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Weather display symbology affects pilot behavior and decision-making

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ABSTRACT

Objective: To examine the basic discriminability of weather display symbols and to assess the effects of weather display symbology on pilot behavior and decision-making.
Method: During a cockpit simulation, 24 instrument-rated general aviation (GA) pilots were randomly allocated to one of three simulation groups. Pilots flew a Cessna 172 single-engine GA aircraft under Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC) while avoiding hazardous weather. We manipulated the weather display so that each pilot group used a different weather symbology (i.e., symbols and colors). We measured dependent variables for weather avoidance, communication, weather display usage, and cognitive engagement (i.e., oxygenation from Functional Near-Infrared [fNIR] measures). During a change-detection experiment, 20 naïve participants performed a detection task of changes in Aviation Routine Weather Reports (METARs), precipitation, Significant Meteorological Information (SIGMET), lightning, and time-stamp images.
Results: The simulation outcome showed credible pilot group differences in weather deviations, cognitive engagement, and weather display usage. The change-detection experiment revealed credible differences in discriminability of METAR, SIGMET, and lightning symbols.
Conclusion: Symbol and color variations in weather displays contribute to perceptual asymmetries which affect pilot behavior and decision-making. We recommend the development of cockpit applications that use weather data to automatically track hazardous conditions and alert the pilot of potential weather conflicts or weather changes.

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1. Introduction

It is important for pilots to evaluate weather information during all phases of flight. A common method for receiving inflight weather updates is the use of cockpit weather displays or commercial weather products that can be viewed on portable devices (Federal Aviation Administration [FAA], 2010). Although these products generally provide the same weather information, each product has its own weather symbology (i.e., symbols and colors). This means that we have a number of display factors that interact and that could, potentially, produce unwanted variability in pilot perception of weather symbology and, therefore, induce variability in pilot behavior, decision making, and cognitive engagement.

Previous research on the effect of weather displays on pilot behavior has examined various factors like onboard radar, precipitation displays, and weather symbols. For example, Wiggins (2014) examined experienced pilots' ratings of turbulence levels associated with simulated weather radar displays and found a lack of reliability in pilots' turbulence assessments. Lind et al. (1994) examined the influence on pilot behavior and decision-making from pilot use of graphical precipitation displays and found that the precipitation displays increased pilots' situational awareness and allowed pilots to make informed go/no-go flight decisions. Beringer and Ball (2004) compared the behavior of pilots using the Next Generation Radar (NEXRAD) information at varying levels of display resolution. They found that pilots who relied more on high-resolution NEXRAD images attempted to navigate between weather more than pilots with low-resolution displays. This seems to imply that pilots' behavior was caused by a difference in perceived affordances triggered by the precipitation symbology. It also implies that different symbology renderings of the same data source can induce more or less tactical behavior on part of the pilot. A similar result was found by Yuchnovicz et al. (2001). They found that the compelling nature of NEXRAD images caused some pilots

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to depend too heavily on the weather display, highlighting the fact that pilots' use of a weather display does not ensure optimal decision-making. Pilot training might help to alleviate some of the problems, especially if pilots are in an early stage of NEXRAD display skill acquisition where they are at a greater risk of making less optimal decisions based on display data. Wiggins et al. (2014) have developed a pilot skill-level assessment method in the form of a psychometric test instrument. Using such an instrument tailored to precipitation displays, researchers could potentially identify those pilots who are at most risk of inaccurate weather-related decisions and provide training in the interpretation of NEXRAD displays.

Besides NEXRAD information, modern weather displays use a number of shapes and symbols to represent weather-related information. Although common in the aviation domain, display symbology is a challenging area as research suggests that symbology can affect decision-making and behavior. For example, Hegarty et al. (2010) examined weather map salience and display design and found that display symbology and cue salience can have large effects on task performance. O'Hare and Waite (2012) investigated the effect of symbol augmentation and found that pilots recalled more information from Aviation Routine Weather Reports (METARs) when the information was presented with both text and symbols. In addition, Arend (2003) states that displays that deviate from the safety color series (green/yellow/red) or other familiar schema have the potential to cause misinterpretation of weather data and negatively affect pilot behavior. Chandra et al. (2009) studied the relation of individual flight deck symbol features to pilots' intuition, learning, and symbol memory. Their four symbol sets were composed of combinations of basic features like triangles, circles, squares, rectangles, and diamond shapes in different colors representing different symbol states. Although some symbol features (e.g., triangle shape) appeared to be intuitive for distinguishing directionality, other symbol features (e.g., symbol borders) lead to pilot confusion.

The fact that variations in symbol features yield perceptual asymmetries (Yamani and McCarley, 2010, 2011) could imply that some features are favored by low-level perceptual processes and, therefore, are easier to detect. Also, as demonstrated by Vandenbeld and Rensink (2003), there are different decay characteristics for visual information associated with object properties for size, color, and shape information. Alvarez and Cavanagh (2004) proposed that there might be separate short-term memory stores for core element features like an object's specific orientation, size, and color. Therefore, some basic weather symbol features (e.g., lines, circles, rectangles, and triangles) could serve as primary features in line with Alvarez and Cavanagh's core element hypothesis. This could mean that certain symbol features provide greater salience and promote detection of symbol location and symbol change while other features have the opposite effect. This was demonstrated by Fine and Minnery (2009) who examined the impact of visual salience in a working memory task where participants memorized the position of three to five distinct symbols on a two-dimensional map. The symbols were core element shapes like the rectangle, diamond, square, and circle in different colors. Fine and Minnery found that participants' ability to recall a spatial location was positively correlated with the object's salience, and the strength of this relationship increased with increasing task difficulty.

Graphical weather presentations could potentially aid a pilot and contribute to enhanced weather situational awareness during flight. However, as long as users must interpret weather symbols there will always be a potential problem with salience, perceived urgency, display clutter, and so forth (Ahlstrom and Arend, 2005). These are important display issues to resolve because weather symbols need to be readily perceived by users. For symbol color changes, there is also a subjective factor involved that affects perception. Kawasaki and Yamaguchi (2012) have demonstrated that subjective color preferences modulate attention-related brain activities. That is, attention to colors is affected by unconscious preferences before conscious decision-making. Therefore, if Alvarez and Cavanagh's (2004) core element hypothesis is valid, it further emphasizes the need to examine different weather symbologies to assess how they affect pilot behavior and decision-making.

Recently, Ahlstrom and Suss (2015) investigated the effect of weather symbology on pilots' ability to detect METAR status changes during simulated flights. They used three different weather display symbologies during the simulation. Each weather symbology displayed the same weather information but used different symbols and colors to display precipitation, METAR, significant meteorological information (SIGMET), and lightning information. During the Ahlstrom and Suss study, the METAR symbol change informed pilots about reductions in ceiling and visibility at airports. Using this information, pilots could avoid hazardous weather conditions by requesting additional weather information from Air Traffic Control (ATC), making a decision whether to continue the flight under Visual Flight Rules (VFR) versus Instrument Flight Rules (IFR), continuing towards the preplanned destination airport, selecting a new destination airport, or contacting ATC and requesting an IFR flight plan. The study purpose was to assess whether pilots systematically differ in their detection behavior and decision-making based on the weather display symbology. The result from the simulation showed that pilots varied considerably in their overall detection of METAR symbol changes during flight. The overall detection performance ranged from 25% to 62%, with METAR circle symbols with a white to red color change giving higher detection performance than METAR triangle or METAR circle symbols with a blue to yellow color change. This change blindness is a well-known phenomenon (Rensink, 2000, 2002) that is particularly strong during multitasking situations (Varakin et al., 2004). In addition to differences in symbol detection, Ahlstrom and Suss found credible differences in pre-frontal oxygenation levels (as measured by fNIR) between pilot groups using different symbologies. Detecting a METAR symbol change resulted in a subsequent increase in pre-frontal blood oxygenation—associated with increased cognitive engagement from flight planning and decision making.

Previous research on symbol discriminability and symbol detection mostly come from laboratory experiments. Much of this research has used basic symbol features that are similar to symbols used on modern electronic weather displays. However, because of a focus on simple symbol displays there is little information on the behavioral outcome from more complex displays. Therefore, there is a need to assess more complex display symbologies during a multi-tasking situation like single-pilot operations. During actual flights, pilots perform many tasks like navigating their route, performing ‘see and avoid’, reading charts, operating the radio and navigational frequencies, listening to radio communications, viewing approach plates, observing the cockpit instruments, while at the same time keeping an eye on the weather presentation. In the course of this multitasking, weather display updates provide new and important changes to the previous weather conditions along the route of flight. Pilots need to monitor these updates and be tuned to symbol changes to maintain their weather situation awareness.

In this study, we first examined the effects of cockpit weather display symbology on GA pilot behavior, decision-making, and cognitive engagement during a weather avoidance flight. In a subsequent change-detection experiment, we systematically manipulate the weather symbols following the recommendation of