating from the point located between the operator's eyes parallel to the participant's two gaze vectors—essentially what the participant's gaze vector would be like if they were a cyclops. (Figure 8.)

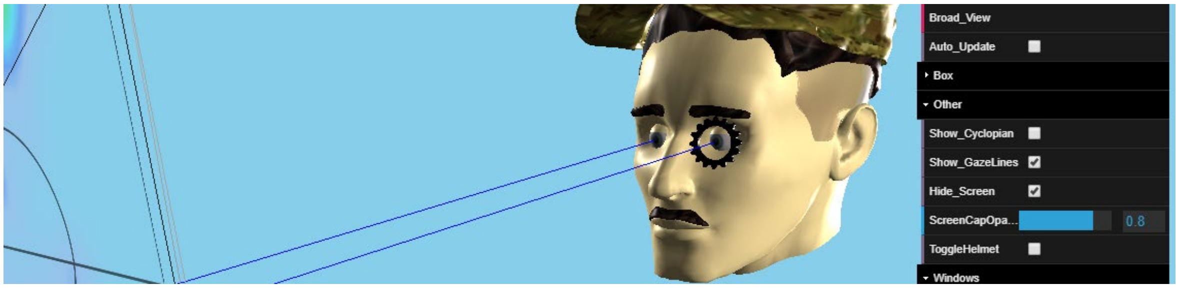


Auto_Update ☐
Show_Cyclopian ☑
Show_GazeLines ☐
Hide_Screen ☑
ScreenCapOpa... 0.8
ToggleHelmet ☐

Figure 8. Show Cyclopian

3.4 Show_GazeLines

The Show Gazeline option draws vectors from the center of each of the participant's eyes until they intersect with an object. (Figure 9.)



Broad_View
Auto_Update ☐
▸ Box
▾ Other
Show_Cyclopian ☐
Show_GazeLines ☑
Hide_Screen ☑
ScreenCapOpa... 0.8
ToggleHelmet ☐
▾ Windows

Figure 9. Show GazeLines

3.4.1. Hide_Screen

By default, a monitor object is drawn with a metallic bezel and reflective screen as shown on the left in Figure 10. When Hide_Screen is enabled, both of these objects become transparent, leaving just their outlines visible (as shown on the right in Figure 10).

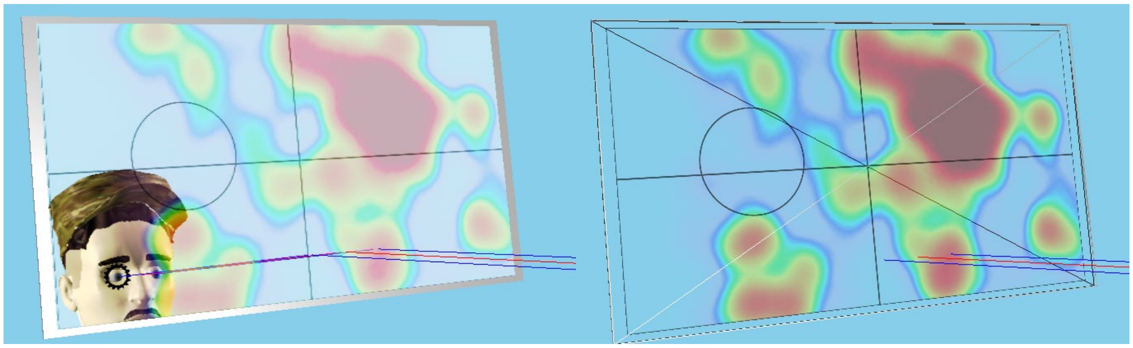


Figure 10. Hide Screen Option

3.4.2 ToggleHelmet

ToggleHelmet allows the user to switch between the two available character models seen in Figure 11.

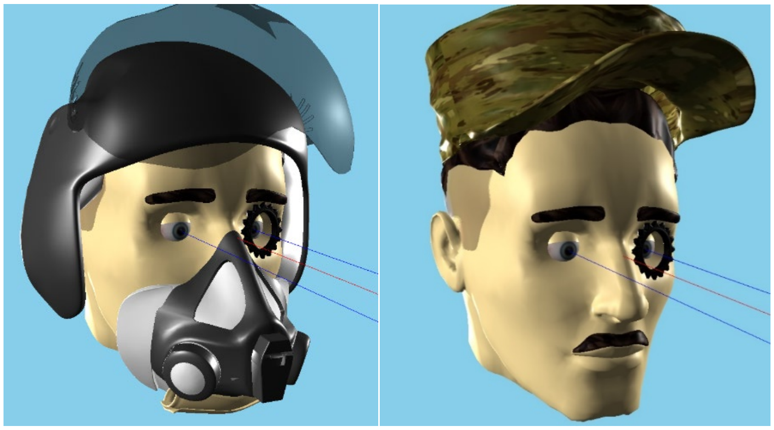
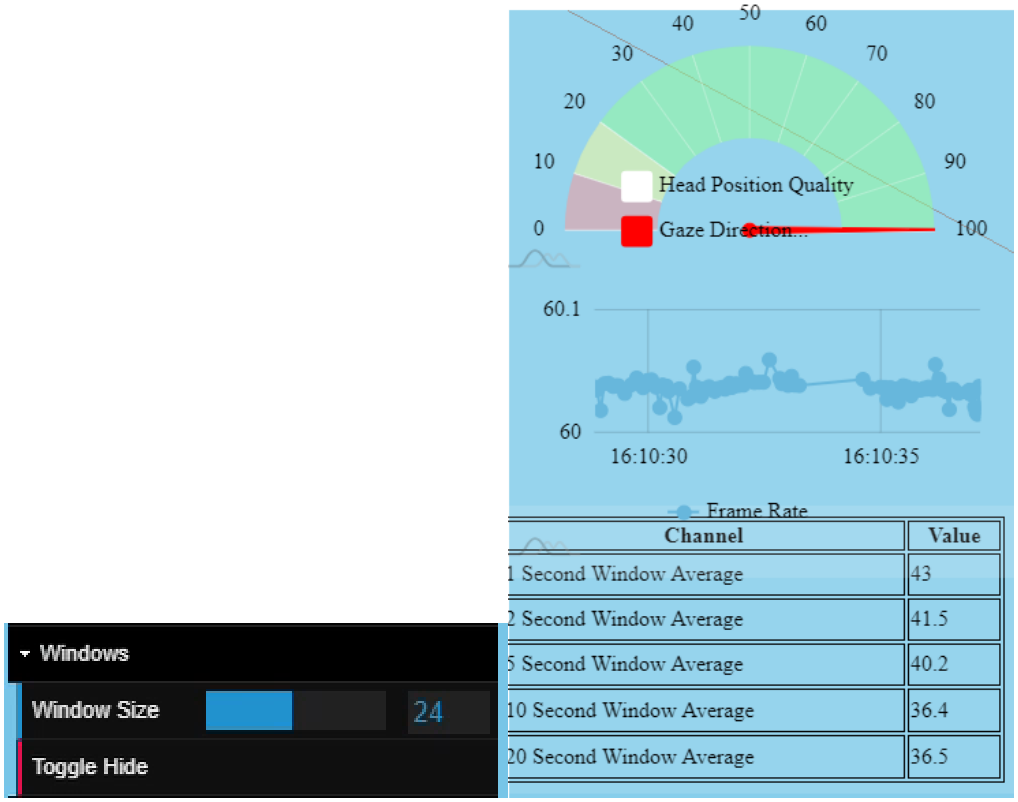


Figure 11. Toggle Helmet Settling

3.5 Windows

In addition to the 3D world model, additional statistical information is also presented as gauges, timelines, and tables. The controls listed in the Windows option control their display properties. (Figure 12.)



Channel	Value
1 Second Window Average	43
2 Second Window Average	41.5
5 Second Window Average	40.2
10 Second Window Average	36.4
20 Second Window Average	36.5

Windows

Window Size 24

Toggle Hide

Figure 12. Windows Settings Sub-Window and Display

3.5.1. Gauge_Size

This slider controls the size of the embedded status windows. Adjust it right or left to increase or decrease the window size.

3.5.2. Toggle Hide

This setting toggles the visibility of these windows.

3.6 Heatmap

3.6.1 Heatmap Algorithm

The heatmap is created by storing a matrix of all gaze intersection pixel locations on each screen. The algorithm then draws a blob for each intersection point that represents the probability distribution of the subject's focus at the given point in time.

Given an intersection point, the most probable focus of the subject's vision is that exact point. However, there is variance. As one gets farther away from the intersection point, the less likely it is that the subject was focusing there. This probability function follows a two-dimensional Gaussian distribution with its center at the intersection point and a standard deviation of two degrees of visual angle. The graphs in Figure 13 depict probability (z) against degrees of visual angle (x & y) away from the intersection point.

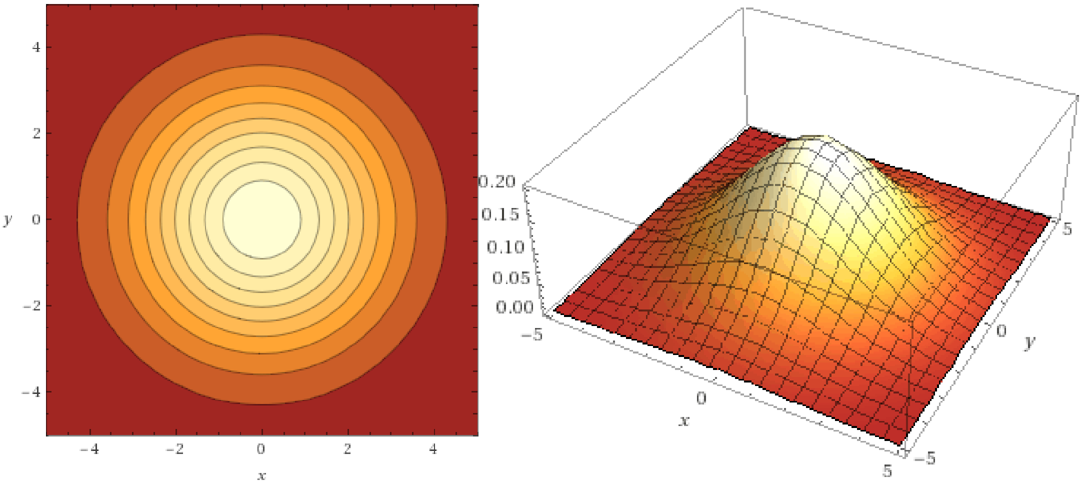


Figure 13. Heatmap Gaussian Distribution Model

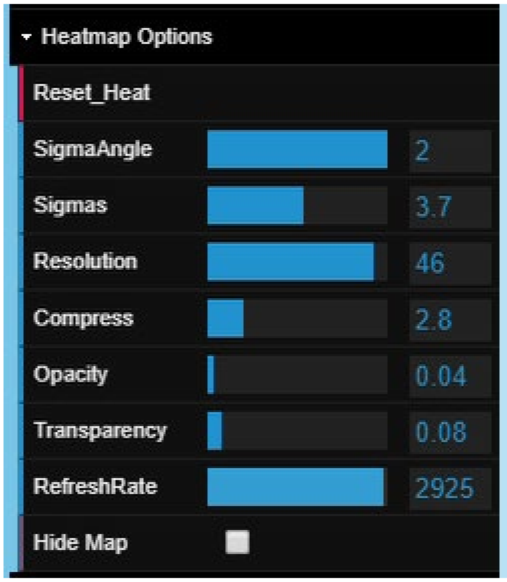
To visualize the heatmap, the radial gaussian distribution is modeled with an HTML canvas radial gradient. For each intersection point, a radial graident is then created and several color stops are added. The amount of color stops used is determined by the "resolution" control—if resolution is set to 10, then 10 color stops will be added. Color stops work very similarly to the 2D contour map seen above, but they instead create a smooth gradient. Additionally, instead of following a yellow-to-red gradient, they follow an opaque black to transparent black gradient. The opacity of a given color stop is determined by a normal distribution whose standard deviation is defined by sigmaAngle. In this implementation sigmaAngle defaults to 2 degress of visual angle, but is configurable as previously mentioned. These radial gradients for each intersection point are laid one on top of another to generate the full heatmap.

This black-and-white heat map is then converted to a more colorful display by mapping its opacity to a color gradient that spans the color spectrum from violet to dark red as shown in Figure 14.

```
defaultGradient: {
    0.3: 'violet',
    0.4: 'blue',
    0.5: 'cyan',
    0.6: 'lime',
    0.7: 'yellow',
    0.8: 'orange',
    0.95: 'red',
    1.0: "#801A04",
},
```

Figure 14. Heatmap Color Gradient Map

The following sections describe each of the editable items of the Heatmap Sub-window in Figure 15.



SigmaAngle 2
Sigmas 3.7
Resolution 46
Compress 2.8
Opacity 0.04
Transparency 0.08
RefreshRate 2925
Hide Map ☐

Figure 15. Heatmap Sub-Window Options

3.6.2. SigmaAngle

The sigma angle refers to how many visual degrees correspond to one standard deviation of gaze probability. The default and most commonly used value is 2 (left image in Figure 16.)

However, this value is adjustable if desired. The image on the right in Figure 16 has a value of 0.7.

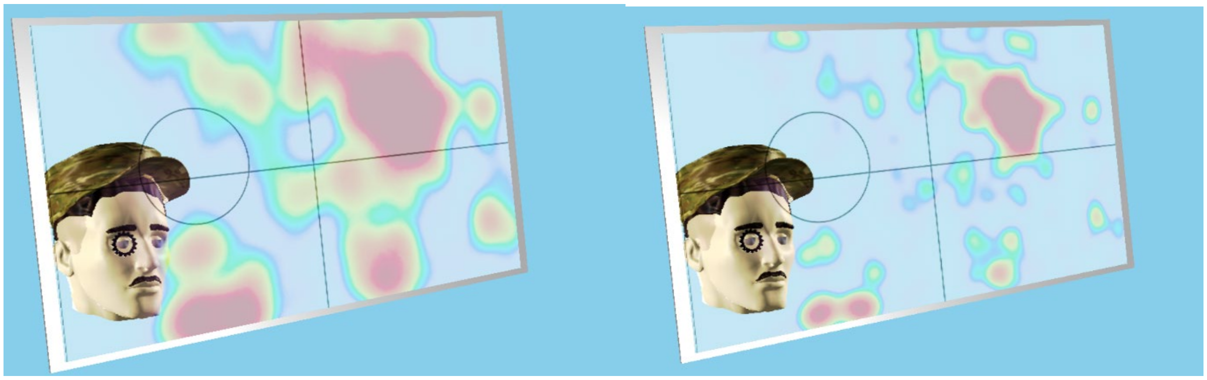


Figure 16. Adjusting the Sigma Angle

3.6.3. Sigmas

Sigmas refer to how many standard deviations of gaze probability are drawn for each gaze point. The decay of gaze probability is generally steep enough that most of the information is visible within just one standard deviation. Figure 17 shows 4.1 standard deviations plotted (left) and 1 standard deviation plotted (right). There is visually no difference. However, the difference may become important in different configurations. Configuring a higher sigma value constructs a more accurate heat map, but requires greater computation to draw.

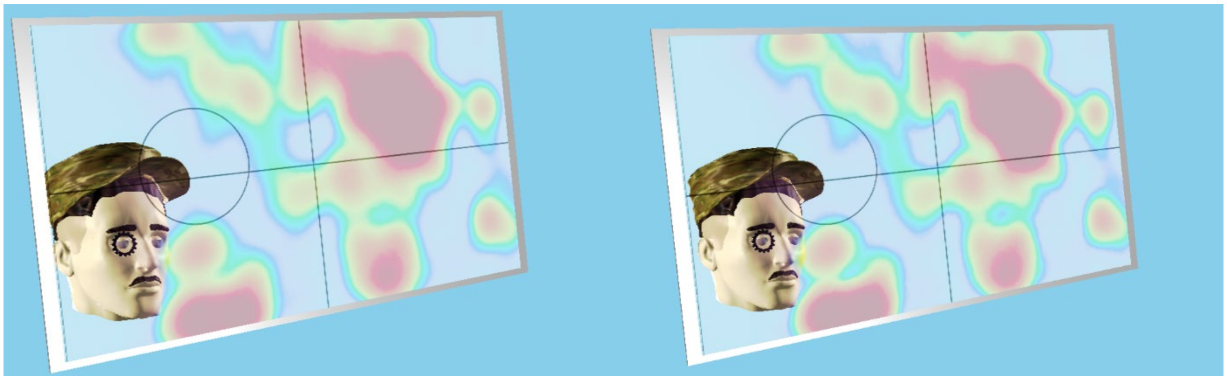


Figure 17. Varying the Sigma Value

3.6.4. Resolution

The resolution setting controls the granularity of the heatmap. Higher resolution value create a smoother, more accurate blur for each dot graphed. It does this by calculating the the exact color value at each radius from the intersection point for more radii with smaller deltas inbetween them. Figure 18 shows a comparision of the minimum resolution against the maximum resolution. Again, it is a very subtle distinction, but may be noticable in different situations. As with Sigmas, higher resolution values will make the graph more accurate, but requires greater computation to draw.

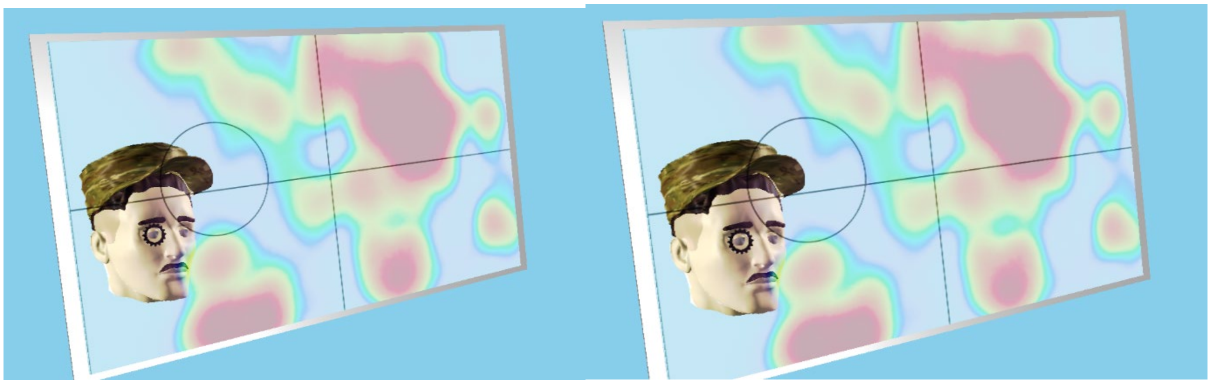


Figure 18. Varying the Heatmap Resolution

3.6.5. Compress

Compress is the factor by which the blob for each gaze intersection on the heatmap becomes compressed (higher compression makes for smaller blobs). Figure 19 conveys a compression value of 2 (left) versus a compression value of 4 (right). The intensity of the color for each dot is unchanged, but the dots become smaller.

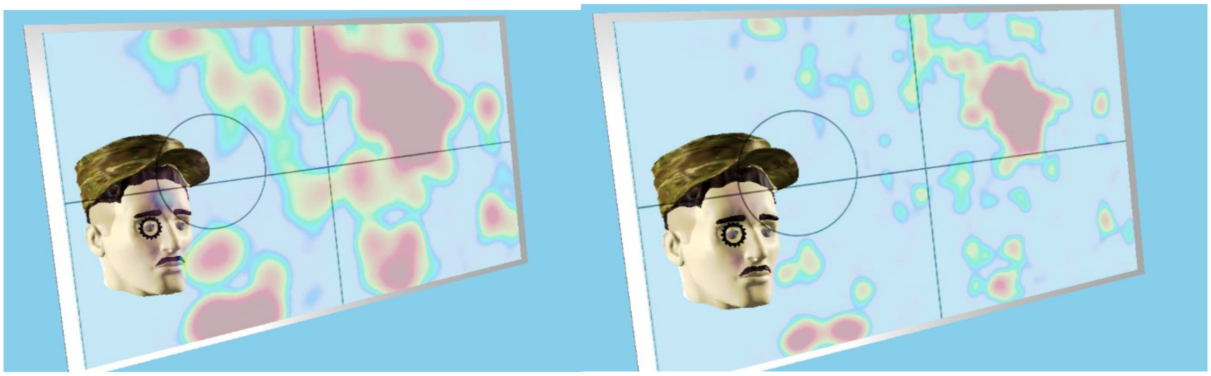


Figure 19. Varying the Compress Value

3.6.6. Opacity

Opacity controls the intensity of each dot in the heatmap. Essentially, how "hot" each dot is. This does not affect the size of each dot but does affect how red each dot is. At very low opacities, individual dots may not be visible until a significant enough number accumulate on top of one another; at very high opacities, individuals dot are dark red. Figure 20 displays a comparison of a low opacity on the left (0.09) with a high opacity on the right (1.0).

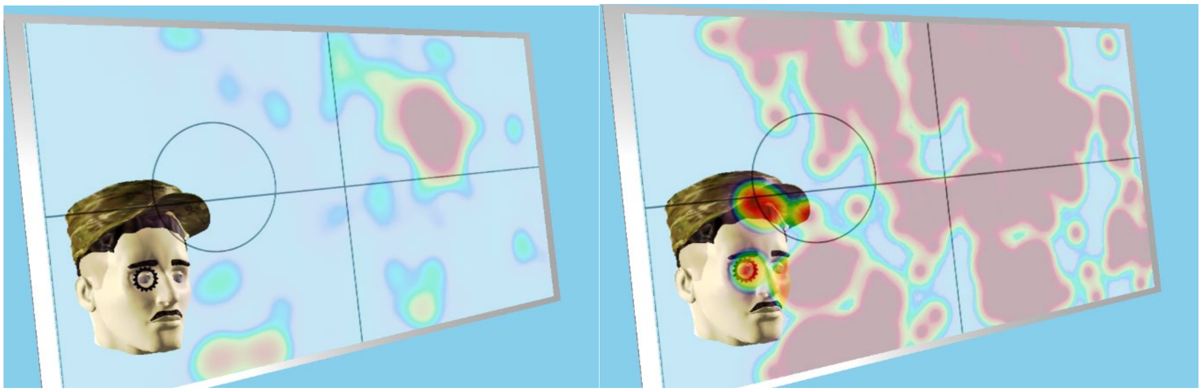


Figure 20. Varying the Opacity Value

3.6.7. Transparency

Transparency controls how bright the heatmap is. Figure 21 compares minimal transparency on the left (0) with higher transparency on the right (0.6). Lower transparency makes the colors more vivid, crisp, and beautiful. The most common configurations prefer lower transparency unless the virtual screen displays other visual items (fixations, remote screen captures, areas of interest, etc.)

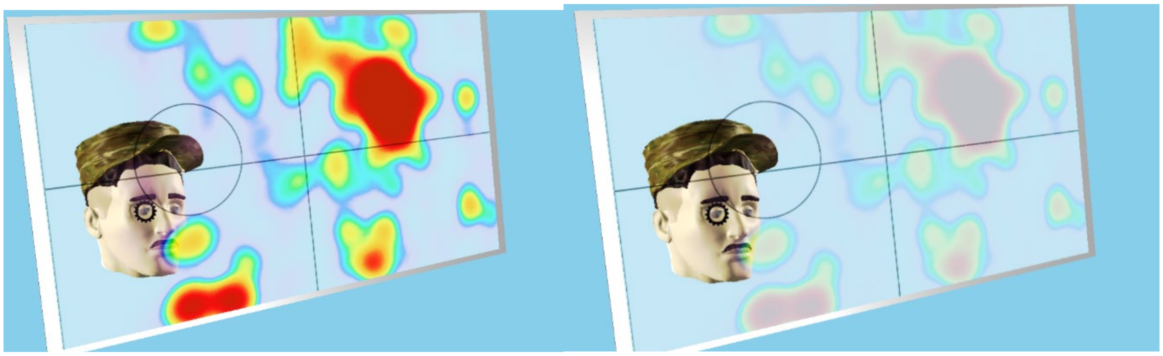


Figure 21. Varying the Transparency Value

3.6.8. Hide_Map

Lastly, Hide_Map, when enabled, hides the heatmap. The heatmap continues to update itself in the background, so no information will be lost. When disabled, the heatmap becomes visible again, since it maintained its history.

3.7 Head Adjust Folder

These controls exist in order to adjust the head model and ensure it appears anthropometrically accurate. In some cases, there may be a need to configure the following settings depending on the differences between participants and world model configurations.

These possible mismatches occur because the head and the eyes are separate models. For example, with a SmartEye sensor, the eye model and head model receive the position and rotation information independently. Unfortunately, if there are discrepancies between the size and shape of the participant's head and that of the head model, then the head will not match perfectly with the eyes, which could affect the realism of the rendering.

3.7.1. HeadX Adjustment

In this example, the head is miss-aligned to its right. For right/left corrections, adjust the value for HeadX. (Figure 22.)

HeadScale 0.706
HeadX 1.4
HeadY 3.1
HeadZ 0.4

Figure 22. Adjusting the Head in the X Direction

3.7.2. HeadY

The below is an example of the eyes being rendered too high in the head as they are clearly occluded by the brow and do not fit neatly into the sockets. Adjust HeadY to correct the model in along the Y-axis. (Figure 23.)

HeadScale 0.706
HeadX 0.4
HeadY 1.78
HeadZ 0.4

Figure 23. Adjusting the Head in the Y Direction

3.7.3. HeadZ

This third example illustrates a situation where the eyes are too far forward. In this instance, use HeadZ to correct the forward/backward position. (Figure 24.)

HeadScale 0.706
HeadX 0.4
HeadY 2.66
HeadZ 4

Figure 24. Adjusting the Head in the Z Direction

3.7.4. Head Scale

In this example, the head is too small for the eyes. Enlarge it with HeadScale.

HeadScale 0.481
HeadX 0.4
HeadY 2.66
HeadZ 0.4

Figure 25. Adjusting the Head Scale

3.8 Advanced Fixation Controls

Unique to COG Pack™ is the ability to perform additional assessments based on physiological data. Once of these assessments is called '*Advanced Fixations*'. This calculation evaluates the cluster of gaze point intersections with an object based on dwell time and dispersion. (Funke, et al., 2016). Adjusting the transparency of these data is possible by changing the value of the AF Transparency slider. (Figure 26.)

AF Transperancy 0.5

Figure 26. Advanced Fixation Controls

3.8.1. AF Transparency

This slider controls the transparency of the Advanced Fixation dots. To hide the dots, set the transparency to 1. Figure 27 compares a transparency of 0.5 (left) to a transparency of 0 (right).

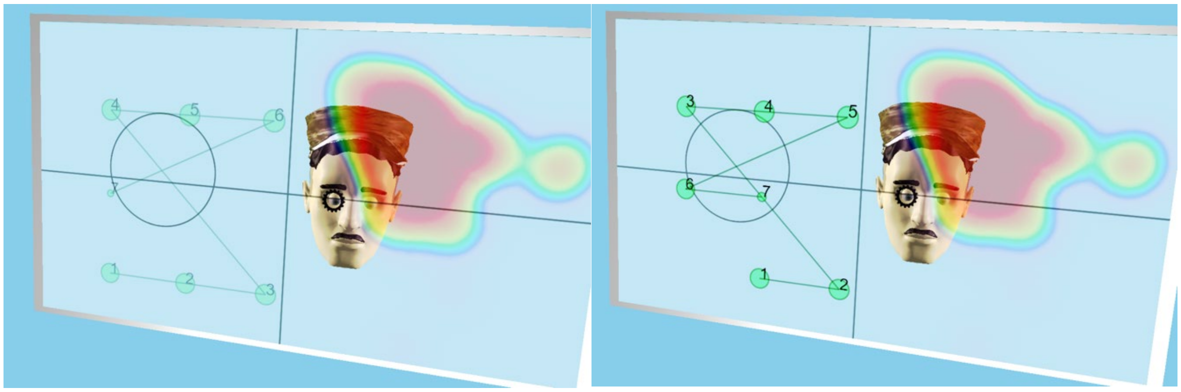


Figure 27. Advanced Fixations Transparency Comparison

4.0 CONCLUSION

In summary, the ability to view and manipulate these eye, head, gaze, and derived data-types supports further insight into understanding and evaluating physiological data. Having the ability to zoom, pan, and rotate in real-time as well as from playback data can be leveraged to recognize cognitive states like attention or fatigue. Visualizing the data spatially, may allow a researcher to better conceptualize and identify the key elements of a participant's decision making process.

5.0 REFERENCES

Funke, G., Greenlee, E., Carter, M., Dukes, A., Brown, R., Menke, L. (2016). Which Eye Tracker Is Right for Your Research? Performance Evaluation of Several Cost Variant Eye Trackers. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 60*, 1240-1244. doi:10.1177/1541931213601289