The Effects of Weather Presentation Symbology on General Aviation (GA) Pilot Behavior, Workload, and Visual Scanning

Presented to: FPAW Meeting

By: Ulf Ahlstrom

Date: 11.01.2012

Federal Aviation Administration

- **Objective:**
  - To explore the effects of cockpit weather presentation symbology on General Aviation (GA) pilot weather avoidance, weather presentation usage, and cognitive workload.

- **Background:**
  - To support the NextGen program, on-going efforts focus on the implementation and use of weather technologies and weather presentations.
  - Currently, there are no Federal Aviation Administration (FAA) or industry standards for the presentation of weather information in the cockpit.
  - Very little empirical data on the effects of weather presentation symbology on pilot decision-making an behavior.

- **Method:**
  - Twenty-five instrument-rated GA pilots were randomly allocated to one of three simulation groups.
  - During two 25-min simulation flights, participants flew a Cessna 172 single engine GA aircraft (using autopilot) under Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC).
  - The pilots had to avoid the weather using the cockpit weather presentation.
  - We manipulated the cockpit weather presentation so that each pilot group used a different weather presentation symbology.

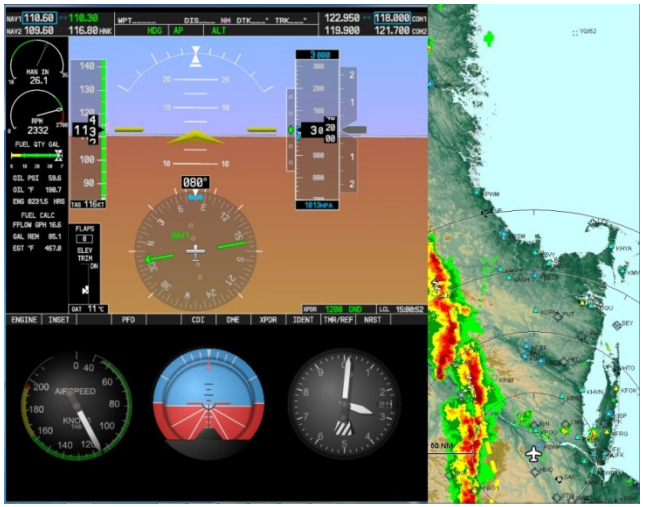
- **Results:**
  - We found group differences in weather deviations, visual scanning behavior, and cognitive workload.

Simulation Group Data for Age and Flight Hours

	Group 1	Group 2	Group 3
Age	Median = 64 Q1 = 59 Q3 = 69.5 IQR = 10.5	Median = 56 Q1 = 49.5 Q3 = 61.5 IQR = 12	Median = 53 Q1 = 42 Q3 = 61.5 IQR = 19.5
Total flight hours	Median = 3500 Q1 = 1750 Q3 = 6330 IQR = 4580	Median = 3100 Q1 = 675 Q3 = 5150 IQR = 4475	Median = 4000 Q1 = 1600 Q3 = 5600 IQR = 4000
Instrument flight hours	Median = 350 Q1 = 225 Q3 = 850 IQR = 625	Median = 150 Q1 = 29 Q3 = 1250 IQR = 1221	Median = 300 Q1 = 175 Q3 = 575 IQR = 400
Instrument flight hours within the previous 6 months	Median = 2 Q1 = 0 Q3 = 6.5 IQR = 6.5	Median = 2 Q1 = .5 Q3 = 21.5 IQR = 21	Median = 7.5 Q1 = 2 Q3 = 30 IQR = 28

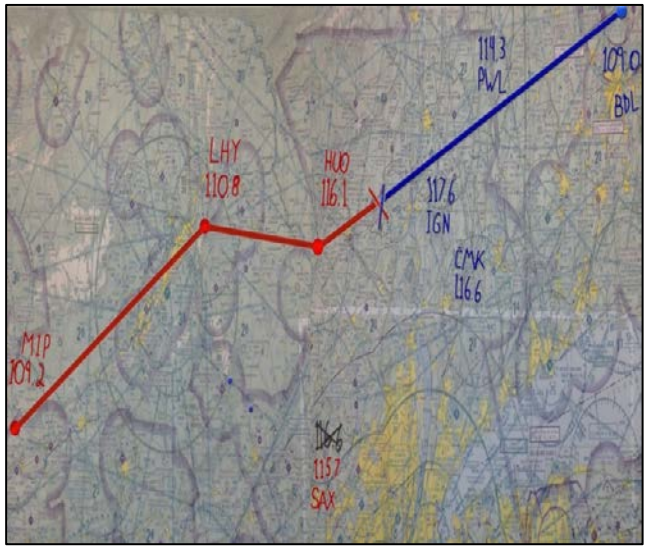
Median (middle value of a data set), First Quartile (*Q1*, median of the lower half of the data set), Third Quartile (*Q3*, the median for the upper half of the data set), and the Interquartile Range (*IQR*, the spread of the middle 50% of the values)

The Micro-jet cockpit simulator (Cessna 172)

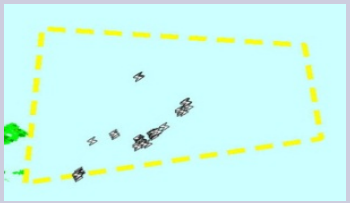
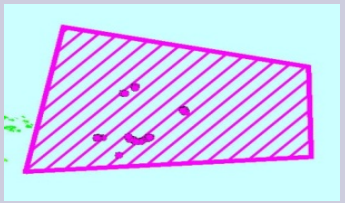
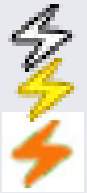
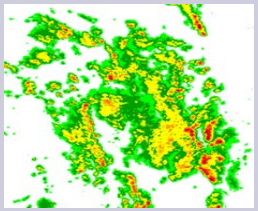
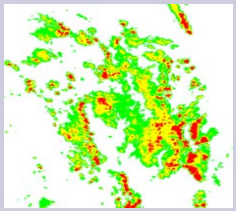
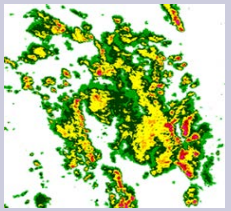


Cockpit glass and weather presentation display (3 zoom levels: 5, 20, and 50 nmi. Range rings)

Eye tracker and functional near-infrared (fNIR) systems

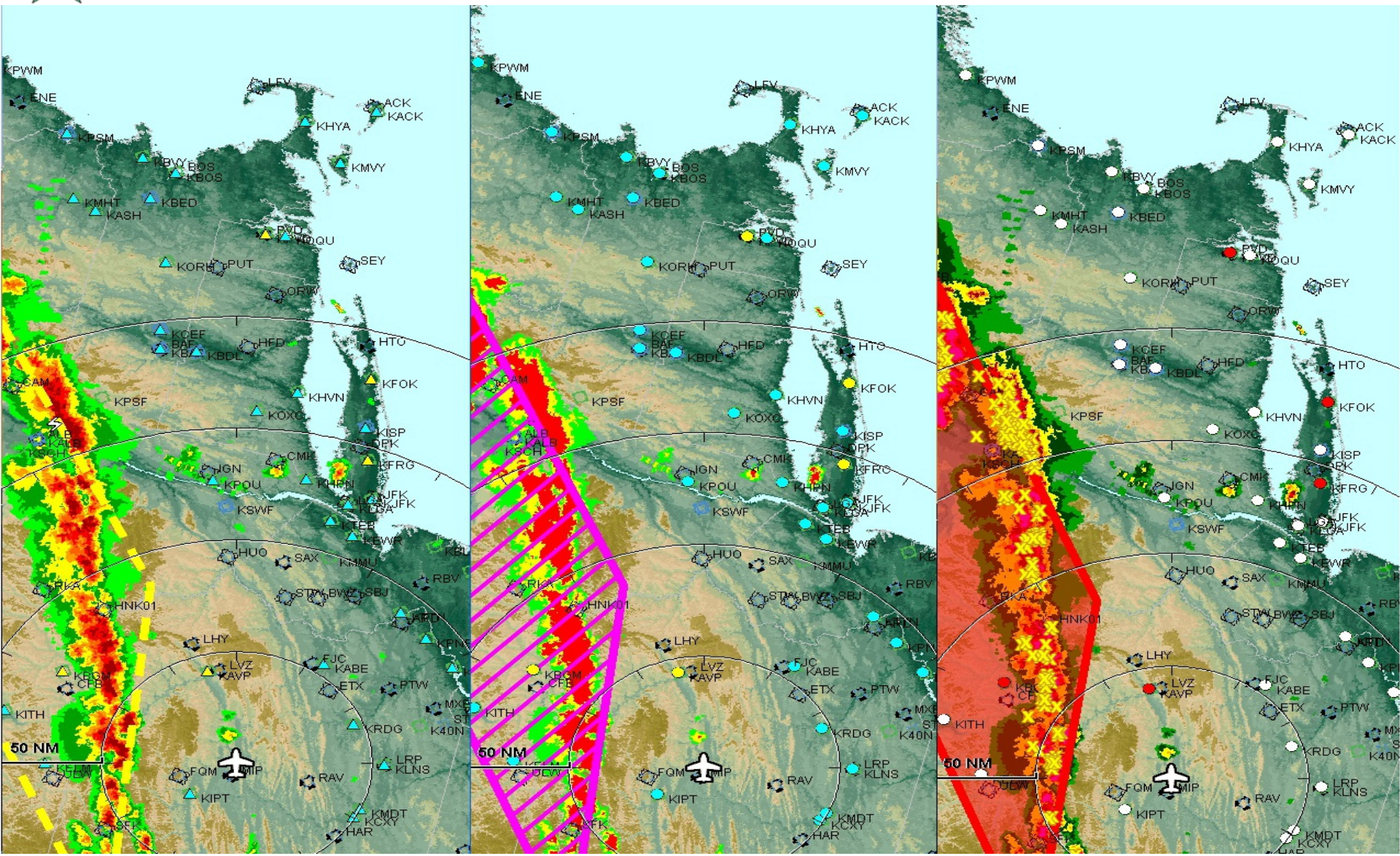


Flight plan (MIP to KBDL) on a sectional map

Weather Data	Weather Parameters	Group 1	Group 2	Group 3
METAR	VFR			
	MVFR			
	IFR			
	LIFR			
SIGMET				
Lightning				
Precipitation		Nine colors 	Five colors 	Nine colors 

Note: for our weather presentations we used commercially available weather symbols

Weather presentations (Group 1-3)

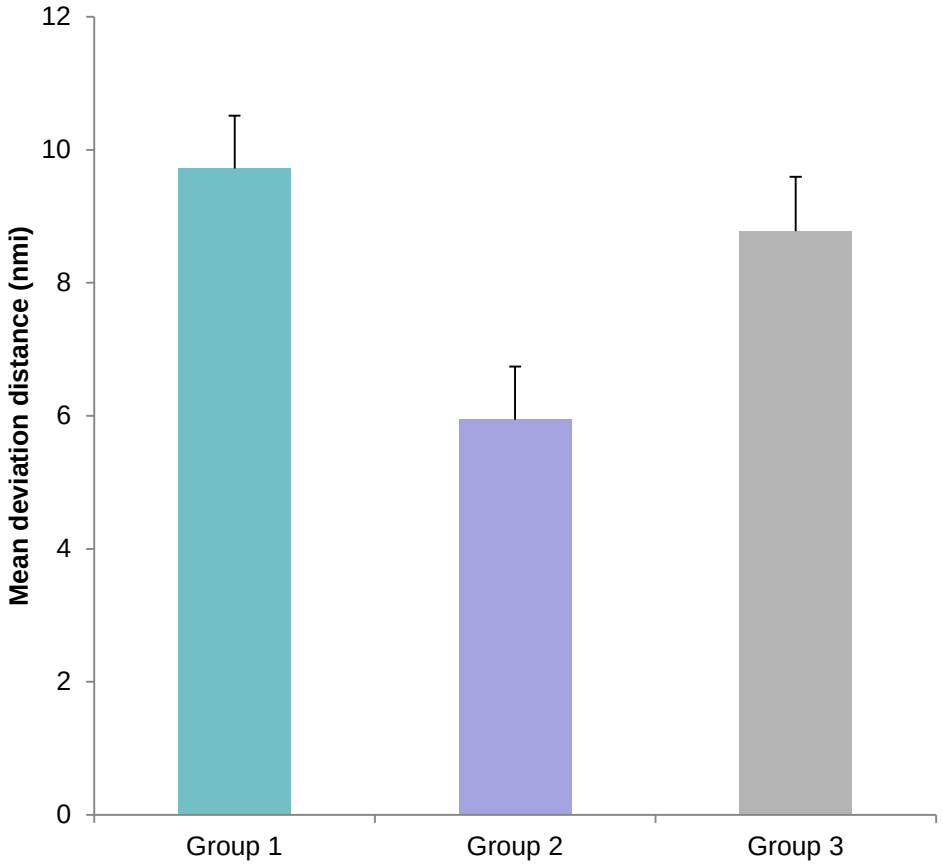


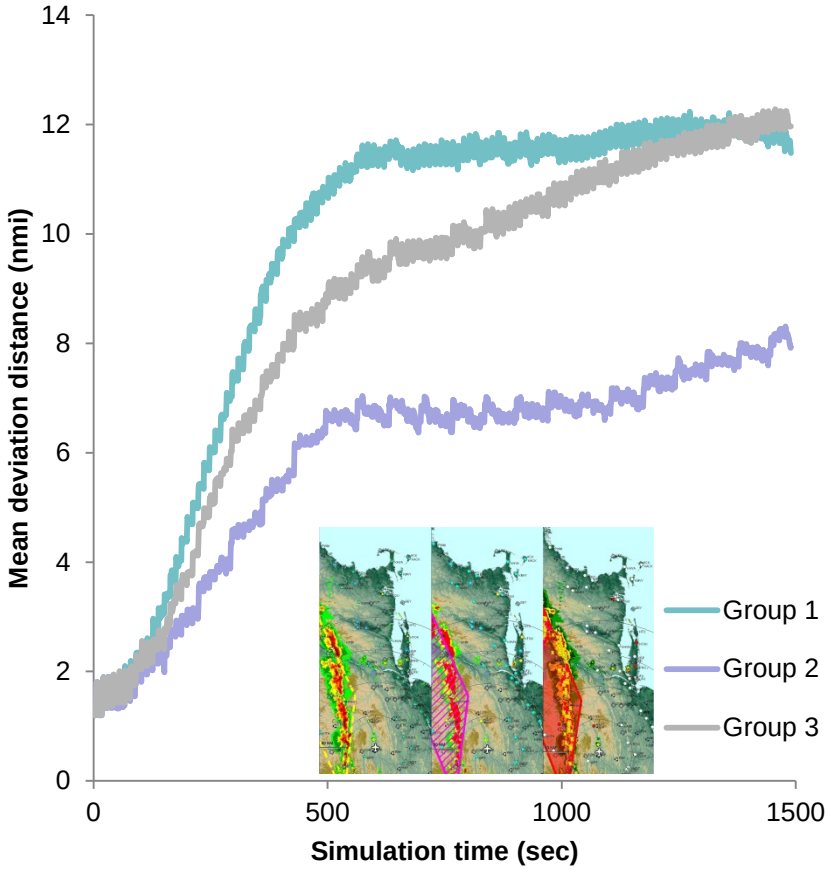
Dependent variables	Description
Distance to weather	Lat/long difference between straight path to destination versus flown path
Weather presentation zoom	The number and duration of all zoom activations
Pilot / ATC communication	The number and duration of PTT communications
Aircraft position, altitude, and heading	Cockpit system measures
Eye movement metrics	Fixations and saccades from point-of-gaze recordings
Visual areas of Interest (AOI)	Cockpit out-the-window, glass display, weather presentation
Workload	Oxygenation changes from the fNIR recordings

Data Collection Procedure

- Flight briefing
- Weather briefing
- Simulator briefing
- Practice scenario
- Fitting of fNIR and eye tracking equipment
- Calibration
- Simulation scenarios (25 min)

Weather deviations

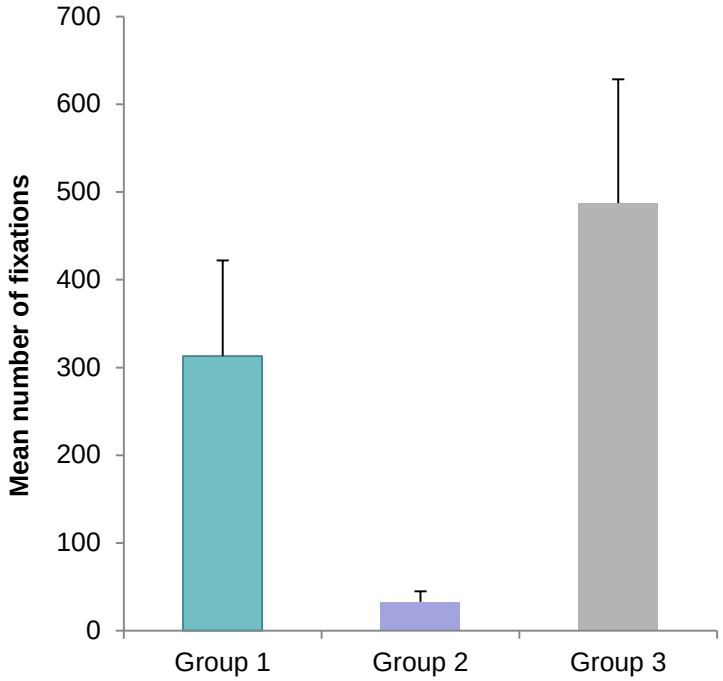


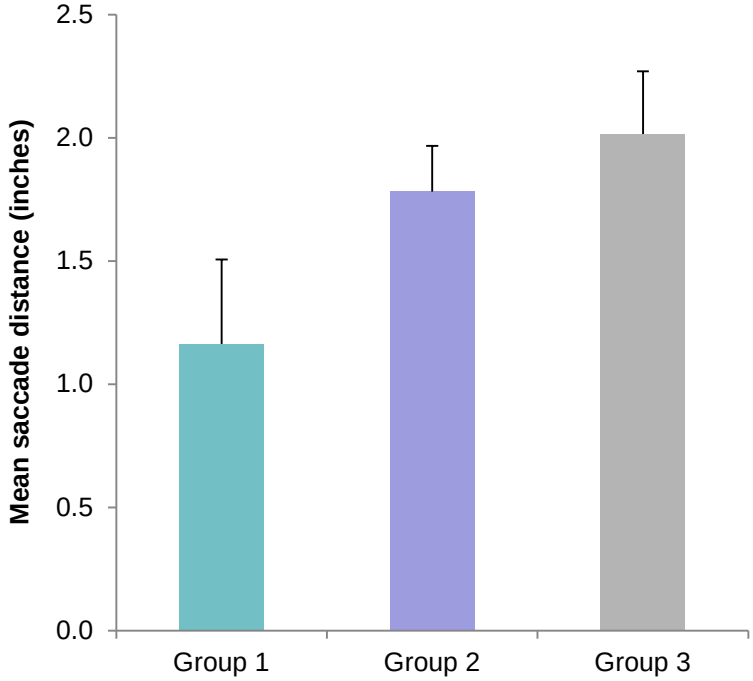


Bayesian model comparison [null (no effect) vs. alternative (effect)]

- **Group 1 (*n*=8) versus Group 2 (*n*=9)** 'substantial' evidence for the *alternative* hypothesis (*t*=3.34, *Bayes factor*= 0.10).
- **Group 2 versus Group 3 (*n*=8)** 'anecdotal' evidence for the *alternative* hypothesis (*t*=2.08, *Bayes factor*= 0.64).

Weather presentation AOI



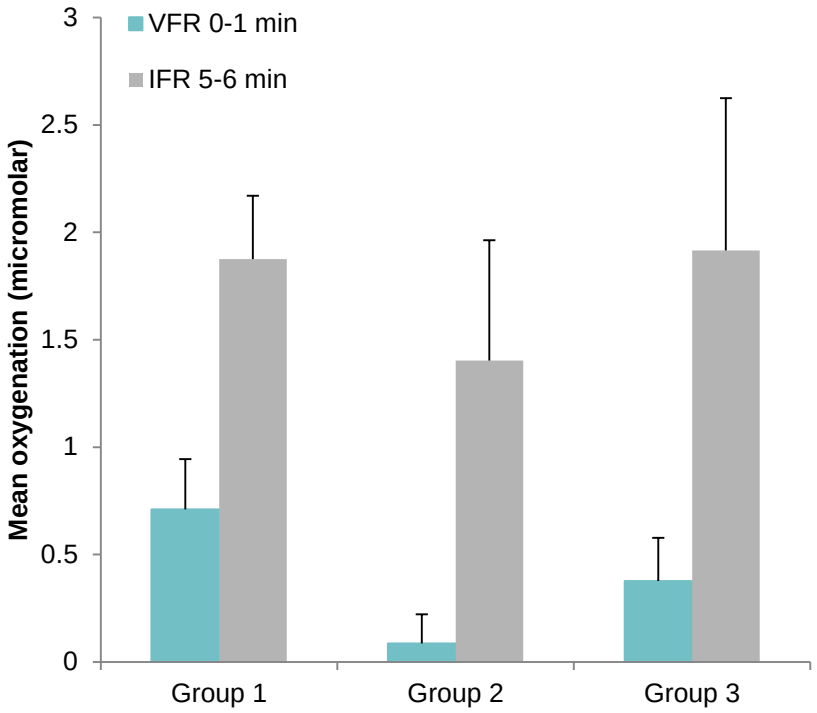


- **Group 1 (*n*=2) versus Group 2 (*n*=5)** 'substantial' evidence for the *alternative* (*t*=4.6, *Bayes factor=0*.12).
- **Group 2 versus Group 3 (*n*=5)** 'substantial' evidence for the *alternative* (*t*=3.2, *Bayes factor=0*.20)

- **Group 1 versus Group 3** 'anecdotal' evidence for the *alternative* (*t*=1.96, *BF=0*.76).

Mental Workload

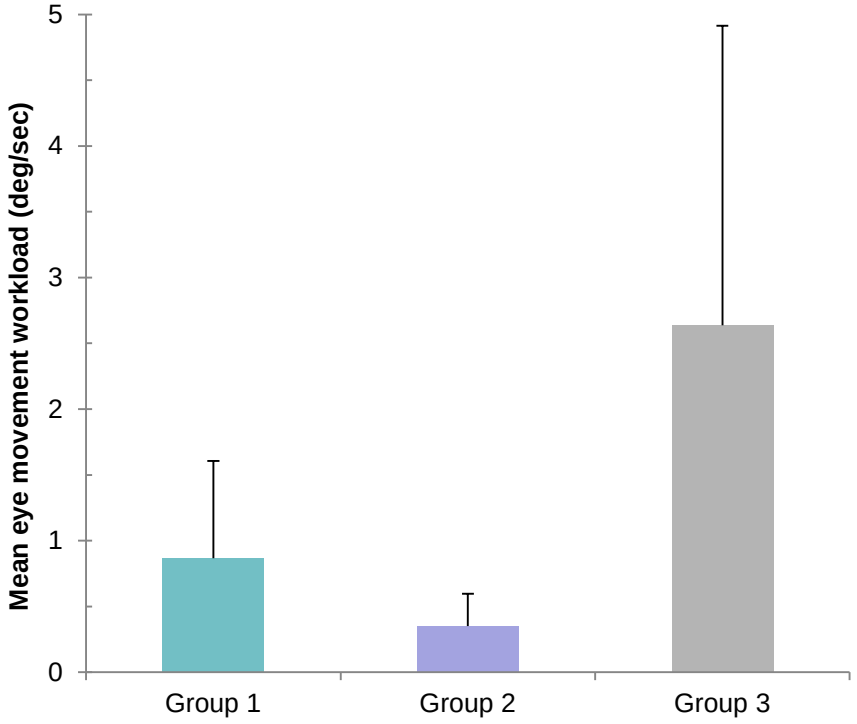
Functional Near Infrared (fNIR) Analysis



- *All groups showed a larger mean oxygenation during the IFR portion of the flight compared to the VFR portion of the flight*.
- **Group 1 versus Group 2** for the VFR portion (0-1 min) of the flight provides 'anecdotal' evidence for the *alternative* (*t*=2.22, *BF=0*.54).

Visual Workload

Eye Movement Workload (EMW)

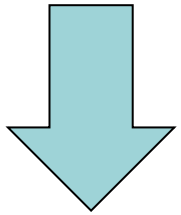


EMW – the average degrees per second that the eyes move around during the course of a flight scenario

- **Group 2 (n=6) versus Group 3 (n=6)**, 'anecdotal' evidence for the *alternative* (*t*=2.44, *BF=0*.43)

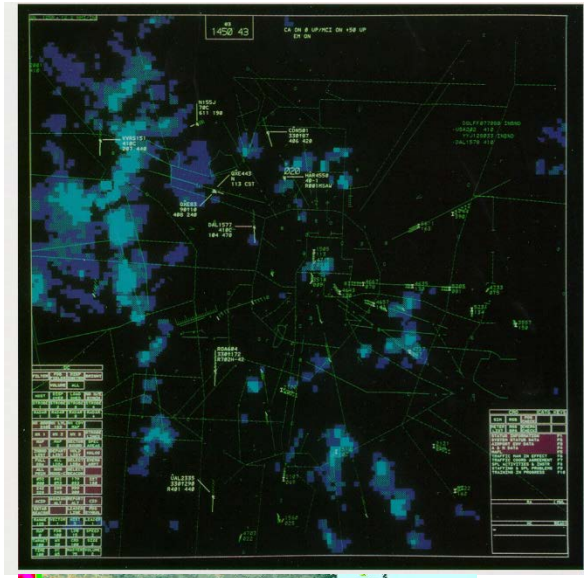
What's next?

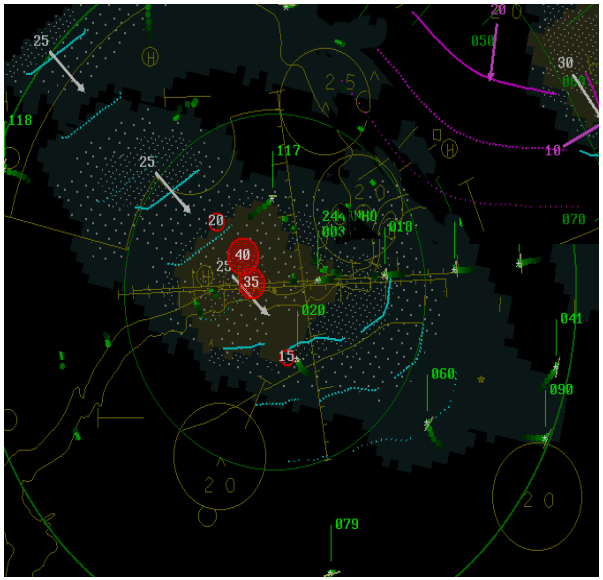
- **Are these effects of weather symbology operationally important?**
- **Are certain weather symbology presentations causing pilots to make non-optimal decisions?**
- **The participants in this study were experienced GA pilots. What about pilots with much less experience?**
- **Weather presentation time stamps?**
- **Are there combinations of symbols and colors that reduce the scan pattern variability among pilots?**

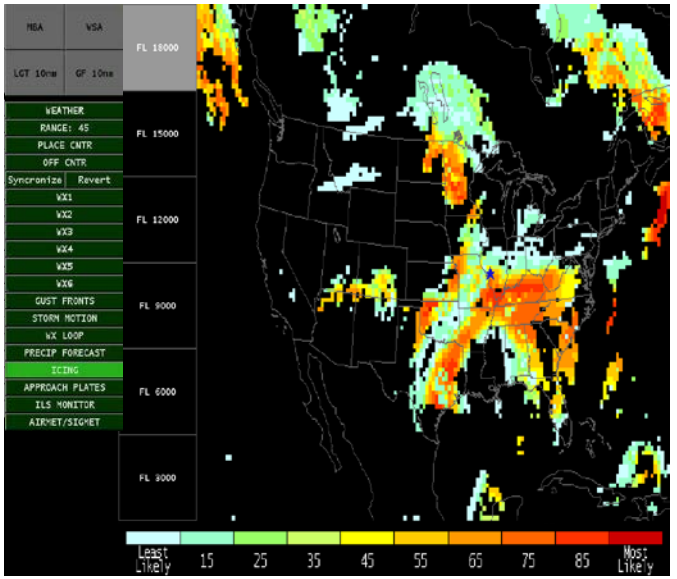


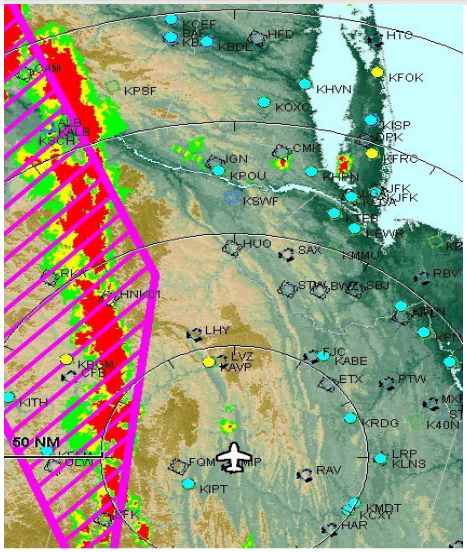
Conduct part-task study

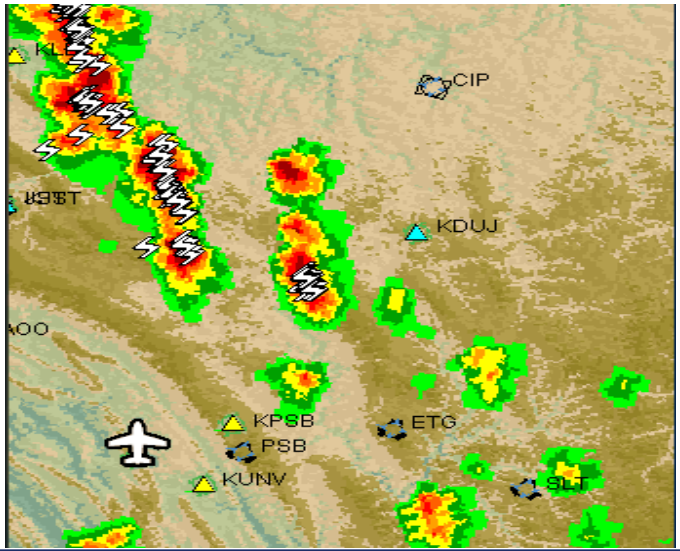
Common Weather Situation Awareness?

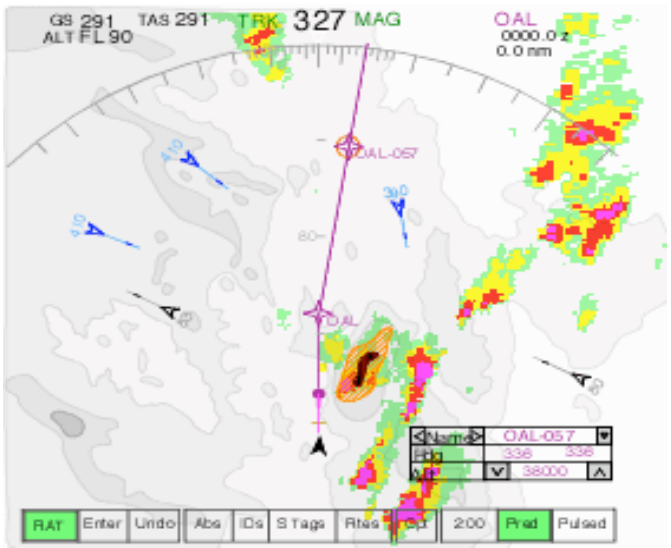


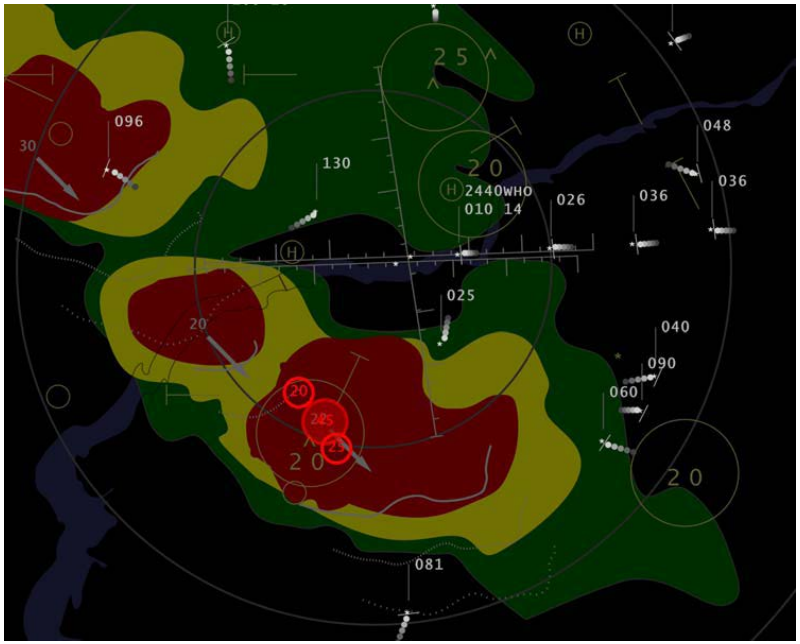












Example presentation illustrating a color palette supporting legibility, color identification, and attention management.

… *provides sufficient luminance contrast for legibility of all symbols and alphanumerics on all backgrounds.*

… *manipulates luminance contrasts to produce a hierarchy of salience that corresponds to the urgency of the coded data elements.*

… color-coding of graphic elements only for specific operational purposes - grouping, caution and warning status, and category labels.

Benefits of symbols and colors

• Symbols and colors have several advantages in weather presentations like indicating class membership of data elements (e.g., METAR symbols).

• Symbols and colors can be used to represent weather hazards, traffic emergencies, terrain, and the status of military special use airspace.

• Symbols and colors can provide visual grouping of spatially distributed but related graphic elements (e.g., METAR symbols).

• Symbols and colors can contribute to a salience hierarchy that visually segregates more urgent display information from less critical context information.

Human Factors Concerns

• ***Legibility, salience manipulation*** (clutter avoidance), and color recognition.

• ***Symbols and alphanumeric data must be readable*** on all weather backgrounds and fixed background areas.

• Current weather visualizations have map-like complexity, ***requires a unified design that considers relations among all of the graphic elements***.

• ***Conflicts among industry standards for color-coding***.

• ***Reduced symbol legibility*** on some textured backgrounds.

• ***Colors and graphics interact with display scale***.

• ***Perceptual grouping based on colors and features*** – unintended visual grouping!