Abstract

EVALUATING HURRICANE ADVISORIES USING EYE-TRACKING AND BIOMETRIC DATA

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The cartography of hurricane advisories is challenged with communicating complex information regarding hazards and spatio-temporal uncertainty. This research presents an exploratory geovisualization study assessing how hurricane advisory maps are perceived. In an experimental laboratory setting, study compared student responses to official National Hurricane Center advisory maps and alternative test map products. Research measured human behavioral response and environmental perception using eye-tracking, electroencephalograms (EEG), electrocardiography (ECG), electromyography (EMG), and a survey questionnaire to support analysis of participants' objective and expressed responses to competing geovisualization products. This approach allows the investigation of biometric responses with digital precision in order to infer cartographic design effects on individual map readers.

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CHAPTER 1: INTRODUCTION

With scientific confidence despite public uncertainty, climate change is under way in the 21st century. Climate change will have effects on tropical storm activities across the globe including the possibility of greater intensity tropical storms in the Northern Atlantic region (Knutson et. al., 2010). The number and intensity of storms under future climate remains uncertain, but one thing is clear: hurricanes are the most dangerous natural phenomena occurring in United States. Hurricanes Katrina and Andrew are estimated as the costliest tropical cyclones worldwide, while the Galveston Hurricane of 1900 was the deadliest natural disaster in United States history (Blake et. al., 2007). Even more deadly have tropical cyclones occurred in the Central America and Asia, where human loss of life were in the hundreds of thousands. The 1970 Bhola cyclone that struck Bangladesh was the deadliest tropical cyclone ever recorded, with up to 500,000 deaths (Reilly, 2009). Surprisingly, most of the population in the area was aware of the risk, but only few sought refuge in fortified structures. In these regions, information about the approaching tropical storms is limited and difficult to disseminate. Evacuation processes and disaster preparedness are not adequate given regional potential risk. Public risk misperception of the hazard is not unique to Asia, it is observed across North America as well. With many impending disasters, large populations have ignored recommended evacuation orders. The public apparently often misunderstands the message given by government officials, denies the risk, or gambles with the odds. The National Oceanic and Atmospheric Administration's (NOAA) National Hurricane Center storm advisories may be misunderstood by the general public. Public misunderstanding of the advisories, coupled with the perceived lower hurricane risk (weather from recent historical events or personal experience or lack of awareness) highlights the need for better storm advisory communication.

The primary purpose of this research is to investigate NOAA National Hurricane Center (NHC) hurricane advisories by comparing their embedded risk graphics against alternative forecast graphics developed at the Renaissance Computing Institute (RENCI) Regional Engagement Center at East Carolina University (RENCI@ECU.) In this study author focuses comparison of human responses to the NOAA and RENCI advisory products using biometric, eye recording and demographic data.

Present State of Knowledge

Hazard risk perception and cartographic design have received increasing attention in research studies with a focus mainly on survey-based research. Use of eye-tracking and often biometric data in risk perception research is an innovative approach with new conceptual and theoretical applications. However, the lack of mature, accepted methodologies to study risk perception and map cartography using these new research approaches requires a review of research drawn from various academic disciplines.

CHAPTER 2: LITERATURE REVIEW

Cartography and Cognition

Geographers use visualization to communicate and present geographic information. Most often thematic maps are used to display the spatial patterns of geographic phenomena through space. Visualization also allows us to investigate and compare spatial patterns in different time periods.

Many scientists use the term "geographic visualization" to define spatial data presentation to the user. More generally, the term "visualization" has its origins in other sciences used to depict graphically scientific data or research findings. Scientists outside geography display large multivariate data sets, such as in medicine, chemistry and physics (Slocum et. al., 2008). These ideas were used by geographers also so the notion of "geographic visualization" was created. Slocum and others define this term as "… a private activity in which unknowns are revealed in a highly interactive environment, while communication on traditional printed maps as a public activity in which knows are presented in a no interactive environment."

Arguably the most common thematic map type is the choropleth map. In this geographic visualization enumeration units are presented in different colors or color shades and depict different magnitudes of events (Slocum et. al., 2008). By using appropriate visualization techniques and tools geographers present valuable information to the user. But use of too many colors or complex representation presents a danger of confusing the map user by making it more difficult to interpret information without carefully examining the legend. According to Slocum and others cartographers should pursue a logical progression of the legend colors so spatial pattern of the map could be revealed.

Geographers have relatively recently turned their research focus on advanced visualization techniques, but cartography has been a part of art and emerging field of science since the Middle Ages when maps were designed as functional and beautiful forms of art. In this period, map communication took a relatively subordinate role in importance. WWII changed many things in modern society and had its impact on cartography as well. Military map production in this historic period was focused on user-friendly or more functional maps for military purposes. Work of Arthur Robinson illustrated that creating map as art form lead users to subjective understanding of geographic information (MacEachren, 1995). He called out for more functionality in maps and pointed out the importance of testing maps in an objective manner.

Following WWII, geography and cartography went through a change in paradigm, and cartographers changed their view on how to create more effective, communicative maps for the public. Effective map cognition became an important aspect of design as it was discovered that some map symbols are more effective in "sending the message" (Slocum et al., 2008). Brain cognition and user perception became primary areas of investigation for cartographers. Slocum further stressed the importance of information acquisition and long term memory in creating more informative maps. Many geographers use the term "perception" in their research, In cartography it primarily explains how map readers react to the map symbols. How a map is understood by individual cognition and perception is key to revealing why certain maps work for some people and others do not. Perception deals with our initial reaction to map symbols, while cognition deals with perception and a person's thought processes, prior experience, and memory (Slocum et al., 2008). Slocum gives the example of contour lines on a topographic map, where readers can interpret lines without looking at legend. The differences in cognitive understanding largely arise from a person's past map reading experience and memory. Cognition thus considers perception *and* the thought processes of prior experience and memory. The concept of cognition can further be broken down into the three types of memory: iconic memory, short-term and long-term visual memory (MacEachren 1995, Slocum et al., 2008).

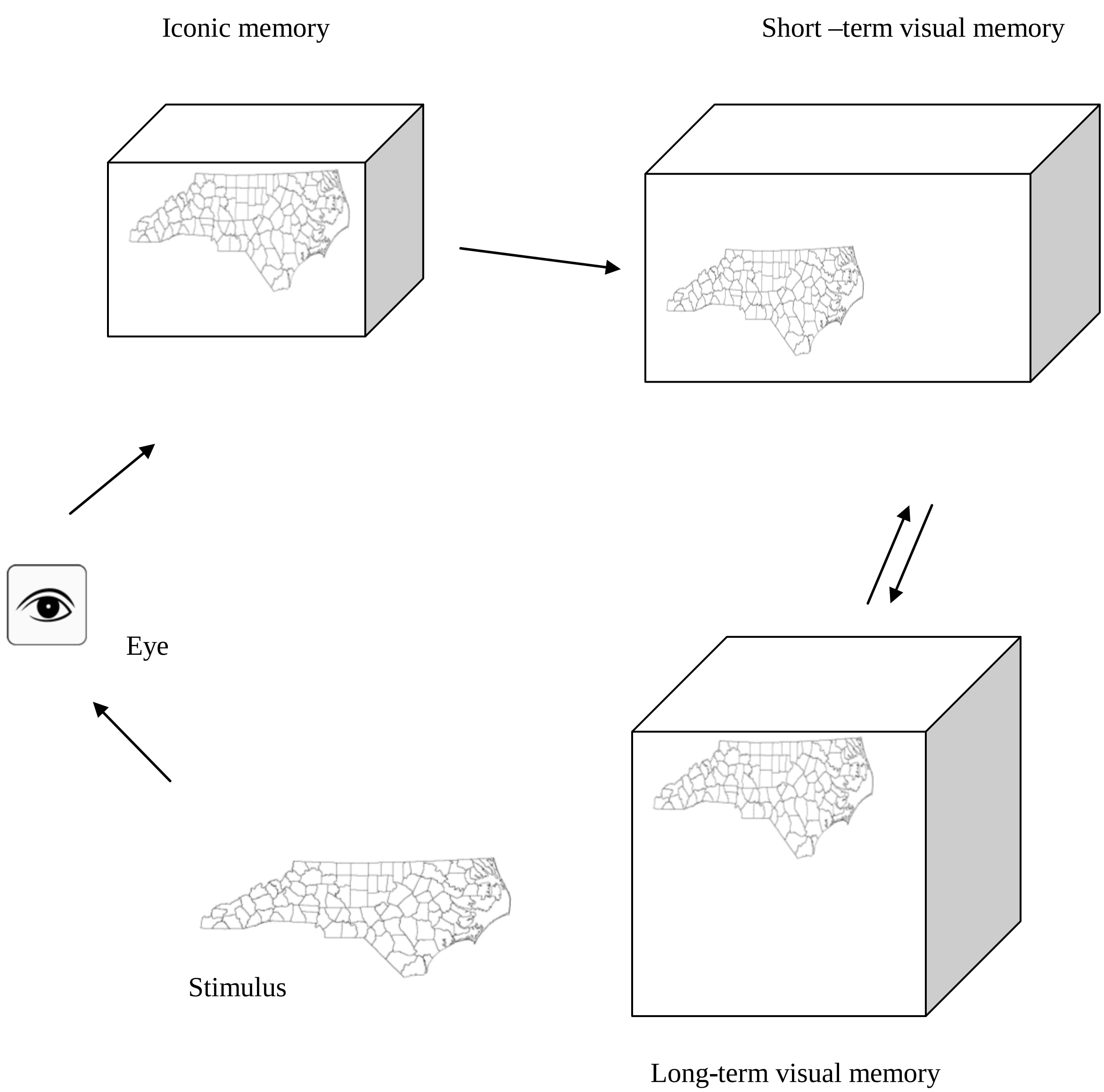


Figure 1: The forms of memory used in communicating specific information (after Slocum et al., 2008.).

Iconic memory deals with initial perception of an object. Visual information is then passed on to the short-term visual memory (Figure 1.) Only selected information is passed on and keeping information in short-term visual memory requires constant attention. From here information is passed on to long-term visual memory.

The change from maps as art to functional maps has caused cartographers to focus on examining why certain map symbols portray information more effectively. This research path is very closely related to psychology where scientists are trying to understand vision and visual cognition and how people see the real world, not controlled two-dimensional, laboratory test stimuli (MacEachren, 1995). The cognitive research approach provides a theoretical basis for map symbol processing explanation and allows us to evaluate map symbology and design. This notion is paramount for this research because the author will investigate individual cognition of a currently operational map product of the National Oceanographic and Atmospheric Administration (NOAA) National Hurricane Center (NHC) and another, experimental map designed by the Renaissance Computing Institute (RENCI) Engagement Center at East Carolina University.

A successful map design ideally would be intuitive and popular with the targeted map user. Nothing speaks to the user better then well organized and presented map. Before the map design even begins, a cartographer has to think about all aspects of the map: information, color, legend, primary map user, static versus dynamic and other aspects. Ignoring one of these factors could lead to poor map design and subsequent user confusion.

Jacques Bertin, the French cartographer famous in his work in information visualization, organizes these design variables in position, size, value, texture, color, orientation, and shape (Aerts et al., 2003). Variables very important for this research are color and size. Gengler goes further and explains that visual graphics are understood through cognition "decoding visual stimuli" and the goal of cartographer is to reduce cognitive effort of the user with better map design (Gengler et al., 1995). Map design should be simple and memorable, so the reader can identify map variables with minimal effort.

For Cynthia Brewer, an active cartographic researcher, focuses her studies on color and argues the importance of color in map design. For univariate data Brewer suggests using sequential color schemes: light colors for low data values and dark for high data values (Slocum et al., 2008). Brewer also successfully developed online tool, “Color Brewer,” to help users chose appropriate color schemes for their maps (Harrower and Brewer, 2003). For bipolar data - a diverging scheme, where two hues diverge from a common light hue or natural gray. Brewer and her colleagues successfully tested these color scheme ideas in experimental conditions but noticed that certain colors work better based on map user age group. Color is also associated through cognition and cultural backgrounds. People even in different countries understand color differently.

It is also important before designing the map to determine who the primary user of the map is. Is map going to be general or specific? Will the user acquire information from the map while investigating it or by recalling if from long term memory (Slocum et al., 2008)? If a user has to investigate the map, he/she will have to use more cognition in this process, versus very popular maps recognized by a majority of the people: isoline contour maps (e.g., Slocum’s topographic map example).

With new technological advancements in computer aided cartographic design, it is easy to produce dynamic maps, characterized by continuous change while the map is viewed. Researchers have found evidence that dynamic maps allow user to absorb more information (Slocum et al., 2008, Fabrikant et al., 2008). With additional information, intuitively perceived, users are likely to draw better conclusions about spatial-temporal geographic phenomena from these maps.

Cone of Uncertainty

Higher quantities and more complex information are frequently portrayed in contemporary cartographic visualizations using geospatial data and methods. However, more information in the display does not mean that more appropriate information is effectively reaching the end user. Data analysis effectiveness decrease as the complexity of the data increases in a visual presentation. Displays may become illegible because of visual clutter and massive over-plotting associated with large volumes of data (Andrienko et al., 2008).

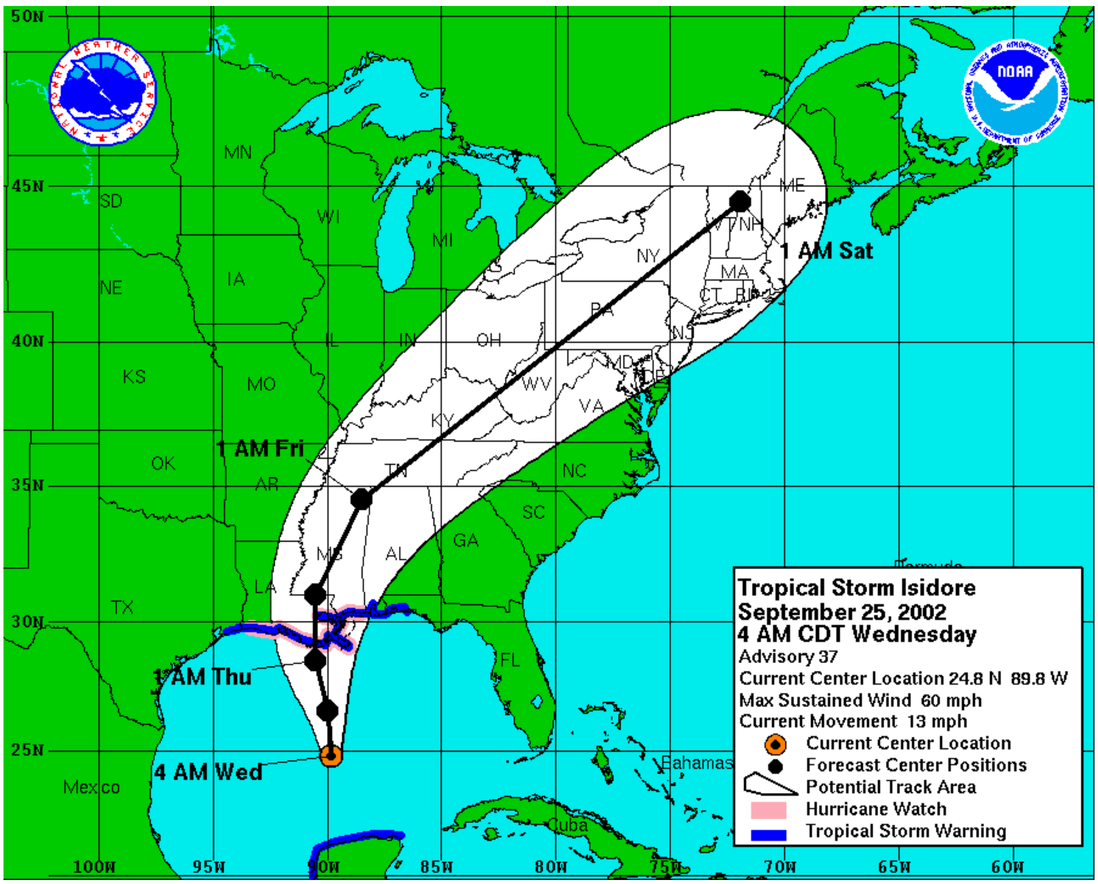


Figure 2: Tropical storm Isidore in 2002 NHC.

The “cone of uncertainty” (COU) is a National Hurricane Center (NHC) hurricane forecast graphic depicting potential storm tracks (Figure 2). The NHC recently removed their forecasted storm track line (the line of a forecaster’s best estimate, often a manual creation drawn from computer models) because many people believed that the area along the black line, the best forecast track, is higher in danger while ignoring both the size and severity of the storm impact extending beyond the track. In essence, the public may be prone to misperceiving the cone as an impact area, not as a range of possible tracks, and this perception could be exacerbated if the forecast track line were included. Another concern is that the NHC cone boundaries may cause the public to assume no imminent risk beyond the boundary, even though boundaries in reality represent a range of uncertainty about the track of the storm eye (Steed et al., 2009). The cone of uncertainty does not provide any direct information about impact risk. It arguably provides too many different pieces of information, including the projected track line, the cone, areas under a hurricane watch, areas under a tropical storm warning and different sustained wind speeds (Broad et al., 2007). Steed et al., (2009) agrees that NHC advisories contain several heterogeneous data types that are difficult to represent graphically in a single map graphic. The map legend in NHC advisories may be overloaded with information, and as the study conducted by Wainer and Francolini (1980) showed, that memorization of legend content is very difficult, if not impossible.

An alternative approach might be to design a more simplistic hurricane forecast map. Ideally, new graphic designs should be empirically tested in controlled experiments before their adoption over an existing one (Wainer and Francolini 1980, Broad et al., 2007, Steed et al., 2009). Such measurement and testing of map design is a primary goal of this study. Evaluation of this map design is difficult since statistical techniques, alternative acceptable means of evaluating tools, and methods for visual exploration and analysis must be developed (Andrienko et al., 2008). Newly developed methodologies used in the expanding field of eye-tracking studies could provide new insights.

Map design for hurricane advisories should be intuitive and informative so readers do not have to look at the legend frequently to understand the map communication. A new graphic, nonetheless, may have an initial “learning curve” as the graphical elements are cognitively processed for the first time. White color is used in NHC COU representation and gives information where the eye of the storm could be within 72 hours. Research by geographers Steed et al., (2009) and Kumler and Groop (1990) found that continuous-tone color maps are more effective then black and white maps. The NHC COU does not include a continuous-tone color map (only white), so there is potential improvement in risk perception and communicating confidence of the forecast track with the design incorporating color gradients. Ultimately, the majority of people in this study may prefer color-tone maps over white or monochromatic designs (Slocum et al., 2008, p.298).

In general, greater use color is the preferred representation technique for the labeling and categorization of information (Slocum et al., 2008). Future NHC COU graphics might be more effective by including color and simpler legends to improve advisory communication message to the public and other users. The COU might also benefit by not using discrete color-coded polygons, because these present additional information in the map due to layer occlusion issues (Steed et al., 2009). Continuous color representation can be used as a better cartographic design alternative. Furthermore, NHC advisory maps with strong, saturated colors in the foreground diminish effectiveness of the cone representation. Steed et al., (2009) suggested the use dull or muted background colors to emphasize cold-warm color contrast between the background and the foreground cone of uncertainty.

Hazard Risk Perception

Hurricane hazard risk perception has recently received more attention by hazard researchers due to the growing population and development of coastal United States (Peacock et al., 2004). Many risk perception studies are focused on investigating populations in hazard-prone areas affected by tropical storms, tornados, earthquakes and various technological hazards. Hazard risk perception is a complex individual and social phenomena influenced by the number of demographic and cultural characteristics. Researchers agree on basic risk perception influencing factors but also mention that this phenomenon is not consistent across geographic areas or populations. Primary factors influencing risk perception include age, gender, ethnicity, place of residence and past hazard experience (Peacock et al., 2004).

Hurricane risk perception is similar to other hazard risk perceptions regarding factors of influence. For example, family decisions on hurricane evacuation are affected by the severity of the hurricane and the likelihood of a nearby landfall. Individual perception of risk, increasing awareness of scientific uncertainty, diversity of information sources, and past experiences are emerging as more significant aspects of household response (Dow and Cutter, 2001). The highest evacuation response rates to the threat of strong storms have been quantified in high risk areas, among mobile home owners, households with children, and tourists (Dow and Cutter, 2001). The decision to ignore evacuation orders is frequently justified by the feeling that one's home is "safe," concern over access to homes after the storm passes, protecting the property, job responsibilities, pets left in the property, and a variety of indirect costs accumulated during evacuation (travel and housing).

Some case studies have found that age has a negative effect on risk perception. However, past hurricane experience has major role in risk perception (Dow and Cutter 2001). This influence holds even if the experience is indirect, where a family member has suffered a loss. The significance of experience does not necessarily diminish over time, but the public has low risk perception during prolonged "quiet hurricane seasons." However, statistical analysis suggests that longer-term residents are more likely to disregard evacuation orders (Dow and Cutter 2001; Peacock et al., 2004). Nonetheless, these residents also invest a great deal of time staying well informed on hurricane issues. There can also be considerable disagreement between public risk perceptions and expert risk analysis. Research has generally found that individuals with higher levels of knowledge are more likely to undertake protective actions or adjustments. However individuals with higher levels of knowledge and experience may also become overconfident and consider themselves and their household invulnerable (Peacock et al., 2004).

Women perceive risks differently from men and have a higher probability of perceiving disaster and hazard events as more dangerous than men (Dow and Cutter 2001; Peacock et al., 2004). In general, women, racial and ethnic minorities, individuals of low income and little education tend to have higher perception of risk from natural hazards. Families with children are more likely to evacuate, while households with elderly are less likely to evacuate.

Relatively little research has been conducted on the influence of a respondent's location and proximity to their perception of risk, especially perceptions to hurricanes. The role of proximity and geographic location is indeed an under-examined relationship in explaining the perception of risk, particularly with regards to hurricanes. Peacock et al. (2004) found that hurricane risk perception is higher in concomitantly higher wind hazard zones. Hence, individuals that have experienced hurricane damage have significantly higher levels of perceived risk. Additional studies may provide important information on the correlation between individual geographic location and the degree to which they perceive risk from natural hazards.

Eye-tracking

Eye movement research has been conducted by psychologists and other researchers for over century now (Wade and Tatler, 2005). Research was mostly done on static displays to learn how people read texts and view various static graphic displays such as advertisements, works of art, diagrams and other images (Fabricant et al., 2008). With advancements in computer technologies, eye tracking research has transitioned to focus on digital images rendered on computer screens. The birth of the Internet and personal computers prompted eye-movement research on Internet websites, computer operating system, and graphic user interfaces. Scientists are interested in innovating the design and usability of the applications and particularly creating “user-friendly” design.

Cartographers have utilized eye-tracking recording as early as the 1970s to investigate how people view and interpret static maps with a goal of creating better, more informative and user friendly maps (Wade and Tatler, 2005, Fabrikant et al., 2008). During the 1970s and 1980s, cartographers increased their interest in eye-tracking research, but until recently the collection of eye-movement data in academic cartography has almost disappeared (Fabrikant et al., 2008). Factors influencing the downward trend in eye-tracking studies could have been the expensive, complex hardware and the difficulties in analyzing more complex data.

Eye-tracking data analysis methods and software reemerged the in late 1990s and early 2000s. Eye-tracking research produces high volumes of data. For example, a 30 minute recording will give around 60,000-100,000 data points depending on the temporal resolution (gaze points per second). This is the one of reasons why raw eye-tracking data is seldom used directly, and instead is filtered based on gaze duration (Fabrikant et al., 2008). No fully developed, mature methodology exists for analyzing eye-tracking data, especially for analyses investigating cascading images or map animations. Some researchers (Wilson, 2006; Fabrikant et al., 2008), found themselves in a situation where they had to create their own spatial-temporal analysis software beyond that available in eye-movement recording software. Some academics suggest that eye-tracking studies do not provide new information which is not already known to cartographers (Franklin et al., 2008). In the past researchers may have also tended to focus their studies on where people looked without getting at the *how* and *why* of the map reading (Fabrikant et al., 2008).

Fabrikant et. al., (2008) developed custom spatial-analytical software using an Adobe Flash user interface software. This research group also promoted a technique, Sequence Alignment Analysis (SAA), as a useful method for analyzing eye-tracking data. The Sequence Alignment Analysis method is also the primary method in Shoval and Isaacson's (2007) research on tourist behavior in sites of an historic old town.

Eye tracking data analysis is similar in concept with time geography (Pred, 1977; Kwan, 2004) because both approaches use temporal data for analysis. Shoval and Isaacson (2006) define Time geography as space-time analysis, which focus on the human time –space constraints and analyses of patterns of human space-time activity (Figure 3). This branch of geographic research was developed by Swedish geographers in 1960s, and studies of human spatial behavior have increased since the 1970s with a number of them analyzing place and space, a subject that has become a key interest within the social sciences (Fabrikant et al., 2008). According to well known time geographer Mei-Po Kwan, this paradigm allows the investigation of "…complex interaction between space and time and their joint effect on the structure of human activity patterns in particular locations.”

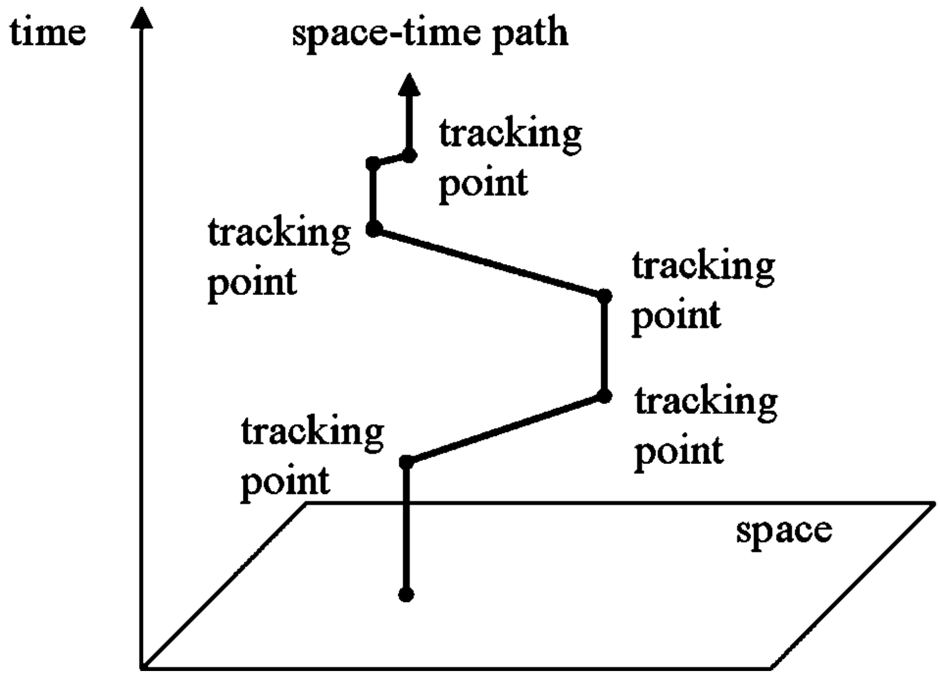


Figure 3: Space-time system and space-time path of time geography (after Shaw et al., 2008).

Time geography poses different kinds of questions from classic regional and historical geographers, as well as “modern” human geographers. The time-geography framework also holds the promise of identifying new questions of social and scholarly significance (Pred, 1977). This approach has different insights into the complex structure of society, particularly structure and interactions between people, people and environment, people and human made objects.

Time-geography analyses social structure and human behaviors. One of the levels of analysis deals with human behavior in time-space sequences for different time scale observations. In essence, an individual’s life can be graphically described as a trajectory of movement in time and space at the same time (Pred, 1977).

Human activity through time and space is not only of interest to geographers, but also transportation researchers, who construct urban models based on urban activity patterns in travel.

New developments in digital information technologies like geographic information systems (GIS) have highlighted the importance of the time-space phenomena research in the scientific community. However, many researchers (Fabrikant et al., 2008; Shoval and Isaacson 2007; West et al., 2006; Wilson, 2006) agree that space –time analysis has fundamental problems in aggregating data into generalized types of varied activities and at the same time extracting patterns. Transportation researchers found themselves in difficulty defining and comparing household activity patterns (Wilson, 2008) or measuring similarity of activity patterns.

To date, no consensus has formed regarding the unit of analysis in travel forecasting. However, according to Shoval and Isaacson (2007), understanding the sequence of activities in space and time allows one to understand an additional integral dimension of activity and to recognize patterns that exist within dimension. These authors also point out other research challenges in human spatial behavior, such as how to record spatial activity and how to pinpoint the location of activity in space at all given times.

Time geography principles are very focused in depicting spatial-time patterns in various phenomena like migration, residential mobility, shopping, travel (Kwan, 2004). Time geography as geographic research branch is gaining momentum in scholarly outlets, and recently the International Journal of Geographic Information Science published a special issue volume entirely focused on time. Many GIS researchers (Kwan, 2004; Hongbo, 2006; Shoval 2007; Demsar, 2010) used this concept to develop new space-time software platforms or GIS methods were geographers could investigate three dimensional pattern. This very unique perspective to the time problems by these researchers allowed them to unveil otherwise invisible patterns from very complex data sets.

Time geography concept provides theoretical base for eye tracking data analysis, where physical movement in geographic space is replaced by eye movement in the computer screen. Geographic coordinates replaced by pixel location on the computer display.

Biometric Measurements and Cartography

Biometric measurements have been used by psychology, medical, and cognitive scientists with the purpose of understanding human emotion, arousal and cognition. In geography this kind of approach has not been used. Most cognitive scientists use some kind of stimulus, usually sound or picture, to create a reaction in a research subject. The subject's biometric measures are then recorded and analyzed against each other for different patterns. Scientists often use known benchmark stimuli recognized by an international scholarly community to have certain effects on participants. These benchmark stimuli are internationally recognized as pleasant, neutral or unpleasant stimuli. According to Lane (200) these stimuli reliably evoke, in the laboratory conditions, psychological and physiological reactions that vary systematically over the range of expressed emotions.

Richard D. Lane and others (2000) indicate that emotions involve multiple responses and are highly variable in their psycho-physiological composition. Physiological reactions are just a part of the emotion indices and are related to emotions. Facial muscle patterns, blushing are examples (Lane et. al. 2000).

"Arousal" is defined as state of being awake in physiological sciences and is less salient than valence in accounting for substantial variance in evaluative reactions (Lane at. el. 2000). Valence in neuroscience is the emotional value associated with a stimulus; for example, pictures of scenic view could have a positive valence. Bipolar scales define this activity parameter, extending from an unaroused state (calm, relaxed, sleepy, etc.) to high arousal (exited, stimulated, wide awake, etc.). For some researchers, valence and arousal is the primary or foundational dimension of emotion which can be measured with biometric instruments (Lane at. el. 2000). Electroencephalography (EEG) which records persons brain electrical activity.

Lane (2000) assumes that emotion is organized by the brain's motivational systems and what by physiological and behavioral reactions to affective stimuli should also reflect this organization, co-varying significantly with valence (referring to the emotional value associated with a stimulus) and/or arousal. To assess this hypothesis, Lane uses electromyogram (EMG) instruments to measure brow and cheek muscle movement. EMG is an electromyogram - recording the electrical activity produced by skeletal muscles. Study findings suggest that brow muscles significantly contract when a picture is rated as unpleasant and response is moderate when viewing neutral materials and shows relaxation below baseline for pictures rated as highly pleasant. The dimensional correlation between valence reports and brow muscle EMG is quite high. When brow EMG activity is averaged over pictures ranked from most to least pleasant for each subject, a strong linear relationship is obtained for pleasant judgment and brow EMG activity (Lane at. el. 2000).

Bradley and others (1993) found that larger corrugators EMG or eyebrow muscle movement for unpleasant materials and demonstrated stronger facial EMG responsiveness in female subjects. Codispoti (2001) found similar changes in corrugators (eyebrow) EMG while viewing pictures. Larger changes occurred when processing unpleasant pictures as compared to pleasant or neutral materials. Corrugator EMG activity was also significantly lower when processing pleasant, compared to neutral pictures (Codispoti at. al., 2001). Lang and others in 1993 found significant linear trends inversely related to pleasure ranks to the most unpleasant contents and dipping below baseline for very pleasant stimuli. This negative correlation was significant only in 52% of the sample data.

Cheek muscle movement according to Lane is involved in the smile response. Cheek activity increases for stimuli which subjects rate as pleasant and is greatest for materials judged to be high in affective valence, and almost nonexistent for pictures rates in moderate regions of the valence dimension. For materials rated as most unpleasant, there is a tendency of cheek muscle activity increase again. Lang et. al. (1993) found greater zygomatic muscle (cheek muscle) responses for pictures ranked as pleasant, smallest for neutral stimuli and slightly higher at the lowest valance ranks. Unlike corrugators activity, zygomatic activity increased linearly with ranked arousal.

Heart rate activity is similar to facial muscle movement trends, with unpleasant stimuli producing more initial heart rate decrease or deceleration, and pleasant stimuli producing greater peak acceleration (Lane et al., 2000). As an index of emotional state, cardiac rate is less straightforward than other physiological measures. “Furthermore the primary direction of heart rate change varies with the type of mental processing (e.g., heart rate is accelerative in recalling memory images and decelerative in orienting to external stimuli)” (Lane et al. 2000). Bradley et al. (1993) examined averaged heart rates for individual slide presentations. It demonstrated a significant effect of picture valence. Viewing pleasant or neutral pictures did not produce difference in heart rate response. On the other hand, unpleasant pictures produced deceleration over the trials. In Codispoti et al. (2001), heart rate response to pictures differed dramatically with a classic pattern of an initial deceleration, followed by acceleration, and a secondary deceleration time. On the other hand, average heart rate change did not significantly vary across the content of the picture. Lang et al. (1993) found peak heart rate response larger when viewing stimuli ranked as more pleasant. This finding was affirmed by a significant linear trend where

61% of the subjects in this experiment had a positive correlation between valence judgments and cardiac acceleration.

Thus, overall there is significantly greater heart rate deceleration for unpleasant pictures, and relatively greater peak acceleration for pleasant materials, particularly during the first viewing.

Electrodermal activity (EDA) is a useful measure of arousal (Lane et al., 2000). In recent studies, the amount of skin conductance activity increased linearly as ratings of arousal increased, regardless of emotional valence. Studies indicated that EDA is higher for pictures that were rated as highly pleasant and highly unpleasant. A significant linear relationship emerges in which unit increases in rates arousal (regardless of valence) are associated with an increase in EDA reactivity. Bradley et al., (1993) in their study determined that average skin conductance for pleasant and unpleasant slides were larger than for neutral pictures and that unpleasant pictures had slightly larger responses than pleasant stimuli. Codispoti et al. (2001) showed that picture content affects skin conductance magnitude where larger increases in EDA associated with emotional pictures (pleasant or unpleasant) compared to neutral pictures. However, no differences were found in EDA when processing pleasant, compared to unpleasant. Lang et al. (1993) found that skin conductance response increased monotonically with ranked arousal. 77% of their subjects showed positive conductance/arousal correlations.

Electroencephalographic (EEG) technology measures brain wave signals and is another important aspect of this biometric research. One innovative approach is to measure and compare EEG readings of participants during map viewing. As with eye-tracking data, EEG data acquired during this study is voluminous. EEG data analysis is also problematic since brain wave signals are unpredictable and highly complex. EEG data has temporal pattern, noises and signal, and is a realization of a random process (Niedermeyer, 2005). It is highly difficult to identify trends, patterns and cognitive meaning of events in raw EEG data. These types of problems may be solved using pattern recognition analysis techniques (Niedermeyer, 2005).

EEG technology reads brain activity with a help of electrodes mounted on the participants head. The electric potentials generated by single neurons are far too small to be picked by this technology. Therefore, EEG activity always reflects the summation of the synchronous activity of thousands or millions of neurons that have similar spatial orientation. Even then the relevant electric signals are so small that they must be amplified by the EEG system. Brain wave activity is represented in the frequency domain which is divided into frequency classes. Most of the brain signal observed in the scalp EEG is in the range of 1–20 Hz. Alpha is the frequency range from 8 Hz to 12 Hz. Activity in this range is seen in the posterior regions of the EEG signals are brought out by closing the eyes and by relaxation and have been noted to weaken with eye opening or mental exertion. Lane (2000) explained EEG waves (10-13Hz) with emotional calm and a progressive increase in frequency with increasing intensity of emotional arousal (from anxiety to rage and panic).

Beta is the frequency range from 12 Hz to about 30 Hz. They are usually observed on both sides in symmetrical distribution and are most evident frontally. Beta activity is closely linked to motor behavior and is generally attenuated during active movements. Low amplitude beta with multiple and varying frequencies is often associated with active, busy or anxious thinking and active concentration. It is the dominant rhythm in patients who are alert or anxious or who have their eyes open (Niedermeyer, 2005) . Gamma is the frequency range of approximately 30–100 Hz. Gamma rhythms are thought to represent the binding of different populations of neurons together into a network for the purpose of carrying out a certain cognitive or motor function (Niedermeyer, 2005).

EEG measurement is promoted by experiment stimuli producing brain activity in different frequencies. Signal frequencies above 12 Hz is the primary interest of this study, because it represents cognitive load of the brain from stimuli. A higher frequency in one of the NHC COU advisories would represent higher cognitive load and arousal of participant. More cognitive load explains better stimuli for the user and better map communication.

EEG is widely used in medicine to investigate brain activities during patient epilepsy, patients with sleep apneas, brain injury or mental illness and other. Montgomery et. al. (1995) and others in 1994 argued the need to use this technology in investigating brain response during cognitive tasks. In particular, EEG activity correlated to subject performance and quantify brain activity changes by cognitive stimuli (Montgomery, 1995).

In order to raise the signal-to-noise ratio sufficiently to reveal the general characteristics (characteristic peaks at certain electrode sites), it is necessary to average a large number of stimulus-gated EEG recordings. A marker signal is usually fed into one the EEG channels to mark the moment of stimulus presentation, then epochs of a given length following such markers are selected and averaged. Epochs containing artifacts are identified visually, so that they can be excluded from the analysis. (Montgomery, 1995)

Montgomery et. al. (1995) and team used a digital cognitive task presentation system to deliver stimuli to participants while EEG signals were recorded. Mental arithmetic problems were presented on volunteers. This research revealed that the subjects' neural activity is directly and highly correlated with task performance, and EEG analysis provides a way of isolating those areas of the brain that are directly related to a task performance.

Klimesch (1999), provides evidence that EEG oscillations in the alpha and the theta band reflect cognitive and memory performance. In particular event-related changes indicate that the extent of upper alpha desynchronization is positively correlated with (semantic) long-term memory performance. Keil et al.)2002) discovered specific enhancement for pleasant pictures over left-hemisphere regions in the late P3 signals.

In a physiological sense, EEG power reflects the number of neurons that discharge synchronously (Niedermeyer, 2005). Because brain volume and the thickness of the cortical layer is positively correlated with intelligence, it is tempting to assume that EEG power too, is a measure that reflects the capacity or performance of cortical information processing. EEG power measurements are strongly affected by factors such as age, arousal and type of cognitive demands during actual task performance (Niedermeyer, 2005). During actual task demands, the extent of alpha power suppression is positively correlated with cognitive performance and memory performance in particular.

Synthesis of the literature

The proposed research incorporates literature review from very disparate disciplines of cartography, geography, psychology, psychophysiology and neuroscience. The disciplines are interested in investigation of stimuli influence to the user. In geography and cartography these images usually are maps. Map design evaluation is very common in cartography, but map evaluation from psychophysiology and cognitive science perspective is rare or noneexistent. Most geographic researchers investigate maps with subjective questionnaires and surveys. Some research has been done evaluating web maps, but only with a map usability perspective. The map reading itself has rarely been investigated using eye recording or psychophysiology methods. This thesis will try to fill this gap in current research.

CHAPTER 3: DATA AND METHODS

Study Design

This study arose from a project of RENCI at ECU that investigates perception of hurricane hazards. A main research hypothesis is that NOAA NHC Hurricane advisories communicate risk less effectively as compared to an experimental, RENCI-developed hurricane risk map. The study null hypothesis is that no difference is measured between the control and test stimulus collected during experiment.

The main objectives of this project are in the analysis of the **eye-tracking**, **Electroencephalography** (EEG), **Electromyography** (EMG), **Electrocardiography** (ECG) and **survey data** gathered in the **hurricane risk perception** study conducted by RENCI at ECU.

From the prior literature review and personal communication with Dr. Nicholas Murray (Visual Motor Laboratory, Department of Exercise and Sports Science), I formulated hypotheses regarding eye-tracking and biometric data. First, specific eye-tracking and biometric indicator measures distinguish between more effective, map communication in the comparing advisory maps. Second, ECG or heart rate would also be higher in more effective hurricane advisories. Then, higher EMG measure of brow movement would indicate negative emotions of the participant and show effectiveness of better map communication. Exploratory and descriptive statistics and spatial analysis would proceed a set of logistic regressions with use of biometric and demographic measures to prediction of participant map advisory preference.

Hypotheses

- Eye-tracking fixation numbers will be lower in the RENCI advisory map legend compared to NHC advisory legend.
- ECG or heart rate will be higher in RENCI advisory map.

- EMG measures of brow movement will be higher in RENCI advisory map.

A sample of 35 student participants were tested in a laboratory environment using eye-tracking and biometric instruments. Each student participant also completed a survey designed to investigate hurricane advisory communication effectiveness. A project committee consisting of Dr. Crawford, Dr. Allen, Dr. Murray and Dr. Kain developed hypothetical hurricane scenario and processed an Institutional Board of Review (IRB) for the methods. Participants were presented with the following scenario:

Scenario

Imagine that it is 11:30 PM on Wednesday, September 17, 2011 and Hurricane Laurie is approaching the east coast of the United States. In a moment, you will see a series of maps produced by the National Hurricane Center that show the storm eye and forecast positions beginning at 5AM Sunday, September 14 and updated every five hours to the most recent advisory map for 11PM Wednesday, September 17. Study the maps you will be shown. The first forecast map will be visible for 20 seconds with following forecast maps updating automatically every few seconds. At the end we will ask you a series of survey questions.

During the first phase of the experiment 35 - student participant biometric data was recorded. Due to the technical issues with eye movement recording equipment additional participant eye movement data had to be captured. During the second phase, 21 participant eye movement and survey questionnaires data were recorded

The experimental design consisted of two groups, where each group received a different sequence of images. To avoid bias from order, learning and fatigue the first group of test subjects will see NOAA NHC advisories (see Figure 4) first and RENCI hurricane advisories second (Figure 5). The second group of test subjects will see RENCI hurricane advisories first and NOAA NHC advisories second. A survey questionair will be the conducted after the eye-tracking and biometric recordings.

NOAA NHC Hurricane advisories where recreated using ArcGIS software. Hurricane Isabel 2003 was chosen as the base hurricane for this experiment, because this storm was last major storm to hit the NC coast. NOAA stores only graphical data of the historic hurricanes and images have different geographical extent so more reliable data source had to be obtained. Hurricane evacuation software for emergency managers – HURREVAC2000 was chosen as more accurate data source. Hurricane data came in shapefile standard format for all Hurricane Isabel advisories from the HURREVAC database. Map design essentials (symbology, color, label annotation, typography, layout, logos and legend) were manipulated in ArcMap to mimic the original NHC Hurricane Isabel advisories of 2003. With a purpose to make this experiment more realistic as possible hurricane name and date was changed to the Hurricane “Laurie,” for 2011.

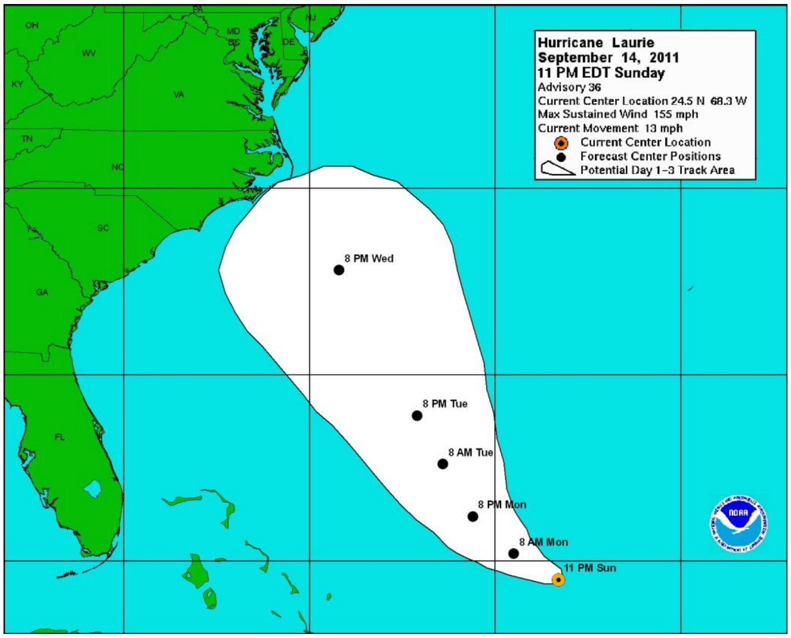


Figure 4: NOAA NHC Hurricane advisory for fictional Hurricane "Laurie".

The next step was to create the experimental RENCI advisory in the fashion which would improve cartographic design and hazard risk communication as discussed in the literature review. The basic design had to be easy to understand and intuitive for the reader. NHC advisories lack color and representation of risk of hurricane effects outside the traditional white cone of uncertainty. For the RENCI advisory cone graphic, a buffer was applied represent storm effects beyond the cone and colored to show different levels of storm effects inside it. Buffer distance was chosen arbitrary and applied to all advisories equally. This gives an implicit indication of relative storm risk zones and safe zones. Color inside the cone was calculated using cost distance from the forecasted storm track line and the current storm center location. While the continuous tone is not an explicit, quantitative mapping of the historical probabilistic error (used by NHC to determine the width of the cone), it nonetheless provides a surrogate for such relative probability (i.e., distance from the forecast track) without an unintentioned focus on a particular line.

Hurricane Laurie advisory maps where created from the 36th advisory to final 48th advisory adapted from Hurricane Isabel track. These advisories were placed in a PowerPoint presentation as a slide show sequence (slides advancing every 7 seconds) to simulate major hurricane track. A sequence of advisories will simulate imminent and evolving hurricane risk for the experiment participants. Advisories are the hazard risk communication tools, so the eye-tracking and biometric instrumentation could capture subject behaviors and risk perception of the participants (Table 1.).

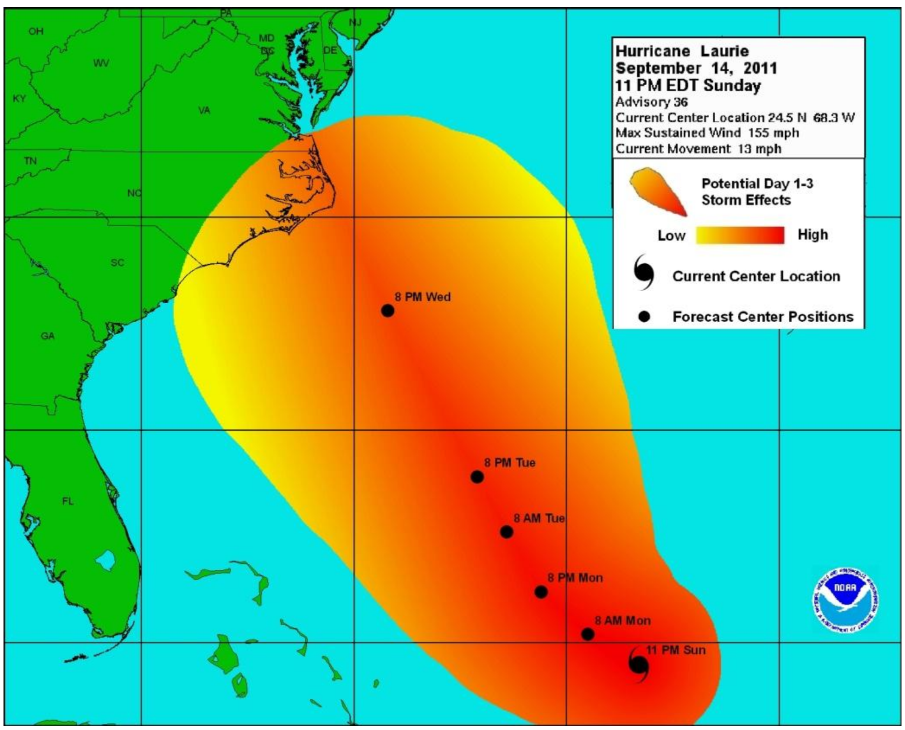


Figure 5: NOAA NHC Hurricane advisory for fictional Hurricane “Laurie”.

A relatively small sample size of 35 is used in the current study, because of the high technological demands of recording data with these techniques (pre- and post-processing) and a time and budget constraints. Participant sample size is a concern, because it will be difficult to extrapolate the study results to a larger population (Duchowski, 2007). To justify sample size in this study, similar historical data would be desirable. In fact, most eye-tracking studies are done using small number of participants like one described by Duchowski (2007) used 16, Thomsen and Fulton (2007) – 63, Henderson et. al. (2000) – 24. As in this study, most of the time eye-tracking studies are conducted in recruiting a convenience sample, such as high school or college student participants (Duchowski, 2007).

Eye-tracking captures very precise and objective data and is capable of identifying behavioral differences with high statistical significance. Lenth (2001) summarizes this issue and gives good examples on how to choose the sample size. Using two-sample t test software, we find that a minimum sample size of the n=23 per group is needed to achieve the stated robustness goals (Lenth, 2001). Since map design is theoretically different from each other, this level of difference will be easily achieved through this experiment. Participant numbers are sufficient to answer key questions about cartographic design of hurricane advisories and risk communication. The methodological approach developed in this study is also likely to be scalable to future, larger scale research studies concerning hazard risk perception.

Data Acquisition

The data were acquired during a laboratory experiment using student volunteers, ages ranging from 19-21 years old (freshmen level students). A number of demographic questions are asked in the survey with the aim of determining age, gender, education, major, place of residence, and each participant's hurricane experience.

An Applied Science Laboratories (ASL; Waltham, MA) 5000 SU eye movement system is used to collect eye tracking data. The 5000 SU system is a video-based monocular corneal reflection system that measures the point of gaze relative to video images recorded by a headband mounted scene camera and an eye camera. The system has the capability to measure pupil position and corneal reflex, which are used to compute visual gaze with respect to the optics(Janelle et al. 2000.) System accuracy was ±0.5º visual angle with precision of 1º in both vertical and horizontal directions with a sampling rate of 60Hz. Recalibration of the eye monitoring equipment was performed continually with manual offset commands throughout the data collection process for each subject.

Eye-tracking data consist of the following eye-tracking metrics: fixation duration (gaze), fixation rate, fixation duration mean, number of fixations, fixation sequence (scan path), areas of interest (AOI), gaze percent of time per AOI, number of fixations per AOI, gaze duration mean per AOI. Fixation naturally corresponds to the desire to maintain person's gaze on an object of interest. The signal is classified as a fixation provided the duration of the stationary signal exceeds a predetermined threshold. Fixation sequence is an indicator of position and sequence similarity among different viewers (Duchowski, 2007). AOI is determined during data processing, with initial areas of interest including the map legend, hurricane cone areas, North Carolina, South Carolina and Virginia states areas, and forecast hurricane landfall area.

Fixation number and duration in AOI is directly influenced by the cognitive load of the brain, so we can make the assumption that devoting more fixations to a region may mean that more cognitive effort is being exerted (Duchowski, 2007). More cognitive loading for the map area means more time is spent to understand the meaning of the stimuli in the particular map area. From this notion we can hypothesize that lower fixation number in the map legend is direct influence of more effective map communication. This hypothesis is paramount in comparing the two hurricane advisory maps.

Table 1 summarizes the biometric data captured during experiment which will be used in this study. Biometric data has wide range of information about participants emotions, arousal and cognitive load.

Instrument	**Measure**	**Type**
Biopac Systems MP35 amplifier	EMG	Zygomaticus major (Cheek muscle)
	EMG	Corrugator supercilii (Brow muscle)
Biopac Systems MP35 amplifier (EDA finger transducer)	EDA	Sweat gland activity
Neuroscan EEG 64-Channel NuAmps system	EEG	Beta 1
	EEG	Alpha
Applied Science Laboratories (ASL, Watham, MA) 6000 SU eye movement system	Eye	Fixation
Biocom system	Heart Rate	BMP

Table 1: Data acquisition instruments used to obtain study data. Information provided by: Dr. N. Murray (Visual Motor Laboratory, ECU)

Analytical Strategy

Primary objective of this research is to compare the NOAA NHC hurricane advisory map cartography (Cone of Uncertainty) with an experimental RENCI hurricane advisory map cartography. The research uses objective biometric and demographic measurements to distinguish map effectiveness using cartographic design. More effective cartographic design is hypothetically to have significantly different measure versus a less effective counterpart.

Objectives:

- Compare biometric and eye fixation data for significant differences.
- Analyze biometric data through time
- Analyze fixation sequences during the experiment for unique patterns based on viewed hurricane advisory
- Display common eye fixation patterns based on space-time cube principles.
- Analyze spatial distribution of eye fixations using exploratory spatial and statistical analysis techniques:
    - Kernel density estimation comparison
    - Geographically weighted regression
    - Moran's I
    - LISA
    - G-Statistic
    - Nearest neighbor statistic
- Test differences in predictive ability of effectiveness using a logistic regression model for hurricane advisory preference variable.

The first step is to analyze difference in biometric averages through hurricane advisory viewing time period. Since biometric and eye-tracking data do not usually have a normal distribution, non-parametric Mann-Whithey U test will be applied.

The second step is to analyze biometric data for groups through time. Biometric data average through time will be correlated by image slide. Pearson's correlation between biometric measure and slide will be determined. Correlation coefficients between two groups will be compared.

Eye Recordings

Fixation sequence analysis is a very important aspect of this research and allows us to understand the viewing, information search behavior, and direct cognitive loading of the brain for each individual as well as discovering similar groupings from an objective data source.

For this analysis five Areas of Interest (AOI) were selected. These areas correspond to most important areas of the Hurricane advisory map: Cone of Uncertainty, Map Legend, North Carolina, South Carolina and Virginia.

For viewing and search behavior analysis, the author uses EyePatterns software , which allows the investigator to identify similar and different fixation patterns (West et al. 2006).

Simple string search function in this software provides for identifying fixation patterns that match a certain sequence (Coltekin et al., 2010). The order of fixation is also an important aspect of this research, and it can be performed on the collapsed or not collapsed sequence. A collapsed sequence is a "compressed" version of original sequence.

CCCCLLLNNNNNN = CLN

Example of original sequence and collapsed sequence.

The most popular sequence similarity detection algorithms is Levenshein dissimilarity measure described by West, 2006; Fabrikant, 2008; and Issacson in 2007. This string-editing algorithm measures the similarity of two string sequences by counting the number of necessary insertion, deletion and substitution steps to convert one string into other (Coltekin et al. 2010).

For example string-editing distance between “Piece” and “Peace” is 2, since you have to perform two steps to get the target word:

Step 1. “Piece” > “Peece” (substitute “i” for “e”)

Step2. “Peece” > “Peace”(substitute “e” for “a”)

Needleman and Wunsch’s global sequence alignment algorithm employs a scoring scheme to align two sequences by introducing a reward for matching and gaps, but a penalty for mismatches (Coltekin et al. 2010). This method also produces the similarity matrix.

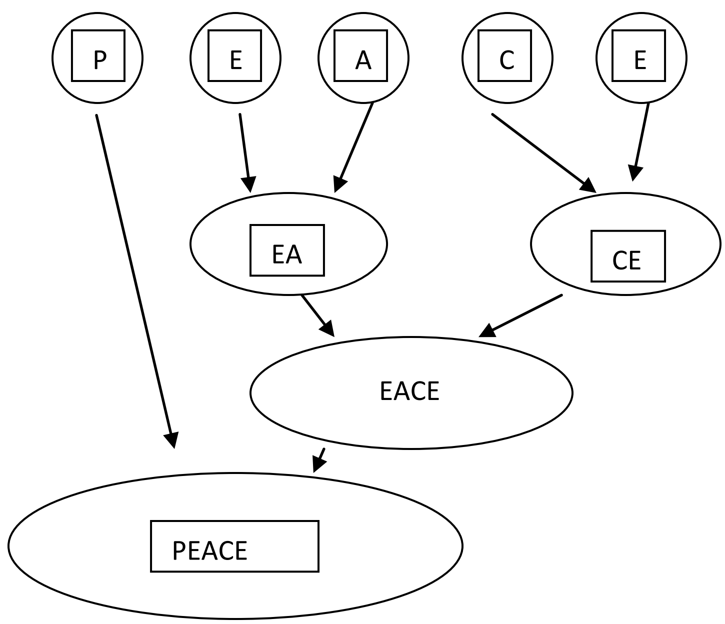


Figure 6: Sequence dendogram example.

Eyepatterns software also employs hierarchical average linkage clustering (West et al. 2006), by parsing similar sequences into a sequence dendogram - where more similar sequences have highest similarity score (see Figure 6).

After similar viewing patterns are discovered, the next step in this study was to verify and visualize similar sequences using advanced GIS geovisualization techniques. The author used time-space cube principles to verify and represent similar fixation sequences. This methodology allows visual comparison of fixation sequences in three dimensions. X and Y representing computer screen dimensions and Z representing time.

3D fixation sequence polylines were visualized using ArcScene, 3D GIS visualization platform. During investigation similar fixation sequences derived from EyePatterns software were plotted together to see how similar sequences actually are.

EyePatterns allows calculation of transition frequencies between events in a sequence, this method is good in identifying transitions between two AOI's which will allow to indicate measure of transition between primary interest of this research – transition in Map legend and Cone of Uncertainty of the Hurricane advisory. This software visualizes these transitions between AOI in the form of a transition matrix. From here averages can be calculated and compared.

Spatial Methods

Spatial analysis of eye fixation data will be performed in this study. Using spatial cluster detection and cluster evaluation measures, spatial distribution differences will be evaluated. In order to determine the differences in group fixation clusters, kernel density estimation had to be calculated. **Kernel density estimation** produces fixation density map as a cell format raster. It associates each known point (in this case fixation points) with a kernel function for the purpose of estimation. It is expressed as a bivariate probability density function centered at the known point and tapering off to 0 over a defined bandwidth or a window area (Chang, 2008). Kernel density function input is the known points and output is the density raster showing expected values. Kernel density estimation was calculated for the two eye-tracking data test groups as a two separate raster files.

Density maps from here will be visually compared and later subtracted from each other so differences can be observed and gratified as a difference surface.

Geographic weighted regression (GWR) was used to analyze spatially varying relationships of NOAA group fixation kernel density estimation map ("heat map") and RENCI group fixation heat map. GWR allows us to understand the difference in two heat maps with statistical significance (Fotheringham, 2002).

This regression generates a separate regression equation for every observation analyzed in the study area and presents spatial variation in the results. GWR model uses Gaussian weights as inverse function of distance in calculations of spatial relationships between observation. GWR incorporates local spatial relationships into regression (Fotheringham, 2002). Traditional spatial models do not account for "local effects" in global regression models. this leaves out large residuals which usually are spatially correlated (Fotheringham describes such as parameters spatial non-stationarity.) A solution to this problem is to derive a global spatial regression for different research area or to use GWR.

GWR Fixed spatial kernel was used in this research. Using spatial kernel regression, each data point is weighted by its distance from the regression point. "Data points closer to the regression point are weighted more heavily in the local regression than are data points further away" (Fotheringham, 2002).

Spatial autocorrelation analysis **Moran's I** and **LISA** was conducted for the fixation points and its duration as an attribute. Analysis of spatial autocorrelation considers the point locations and the variation of an attribute at the locations. This spatial analysis measures the relationship among values of a variable according to the spatial arrangement of the values (Chang, 2008). The relationship between values may be described as highly correlated if like values are spatially close to each other and random if no clustering can be detected. A measure of spatial autocorrelation is Moran's I which detects the presence of the clustering of similar values.

Moran's I is calculated by:

Equation 1: $$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{s^2 \sum_{i=1}^{n} \sum_{j=1}^{m} w_{ij}}$$

W_{ij} (d) = spatial weight

$\overline{X}$ = mean of X

X_i = value of location i

X_j = value of location j

S^2 = variance of X

X in this research represents eye fixation value for particular location. X is calculated by using Kernel density estimation function. Kernel density of 4 screen pixels aggregated for two groups.

The values Moran's I takes on are anchored at the expected value E(I) for random pattern (Chang, 2008). If Moran's I is closer to E(I) than the pattern is random. If greater than E(I), than points have similar values and if Moran's I is smaller than E(I) adjacent points have different values.

Equation 2: $E(I) = \frac{-1}{n-1}$

Local Indicators of Spatial Association (LISA) a local version of Moran's I produces "hot spot" analysis where high positive or high negative Z scores suggests the presence of clusters - hot spots or cold spots.

G-statistic detects clustering of similar high or low values. A high G(d) value points to a clustering of high values, and a low G(d) value shows a clustering of a low values.

G- statistic is calculated using equation:

Equation 3: $$G(d) = \frac{\sum\sum w_{ij}(d)x_i x_j}{\sum\sum x_i x_j}, \quad i \neq j$$

W_{ij} (d) = spatial weight for distance - d

X_i = value of location i

X_j = value of location j

And expected value of G(d) is expressed as:

Equation 4: $$E(G) = \frac{\sum\sum w_{ij}(d)}{n(n-1)}$$

The **nearest neighbor statistic** is the ratio of the observed average distance between nearest neighbors to the expected average for a hypothetical random distribution. If the ratio value is lower than 1 it means that point pattern is more clustered then random. If the ratio value is greater than 1, then the point pattern is more dispersed than random.

Logistic Regression

The final stage of this study is to understand which hurricane advisory is more preferred by the participants and why. Binary Logistic regression was constructed using survey answer to the question: which hurricane advisory map test subject prefers - NOAA NHC or RENCI@ECU? Survey demographic data, eye-tracking and biometric data (EEG, EMG, and ECG) are independent variables for this model. The demographic, eye-tracking and biometric measures will allow to understand why particular advisory was chosen and explained it with statistical significance.

Logistic regression is used to predict a categorical variable from a set of predictor variables. Logistic regression has been especially popular with medical research in which the dependent variable is whether or not a patient has a disease.

The logistic regression in this research is used in order to predict participant's answer. In logistic regression, the binary categorical outcome is the probability of choosing NOAA or RENCI hurricane advisory.

Logistic regression is presented in this equation:

Equation 5: $P_i = e^{\beta Xi} / 1 + e^{\beta Xi}$

The probability of choosing one of the advisories by the participant P_i is portrayed as a function of biometric or demographic indicator(s) as independent variables. These variables are accounted for in the matrix (X) and the relative influence of each factor on the choosing one of the advisories is reflected in the size of its estimated coefficient (β). The response of this probability to the linear combination of independent indicators is expressed graphically as in Figure 7.

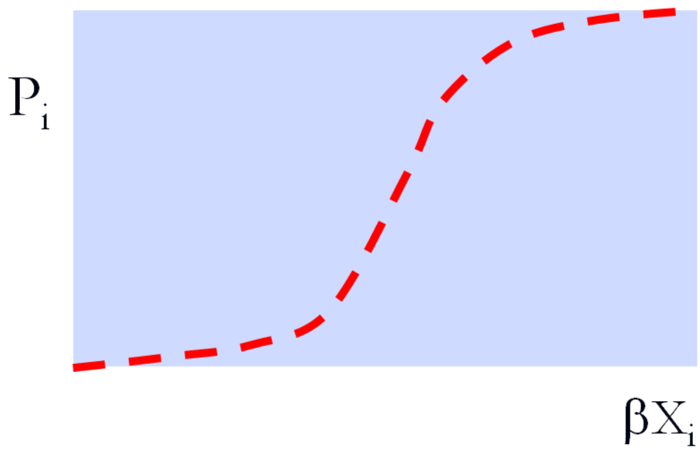


Figure 7: Logistic curve relating probability of advisory preference to biometric or demographic attributes.

after probability is calculated its results are linearized forming the odds – the ration of probability for two possible outcomes taken by the natural log of odds.

Equation 6: $logit(i) = \ln (p_i/1-p_i) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i}$

CHAPTER 4: RESULTS

Biometric Data Analysis

During the first phase of the experiment 35 - student participant biometric data was recorded. Due to the technical issues with eye movement recording equipment additional participant eye movement data had to be captured. During the second phase, 21 participant eye movement and survey questionnaires data were recorded.

The first phase of experiment (N=35) participant average age was 22 years with an average of 3 years of higher education (Figure 8 and 9). 27 participant's home state was North Carolina. 8 out of 35 students experienced hurricane evacuation. On average students rated themselves as having below average knowledge and understanding of hurricanes (Figure 11). Most data recording was done in months of March and April. Most participants listed the Weather Channel as primary weather related news source.

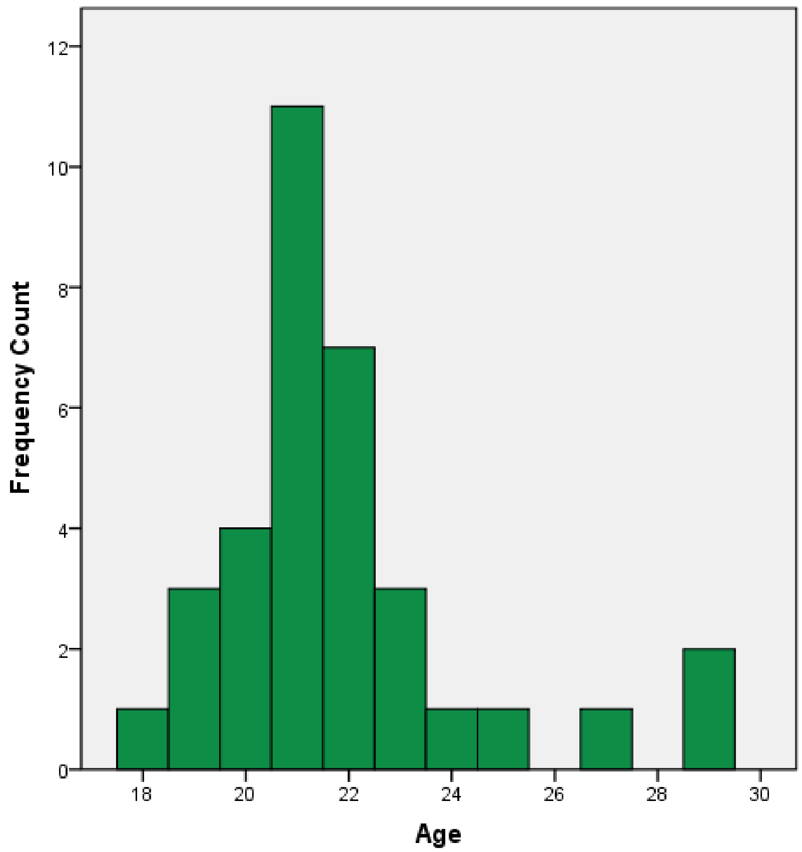


Figure 8: Histogram of participant's age.

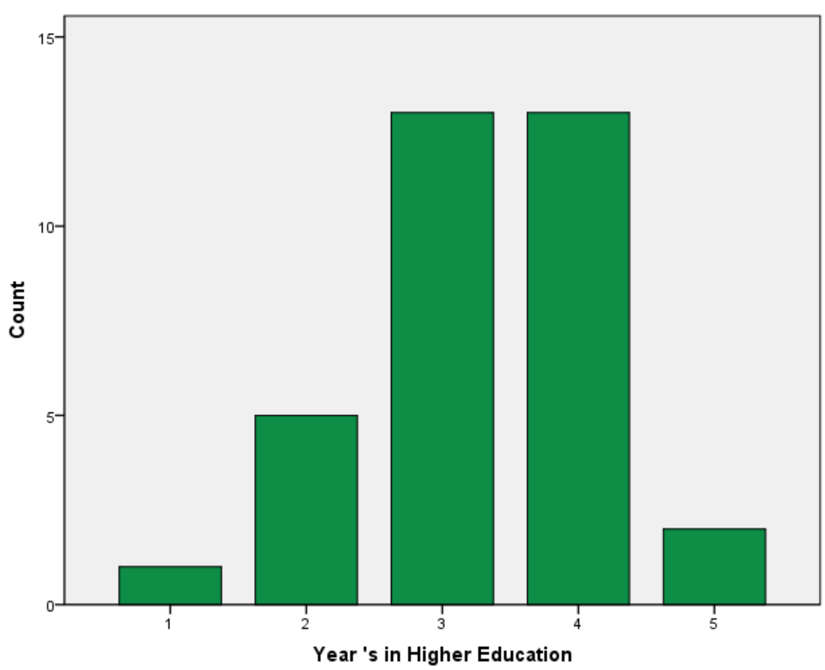


Figure 9: Histogram of participant's age.

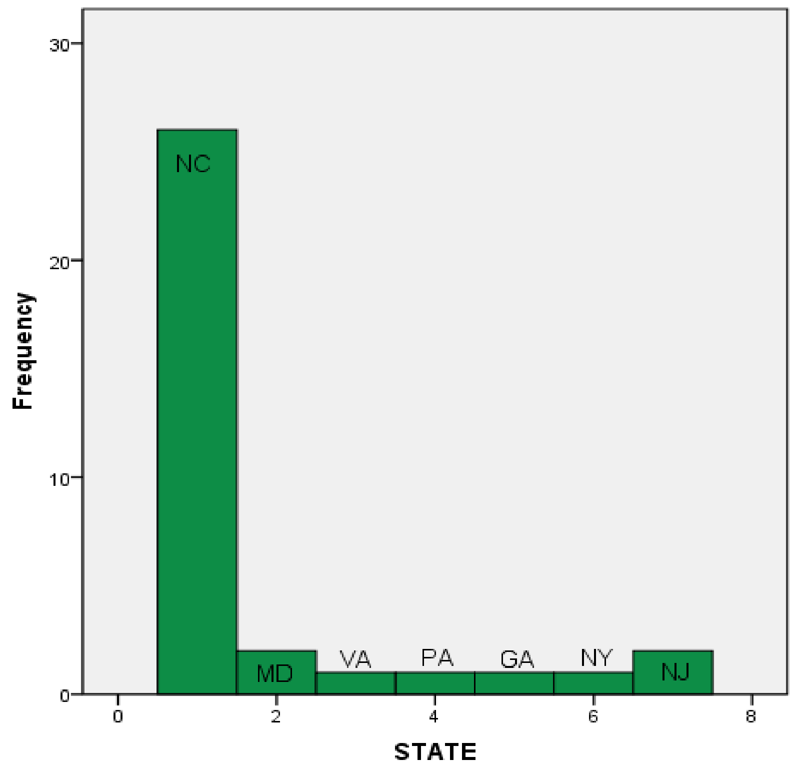


Figure 10: Histogram of participant’s home state

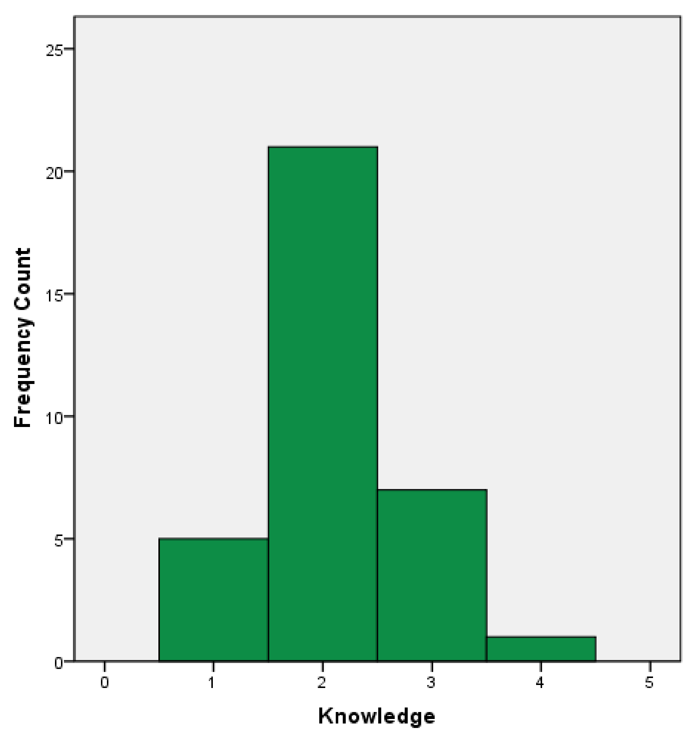


Figure 11: Histogram of participant’s self-rated knowledge of hurricanes.

For the first phase 33 participant biometric data (EEG, ECG and EMG) was used in data analysis while all 35 survey data was used in survey data analysis. Only 12 participant eye movement data could be used in this study from the first phase. For the second phase, 16 eye movement recordings were used in eye movement analysis.

The data from the two groups was analyzed in Statistical Package for the Social Sciences (SPSS) for statistical analysis. NOAA and RENCI group descriptive statistics were calculated and non-parametric tests on the outcome differences performed.

Group averages for biometric and eye-tracking data are showed in Table 2. All averages are higher for RENCI test group, especially for cheek and EDA data. Higher increasing EDA and HR are associated with high arousal, while increasing brow and cheek muscle movement is associated with negative and positive effect or emotion respectively. Eye movement fixation metrics are different for the two groups. Total fixation number and fixation number average per participant for NOAA group is higher, perhaps indicating a less efficient search strategy (Coltekin et. al, 2010) and explained as higher user confusion. The same conclusion arises from analysis of fixation average for two groups, 308.2 and 298 respectively. Higher fixation numbers also indicates larger cognitive loading, this could be construed as poorer map design (or complexity.)

Group Averages	NOAA	RENCI	Significance
Brow	0.000581 V	0.000659 V	0.311
Cheek	0.000609 V	0.00516 V	0.406
EDA	5.680227 µS	8.375907 µS	0.429
HR	72.106515 BPM	73.64791 BPM	0.914
Frontal EEG	0.368	0.427	$F(1, 496) = 3.724$, $p < .05$
Fixation number	4315	4175	0.662
Fixation average	308.2143	298.2143	0.468
Fixation duration mean	0.209924	0.226755	0.532
Fixations in Legend	895	1262	0.141
Fixation in Legend per square pixel	0.006635134	0.006038	0.818

Table 2: Eye movement, biometric data averages, and significance (Mann-Whithey U test)

Eye fixation data is very important for the map legend. This metric show how many times participants looked at the map legend. In cartography more effective map would have less fixations in the legend equal to lesser user confusion and better map cartography overall. Fixation count in the map legend is larger for RENCI group 1262 then in NOAA group – 895 this occurs because RENCI maps has larger map legend area. For this analysis both group map legends were buffered equally to account for eye movement recording error which allows to count eye fixations in the map legend (Figure 12.)

The legend fixation number in map legend area was divided by the legend area in square pixels. From this metric - RENCI maps has less fixations per square pixel than NOAA maps (0.0060 and 0.0066 respectively). This implies that NOAA maps have poorer map cartography compare to RENCI map cartography.

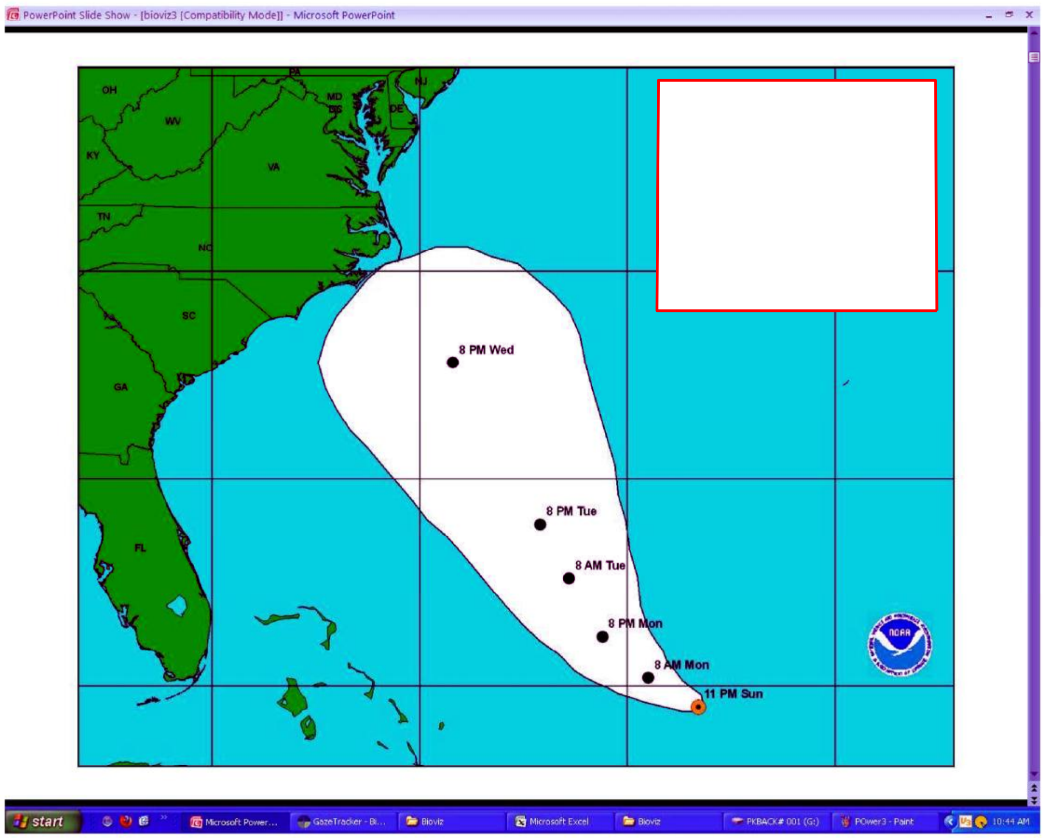


Figure 12: NOAA hurricane advisory slide and polygon (red) were fixation classified as legend fixations.

Fixation duration mean is another key attribute in fixation analysis. For RENCI group this measure is higher - 0.226755 and for NOAA group lower - 0.209924. This measure explains that fixations are longer for RENCI group, meaning better map design and shows that participants spend more time in searching for information in the NOAA maps. In this case NOAA maps are also more difficult to interpret, perhaps less familiar as well. The Mann-Whithey U test was used to determine statistical significance for two groups, but in both cases no statistical difference was found (total fixation difference in N = 28).

While fixation data accounts for cognitive loading of the brain, biometric data helps to understand how participants felt and reacted during the experiment. Biometric data analysis reveals that Heart Rate – HR, electro dermal activity – EDA and facial muscle movement (brow and cheek) does not have normal distribution (Figure 13 and 14.).

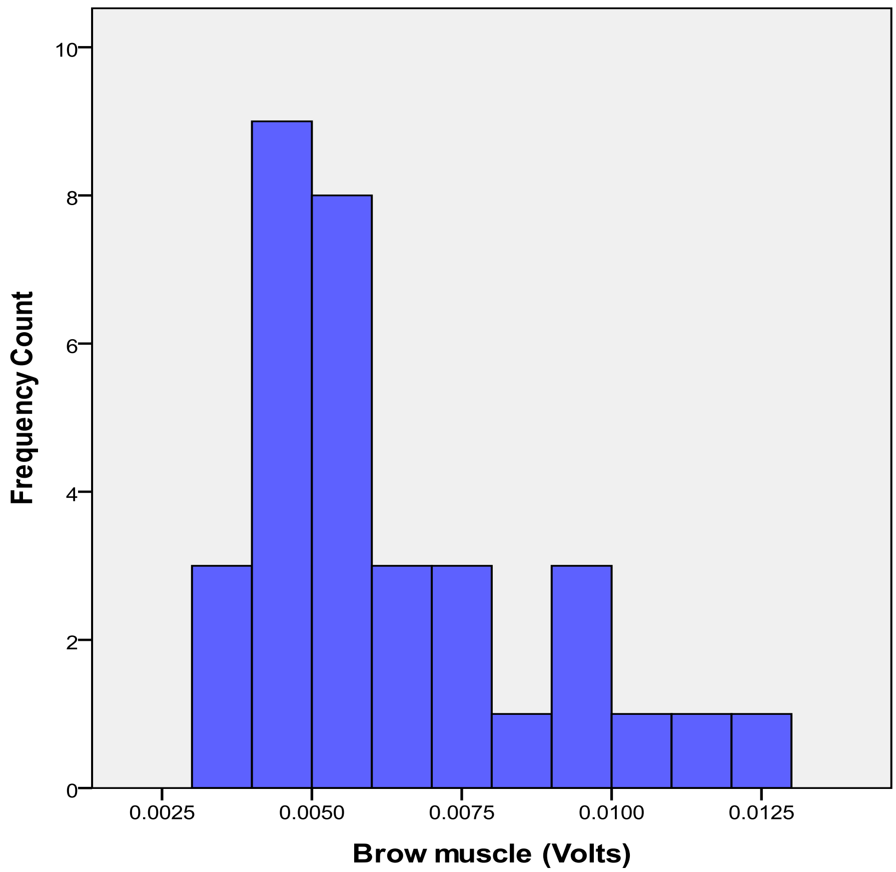


Figure 13: Brow muscle movement histogram.

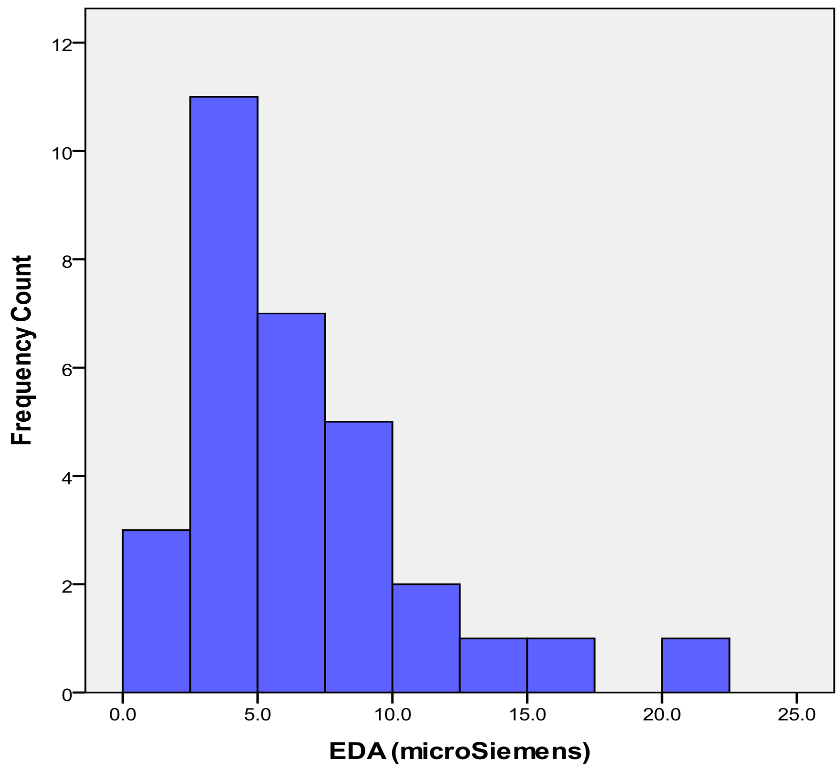


Figure 14: Electro Dermal Activity (EDA) histogram.

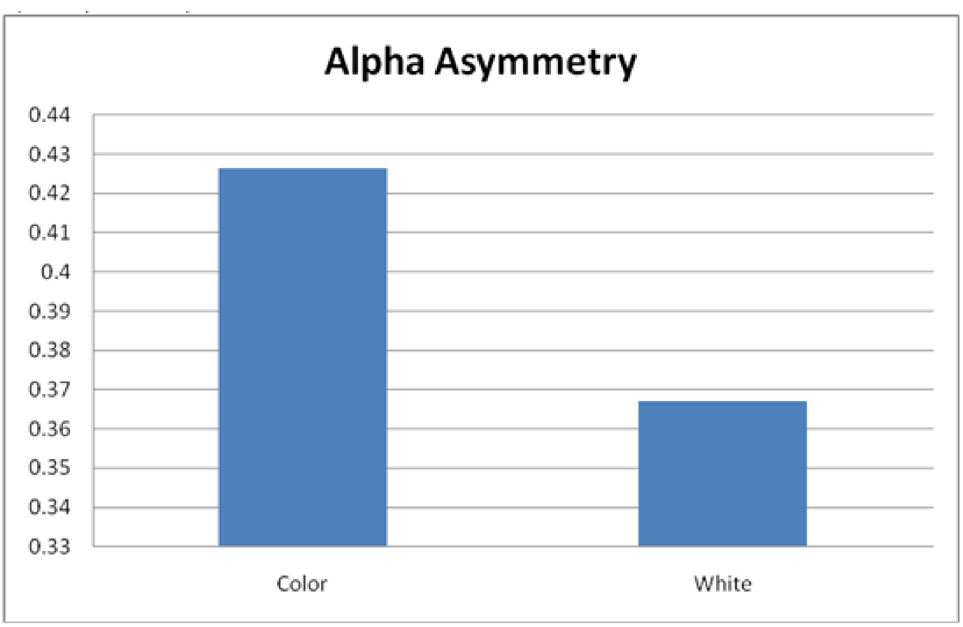


Figure 15: Left Frontal Dominance Color Cone. Data source: Dr. N. Murray (VML).

Brain wave activity data recorded by EEG was processed and analyzed by Dr. N. Murray (VML) with analysis output shown in Table 2. The RENCI hurricane advisory map had larger alpha wave activity in left frontal brain area, which according to Keil and Dr. Murray (Keil et al., 2002) implies pleasant pictures, enhancing the EEG signal over left-hemisphere regions. This notion suggests larger, positive effect to the user from the RENCI maps.

Many cognitive research scientists correlate biometric data with stimuli by ranking its content as neutral, pleasant, or unpleasant and observing participants' biometric reaction to the stimuli. In this research the author assumed that all hurricane advisory maps are unpleasant in their content under real life situations, but unpleasantness has different levels so all hurricane advisory maps were ranked from 1 to 12 (1 is least unpleasant and 12 is most unpleasant.) The first advisory map represents the hurricane at the longest distance to the mainland over the period, and map twelve represents the hurricane when closest to landfall. Pearson correlations were calculated by correlating pictures' unpleasantness rank to the particular biometric measure to understand which hurricane advisory is more effective through time. A more unpleasant map will thus be understood as a more effective map design in communicating hurricane risk.

Brow muscle movement is associated with unpleasant stimuli (picture, sound) (Lane and Nadel, 2000). Both groups had similar brow muscle movement, but RENCI group brow muscle average was higher than NOAA group explaining higher negative effect to the map user. Correlation of brow muscle movement and ranked hurricane advisory images reveal that no correlation exists between two measures in both groups (Table 3.). This explains that participants for both groups did not see maps more unpleasantly, although the stimuli theoretically was getting more unpleasant thru time.

Correlation coefficients	NOAA	Significance	RENCI	Significance
Brow	0.07	0.944	0.093	0.322
Cheek	-0.043	0.65	0.0723	0.442
EDA	-0.546	0.001	-0.564	0.001
HR	0.187	0.05	0.269	0.004

Table 3: Group biometric measures Pearson correlation to the map stimuli thru time.

Cheek muscle movement increases for stimuli rated as pleasant or most unpleasant underlie violent pictures (Lane and Nadel, 2000). Cheek muscle movement averages were different, but no statistical difference was detected. NOAA group cheek muscle movement was larger than RENCI group by 8 times, which could be explained by RENCI maps being more pleasant to the user. As with brow muscle movement, cheek muscle movement correlation to map stimuli was none existent for both groups (Table 3).

Electro dermal activity or EDA is usually used to measure arousal and it usually increases as ratings of arousal increase (Lane and Nadel, 2000.) This increase is inferred by viewing highly pleasant or highly unpleasant slide images. EDA activity average for both groups were quit high NOAA group average of 5.68 μSiemens and RENCI group 8.38 μSiemens that is 1.48 times larger than NOAA group average.

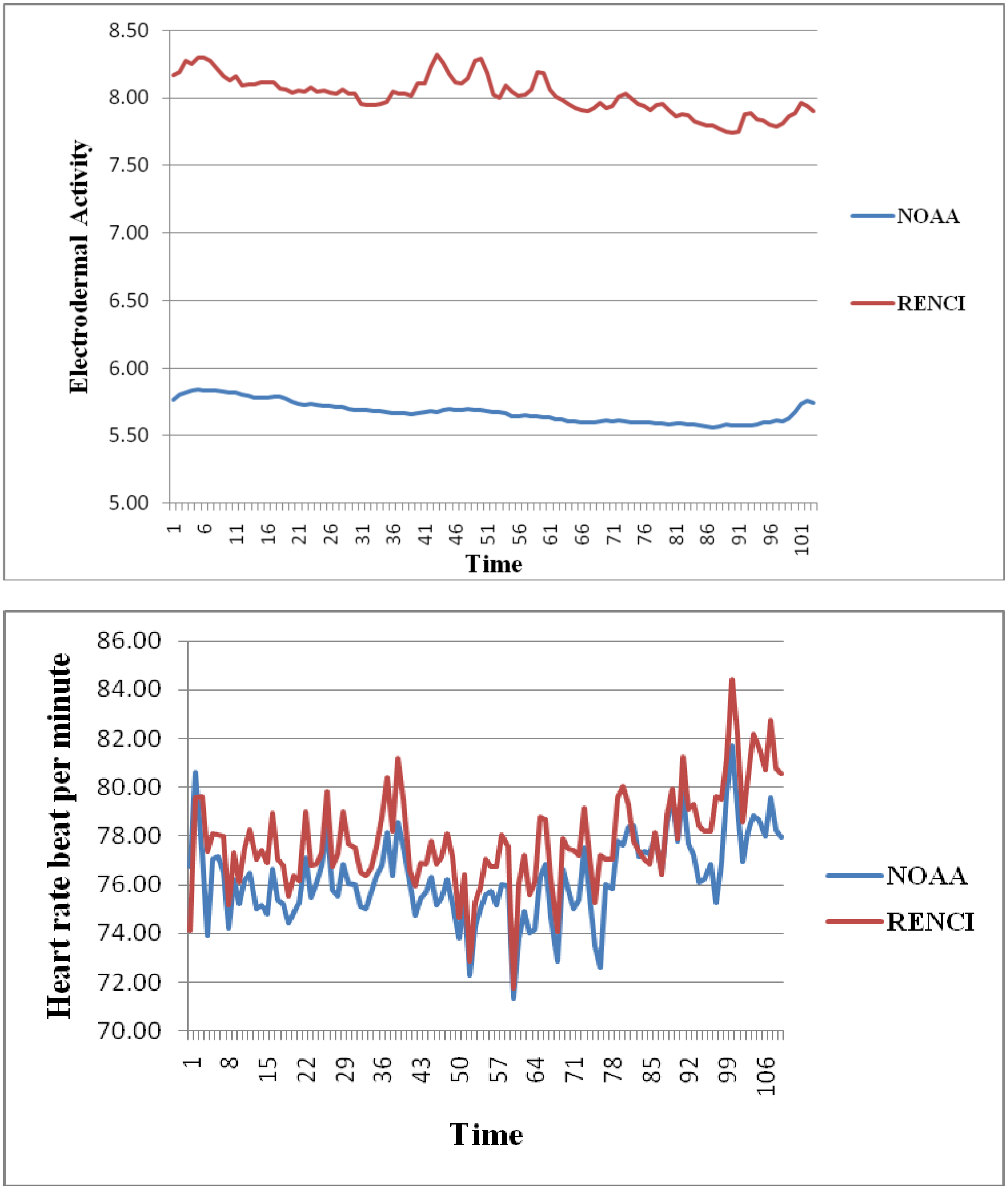
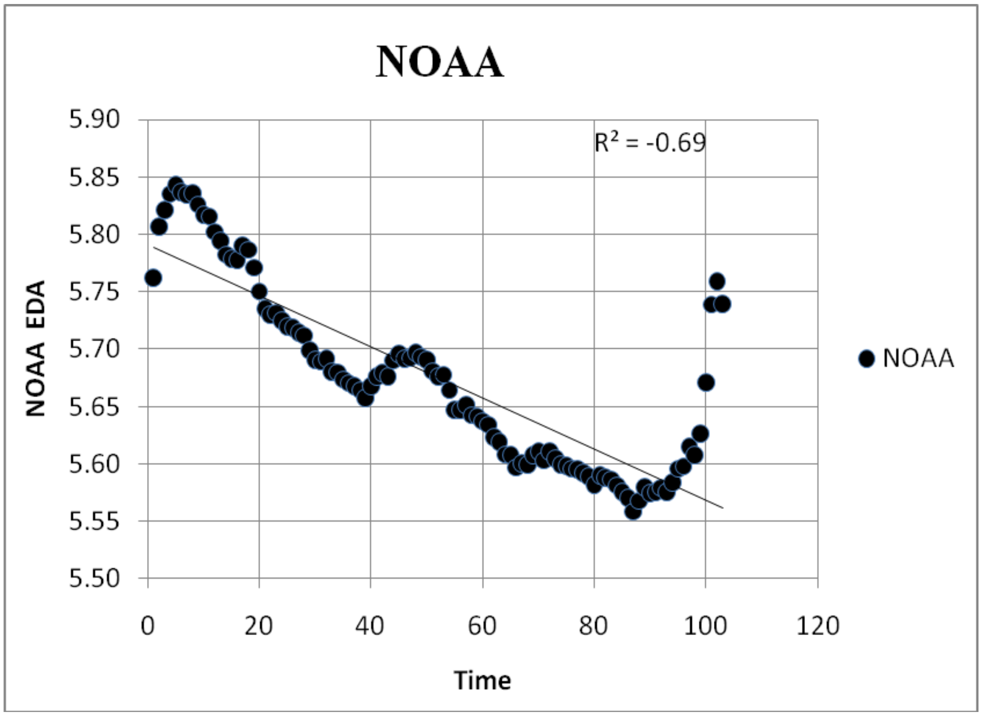


Figure 16: Electro dermal activity (EDA) and Heart rate (HR) for both groups thru time.

Time series acroos both groups reveal that EDA does not show high variability during this experiment, but the differernce beetween two groups is quite large. The RENCI group has much higher EDA during the experiment. This information allows us to conclude that RENCI slides produced higher arousal of the user, but not significantly different.

Large EDA for both groups is a good result, but correlation was negative for both groups (NOAA -0.54, RENCI -0.56). Even participants whose initial viewing was more negative images did not increase their arousal, but in fact, the opposite occurred, a decrease through time (Figure 16). Although EDA decreased through the experiment time, its distinctive difference between the NHC and RENCI cones is quite a good result for this study. Given its color and stronger figure-ground relationship, the larger EDA for RENCI is not an unexpected result. In addition, EDA is not constant during the experiment but spikes at the beginnng, which is not unusual finding (Figure 17). Very often participants “get worried” by the first slides and gradually addapt to experiment and EDA starts to drop and similar effect of images are observed in biometric measurments by Lane and others in 2000. Similar responses are observed in HR through time and discussed later in the chapter. After the initial spike and following drop in EDA activivy, we observe increased EDA in 40 to 60 seconds of this experiment for the both groups. This is also an interesting finding, because an increase is not associated with a posted hurricane warning which appears at the advisory at 60 seconds mark in the experiment. The increase is probably influenced by an effect of the spatial proximity decreasing as the hurricane approaches land (and the cone intersects the State of NC boundary) ” visualized by the slide animation. Participants gradually adapt to the slide animation and start to anticipate the next slide after this period, but by the end of slide animation participants start to expect the end of experiment and their EDA starts to increase. This increase is also influenced by the participants' foreknowledge that they will have to answer questions about the slide animation just viewed.



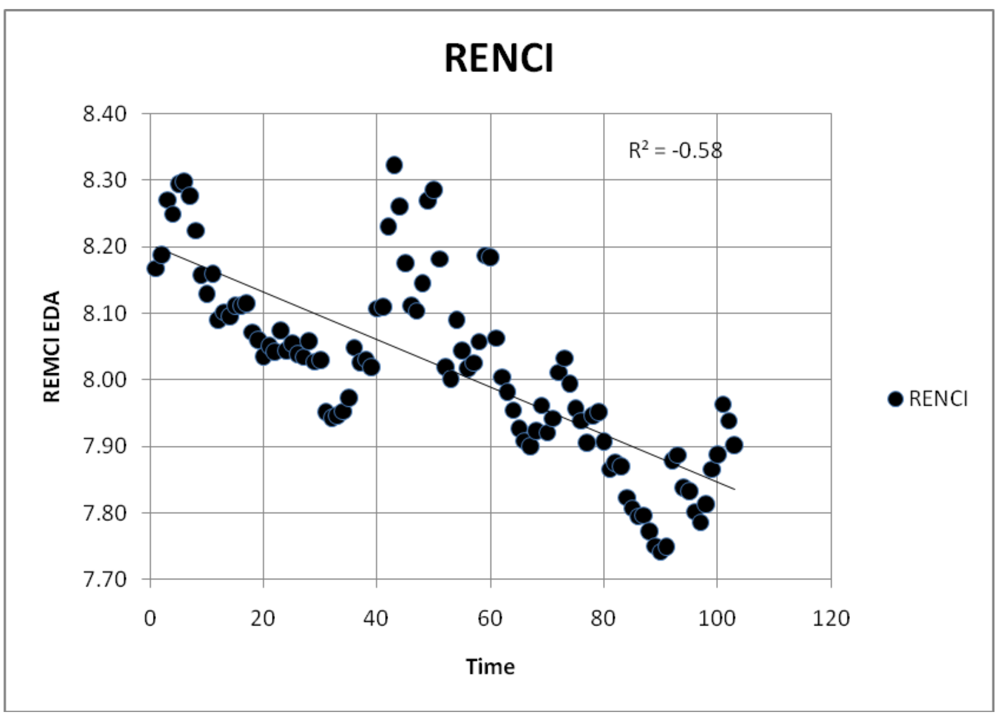


Figure 17: Coorelation of EDA with time for both groups.

Heart rate (HR) is another important biometric to measure when trying to understand the emotional value of the stimuli. The HR averages for both groups were quite similar. However, it was a little higher for RENCI group than NOAA group. Figure 18 shows heart rate variability through time, illustrating HR for RENCI slides that is continuously larger than NOAA slides and correlating higher participant arousal during the experiment. It is important to point out that HR starts to increase at 60 seconds into the experiment. This is the time where participants starFt to see a hurricane warnning for the coastal areas of North Carolina for the first time in the advisory. From that point in time, both groups show increasing HR, but the RENCI group heart rate is higher and furthermore accelerates to higher rate. This investigation reveals that the RENCI hurricane advisories caused higher participant arousal even after they saw looming hurricane warnnings.

When investigating HR metrics, scholars have particularly focused on acceleration and deceleration patterns (Lane and Nadel, 2000.) For both groups, this classic trihasic pattern is visible – initial deceleration followed by acceleration and a second deceleration. “Affective valence” (referring to the emotional value associated with a stimulus) contributes to the amount of initial deceleration and acceleratory activity, with unpleasant stimuli producing more initial deceleration, and pleasant stimuli producing greater peak acceleration” (Lane and Nadel, 2000.)

Figure 18 investigation reveal inconclusive results where RENCI map produce more negative and more positive impact to the user. A change pattern after the first four slides also reveals an acceleration trend for for both groups (see Fig. 18). Overall RENCI slides produced higher effect to the partisipant than NOAA slides this result could be understood as positive, since hihger influence is welcome in any case.

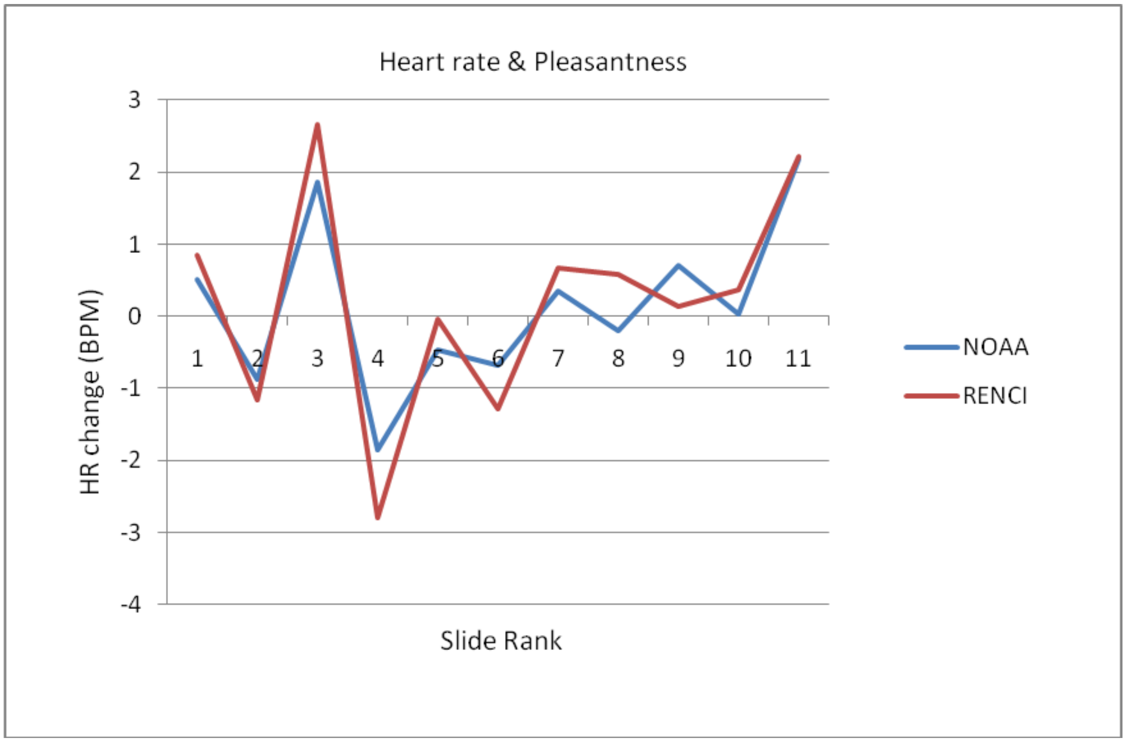


Figure 18: Heart Rate change over time.

Fixation Sequence and Time Space Analysis

Fixation sequence analysis is a very important aspect of this research and allows us to understand the viewing and information search behavior for each individual and discover similar groups from an objective data source.

Hurricane Laurie advisory 36 is the first advisory participants see in this research, and this image is also one the longest images, lasting 20 seconds. As such, the image is not affected by the learning differential and later map and symbolization changes in the advisories and the warnings. For these reasons, the first advisory was chosen for conducting fixation sequence analysis.

For this analysis five Areas of Interest (AOI) were created. These areas correspond to the most important areas of the hurricane advisory map: Cone of Uncertainty, Map Legend, North

Carolina boundary, Virginia boundary, and South Carolina boundary (Table 4). Each areas was delineated and encoded for analysis in the EyePatterns software.

EyePatterns Code	Areas of Interest (AOI)
L	Map Legend
C	Cone of Uncertainty
V	Virginia state areas
N	North Carolina state area
S	South Carolina state area
O	Other areas of the map

Table 4: Eye fixation sequence analysis AOI's.

Fixation data was intersected with AOI polygons to produce a fixation sequence code for each AOI. The next step was to sort the code file by the time sequence based on the fixation events. The author used Python script to extract code sequences to fit EyePatterns software format. All fixation sequence codes were split into two groups based on RENCI and NOAA groups.

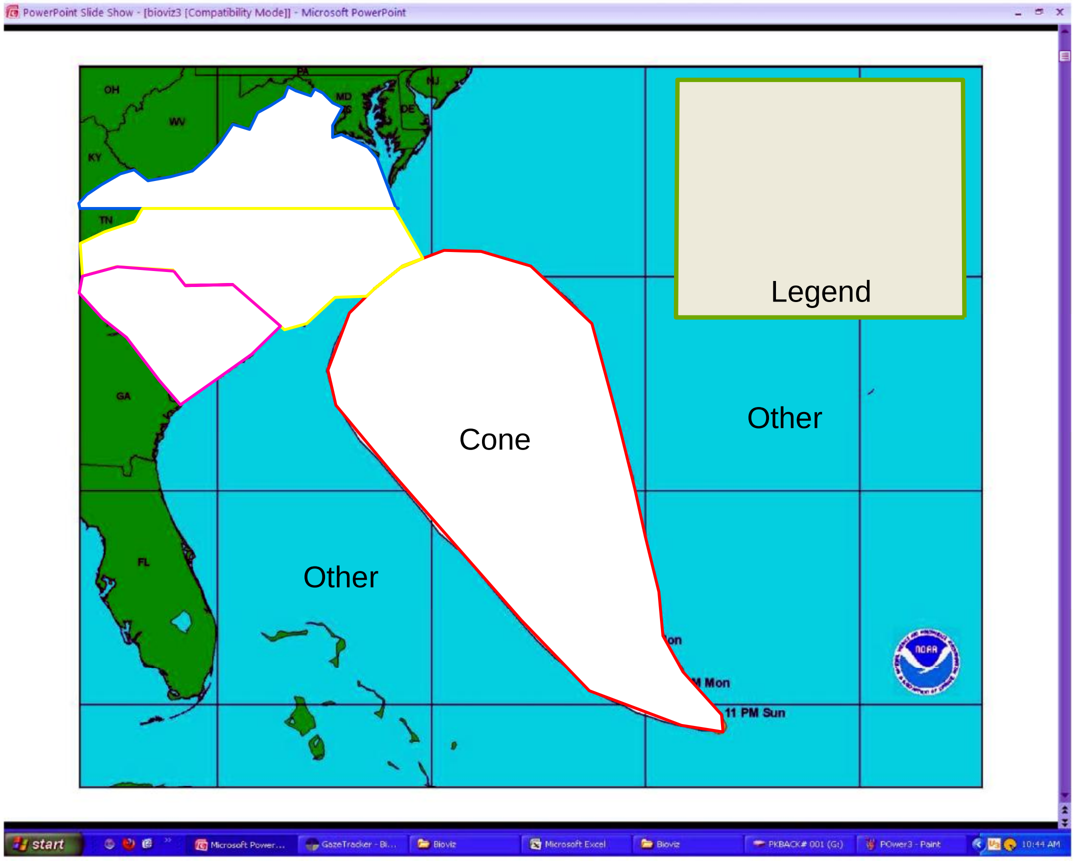
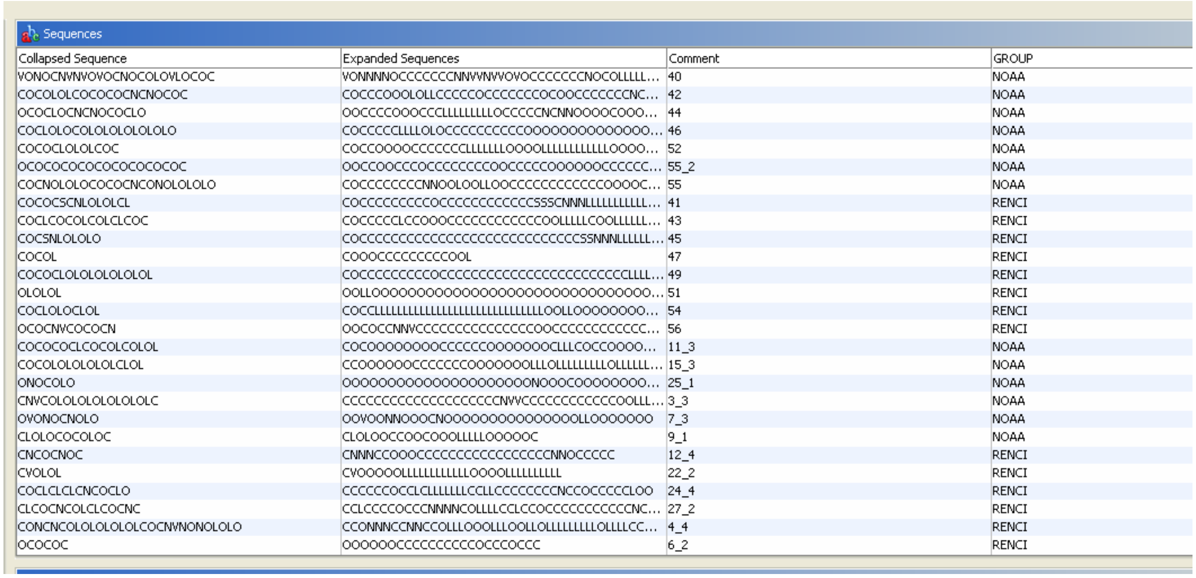


Figure 19: Hurricane advisory Areas of Interest (AOI) used for Fixation sequence analysis.



Sequences

Collapsed Sequence	Expanded Sequences	Comment	GROUP
VONOCNVNVOVOCNOCOLOVLOCOC	VONNNNOCCCCCCCNNVVNVVOVOCCCCCCCNOCOLLLLL...	40	NOAA
COCOLOLCOCOCOCNCNOCOC	COCCCOOOLOLLCCCCCOCCCCCCCOCOOCCCCCCCNC...	42	NOAA
OCOCLOCNCNOCOCLO	OOCCCCOOOCCCLLLLLLLLLOCCCCCNCNNOOOOCOOO...	44	NOAA
COCLOLOCOLOLOLOLOLOLO	COCCCCCLLLLOLOCCCCCCCCCCCOOOOOOOOOOOOOO...	46	NOAA
COCOCLOLOLCOC	COCCOOOOCCCCCCLLLLLLLOOOOLLLLLLLLLLLLOOOO...	52	NOAA
OCOCOCOCOCOCOCOCOCOC	OOCCOOCCCOCCCCCCCCCOOCCCCCOOOOOOCCCCCC...	55_2	NOAA
COCNOLOLOCOCOCNCONOLOLOLO	COCCCCCCCCNNOOLOOLLOOCCCCCCCCCCCCOOOOC...	55	NOAA
COCOCSCNLOLOLCL	COCCCCCCCCCOCCCCCCCCCCCCSSSCNNNLLLLLLLLLLL...	41	RENCI
COCLCOCOLCOLCLCOC	COCCCCCLCCOOOCCCCCCCCCCCCOOLLLLLCOOLLLLLL...	43	RENCI
COCSNLOLOLO	COCCCCCCCCCCCCCCCCCCCCCCCCCCCCSSNNNLLLLLL...	45	RENCI
COCOL	COOOCCCCCCCCCCOOL	47	RENCI
COCOCLOLOLOLOLOLOL	COCCCCCCCCCOCCCCCCCCCCCCCCCCCCCCCCCCCLLLL...	49	RENCI
OLOLOL	OOLLOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO...	51	RENCI
COCLOLOCLOL	COCCLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLOOLLOOOOOOOOO...	54	RENCI
OCOCNVCOCOCN	OOCOCCNNVCCCCCCCCCCCCCCCOOCCCCCCCCCCCCC...	56	RENCI
COCOCOCLCOCOLCOLOL	COCOOOOOOOOOCCCCCCOOOOOOOOCLLLCOCCOOOO...	11_3	NOAA
COCOLOLOLOLOLCLOL	CCOOOOOOOCCCCCCCOOOOOOOOLLLOLLLLLLLLLOLLLLLL...	15_3	NOAA
ONOCOLO	OOOOOOOOOOOOOOOOOOOOONOOOCOOOOOOOOO...	25_1	NOAA
CNVCOLOLOLOLOLOLOLC	CCCCCCCCCCCCCCCCCCCCNVVCCCCCCCCCCCCCOOLLL...	3_3	NOAA
OVONOCNOLO	OOVOONNOOOCNOOOOOOOOOOOOOOOOLLOOOOOOO	7_3	NOAA
CLOLOCOCOLOC	CLOLOOCCOOCOOOLLLLLOOOOOC	9_1	NOAA
CNCOCNOC	CNNNCCOOOCCCCCCCCCCCCCCCCCNNOCCCCC	12_4	RENCI
CVOLOL	CVOOOOOLLLLLLLLLLLLOOOOLLLLLLLLLL	22_2	RENCI
COCLCLCLCNCOCLO	CCCCCCOCCLCLLLLLLLCCLLCCCCCCCCNCCOCCCCCLOO	24_4	RENCI
CLCOCNCOLCLCOCNC	CCLCCCCOCCCNNNNCOLLLLCCLCCOCCCCCCCCCCCNC...	27_2	RENCI
CONCNCOLOLOLOLOLCOCNVNONOLOLO	CCONNNCCNNCCOLLLOOOLLLOOLLOLLLLLLLLLOLLLLCC...	4_4	RENCI
OCOCOC	OOOOOOCCCCCCCCCCOCCCOCCC	6_2	RENCI

Figure 20: Fixation sequences in EyePatterns software.

EyePattens software (West et al., 2006) allows user to identify similar and different fixation patterns. It also employs hierarchical average linkage clustering by paring similar sequences in a sequence dendogram, a branching diagram representing a hierarchy of categories based on degree of similarity or number of shared characteristics (West et al., 2006). In essence, more similar sequences have higher similarity scores.

Hierarchical average linkage clustering was preformed for combined data from phase one and phase two experiment sets (12 people from phase one and 16 people from phase two). Figure 21 depicts an output dendogram from this operation. Three major fixation sequence clusters are clearly visible, because fewer branches that are between 2 sequences in the dendogram, the more similar those sequences are. (West et al., 2006.)

Cluster A – harbors majority fixation sequences of RENCI group, clusters B and C are essentially two different sequence clusters and they have majority of NOAA group clusters. From this result, we can conclude that fixation sequence clustering is based on the participant's being either in NOAA or RENCI groups.

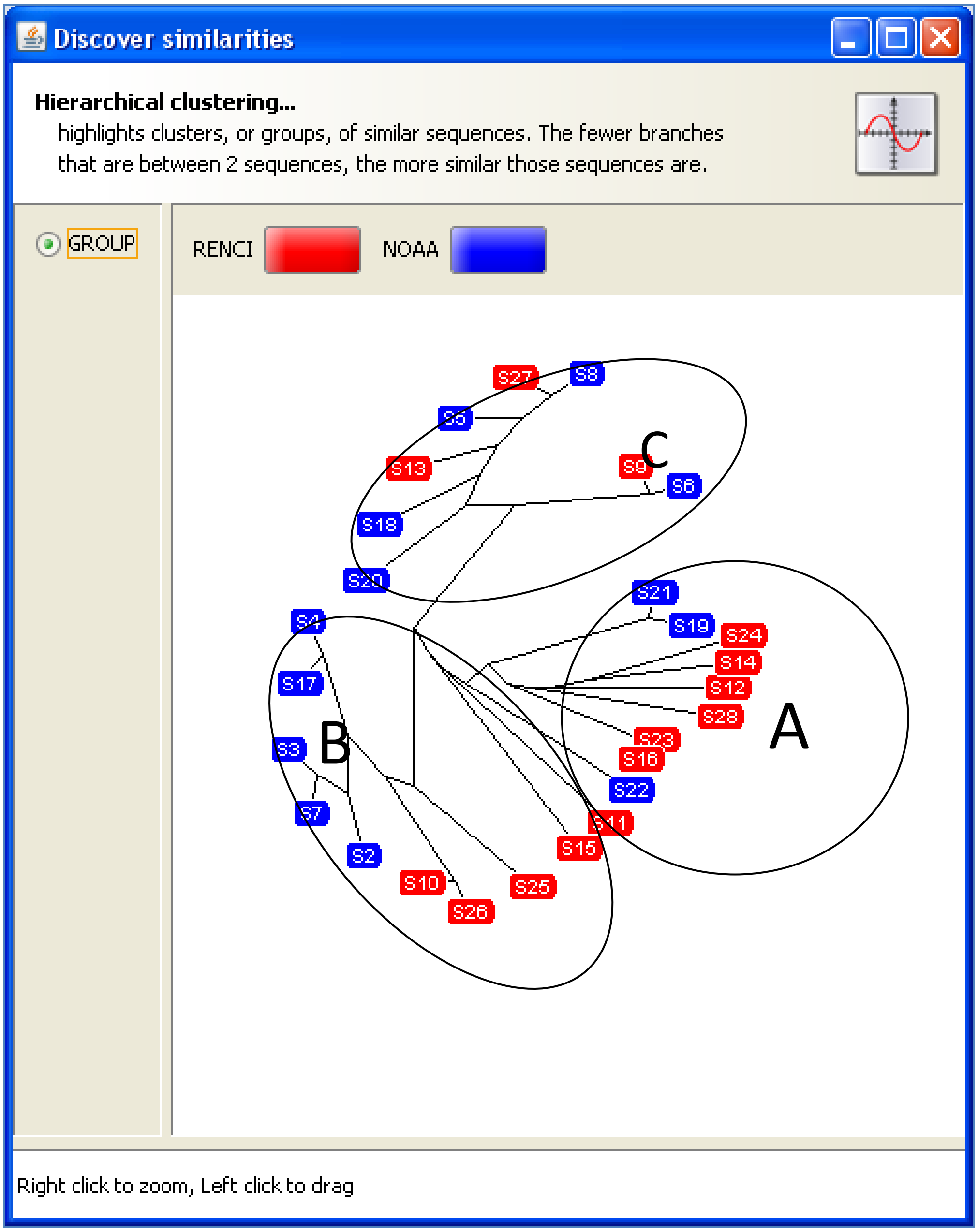


Figure 21: Hierarchical average linkage clustering by EyePatterns.

EyePatterns software allows one to identify similar fixation sequences, but the next step in this study was to verify and visualize similar sequences using advanced GIS geovisualization techniques. The author used time-space cube principles to verify and represent similar fixation sequences. This methodology allows visual comparison of fixation sequences in three dimensions. X and Y representing computer screen dimensions and Z representing time.

To conduct this investigation regular fixation sequence polylines had to be transformed to 3D polylines. The author used a custom ArcScript developed by Neal Banerjee (script available at: http://arcscripts.esri.com/details.asp?dbid=14549) to perform these transformations.

3D fixation sequence polylines were visualized using ArcScene, a 3D desktop GIS visualization platform. During investigation similar fixation sequences derived from EyePatterns software were plotted together to see how similar sequences actually are. The similarity in fixation sequences were observed and they followed the similar trends.

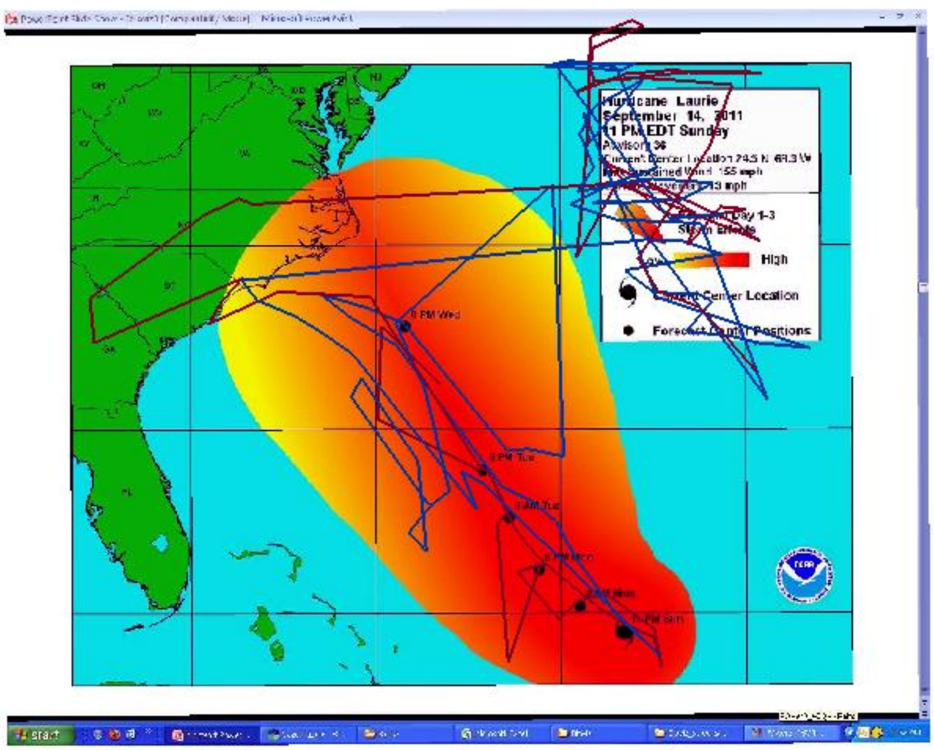


Figure 22: 2D image of two fixation sequences identify as similar by EyePatterns cluster A.

Figure 22 shows fixation sequences clearly illustrating the similar fixation patterns in the same map areas. But this image does not portray how similar participant fixation sequences are in time. Use of ArcScene 3D imaging and rotation capability allowed to examine whether these sequences have similar fixation sequences in time, too. In other words, two participants looked at the similar map areas at the similar time.

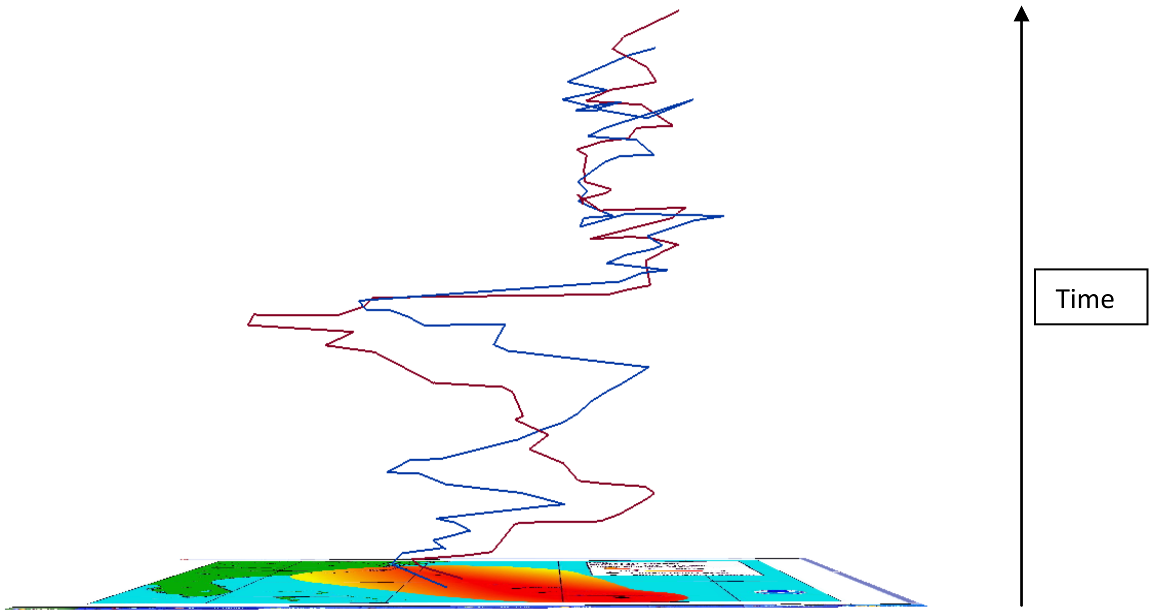


Figure 23: 3D image of two fixation sequences identified as similar by EyePatterns in cluster A.

Figure 23 shows the same sequences as in Figure 22, with the difference being display in 3D. Fixation sequences in this image are indeed similar not just in fixation location, but it is similar in time when these fixations occurred. The height of the 3D line represent time, from bottom to top is 20 sec time lapse. The blue line represents participant S14, and the brown line is participant S11. Space-time cube investigation reveal that those two participants spent half of their time in the cone of uncertainty of the map S11 participant briefly looked at the USA mainland. And half of their time they spent looking at the Map legend. This space-time pattern was observed for a majority of cluster A fixation sequences identified as similar by EyePatterns.

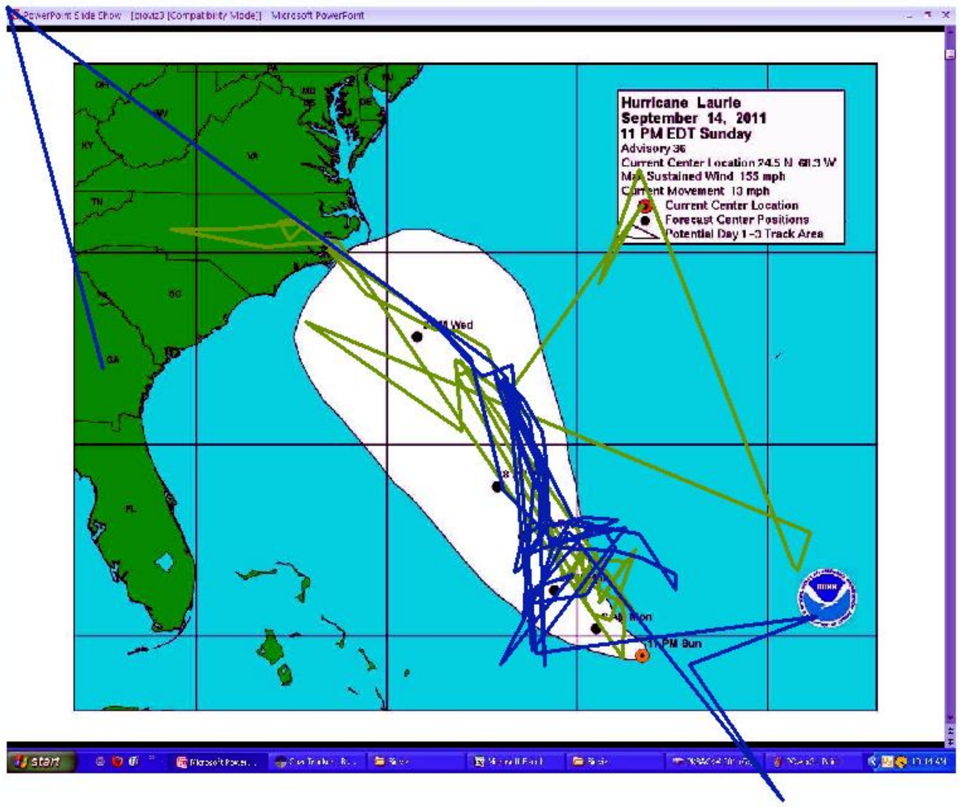


Figure 24: 2D image of two fixation sequences identify as similar by EyePatterns cluster B.

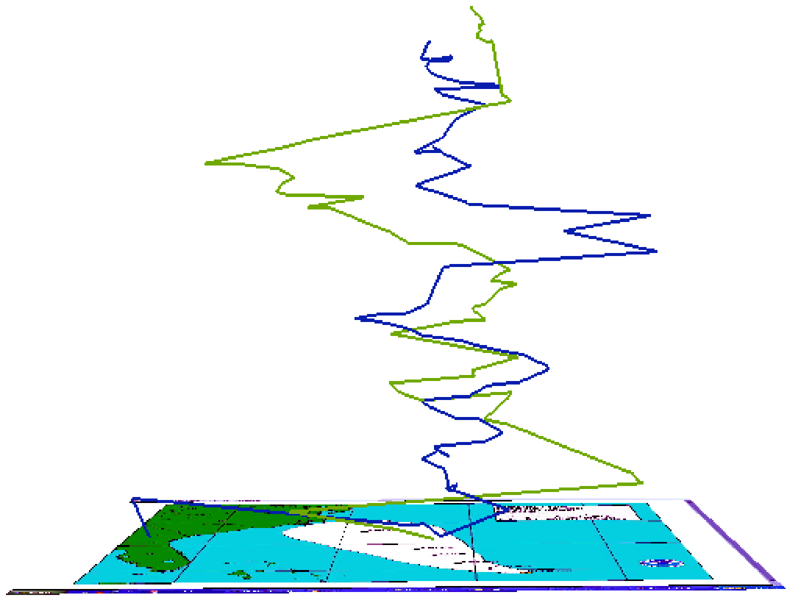


Figure 25: 3D image of two fixation sequences identify as similar by EyePatterns cluster B.

Cluster A had a majority of RENCI group participants (n=8), while cluster B and C had mostly NOAA group participants (n=10). The investigation of clusters B and C reveals different fixation sequence patterns. A majority of the time these participants spent in the cone of uncertainty of the map, only seldom venturing to the map legend for the cluster B, while for cluster C participant fixation sequences are more similar to cluster A.

This methodology allows the investigation of the viewing patterns in great detail and is clearly a robust method for investigating human behavior in space and time.

EyePatterns allows calculation of transition frequencies between events in a sequence, this method is good in identifying transitions between two AOI's which will allow one to assess specific transitions of primary interest to this research – i.e., transition from reading Map legend and the Cone of Uncertainty of the hurricane advisory. The software visualizes these transitions between AOI in the form of a transition matrix.

	L	C	V	N	S	O	To-Total
L	0	6	0	0	0	37	43
C	7	0	0	11	0	42	60
V	1	1	0	1	0	4	7
N	0	3	3	0	0	10	16
S	0	0	0	0	0	0	0
O	37	48	3	4	0	0	92
From-Total	45	58	6	16	0	93	218

Transition matrix NOAA group.

	L	C	V	N	S	O	To-Total
L	0	12	0	0	0	24	36
C	12	0	1	10	2	27	52
V	0	1	0	1	0	1	3
N	2	6	2	0	0	3	13
S	0	1	0	1	0	0	2
O	28	25	0	2	0	0	55
From-Total	42	45	3	14	2	55	161

Figure 26: Transition matrix RENCI group.

The number of transitions between AOI's determine which group is more efficient in understanding map cartography between the two groups. Matrix tables show transitions between AOI's. Total column on the right hand represents transitions towards particular AOI and the total column on the bottom of the transition matrix represents transitions from particular AOI.

For example in NOAA group transition matrix where was 43 transitions to the legend map area (L), 6 of these transitions occurred from map cone of uncertainty (C) and rest of them came from other map areas (O).

Transition matrixes revealed that there where 43 fixation transitions to the Legend (indicated as L in the matrix) from all map areas in the NOAA group and 36 transitions in the RENCI group. This measure is a key to understanding the map search efficacy and participant viewing confusion. More efficient map would have smaller number of transition to the map Legend, from this notion we can conclude a *slightly* higher search confusion in the NOAA map reading group, because it has higher number of fixation transitions to the map legend (L in the matrix Figure 26).

Kernel Density Estimation and Geographically Weighted Regression (GWR)

Kernel density estimation associates each known point (in this case fixation points) with a kernel function for the purpose of estimation. It is expressed as a bivariate probability density function centered at the known point and tapering off to 0 over a defined bandwidth or a window area (Chang 2008). Kernel density function input includes the known points; output is the density raster showing expected values.

For this analysis eye fixations for two groups were extracted by time, where experiment participants viewed NOAA hurricane advisories or RENCI hurricane advisories for the first time. Fixations for individuals were combined into two groups representing NOAA and RENCI groups.

For each group Kernel density estimation was performed producing a fixation "heat map" for each group as a raster (Figure 27 and 28). Rasters were produced using fixation density per 4 square screen pixels and search radius of 34 pixels. The author classified rasters with a defined equal interval of 0.0 - 0.007 square pixels. Resulting classified map areas 1 to 5 thus represent fixation density areas, from very low to very high.

As expected, the eye fixation density is very different between the two groups. NOAA group density has much higher values than RENCI group and reaches a very high density in the center areas of the hurricane cone of uncertainty.

Another noticeable difference is the spatial distributions of the two density maps. NOAA group eye fixation density is very clustered around the center part of the cone of uncertainty and the legend, while the RENCI group eye fixation has a much wider spread in the cone of uncertainty and the legend areas. The distribution of eye fixations is also elongated in the NOAA group as compared to RENCI group. These fixation differences can be explained due to the fact that RENCI cone is much wider, so more fixations are registered in the cone. These results are expected because the RENCI map design was based on the philosophy that more risk exists beyond the projected hurricane track line, so more spread is observed in RENCI group fixation density. NOAA group eye fixation concentration by the projected hurricane track line is also a predictable result, because many scholars believe that too much attention has been paid to this single line (Steed et al., 2009). Fixation density in map legends is similar in both groups.

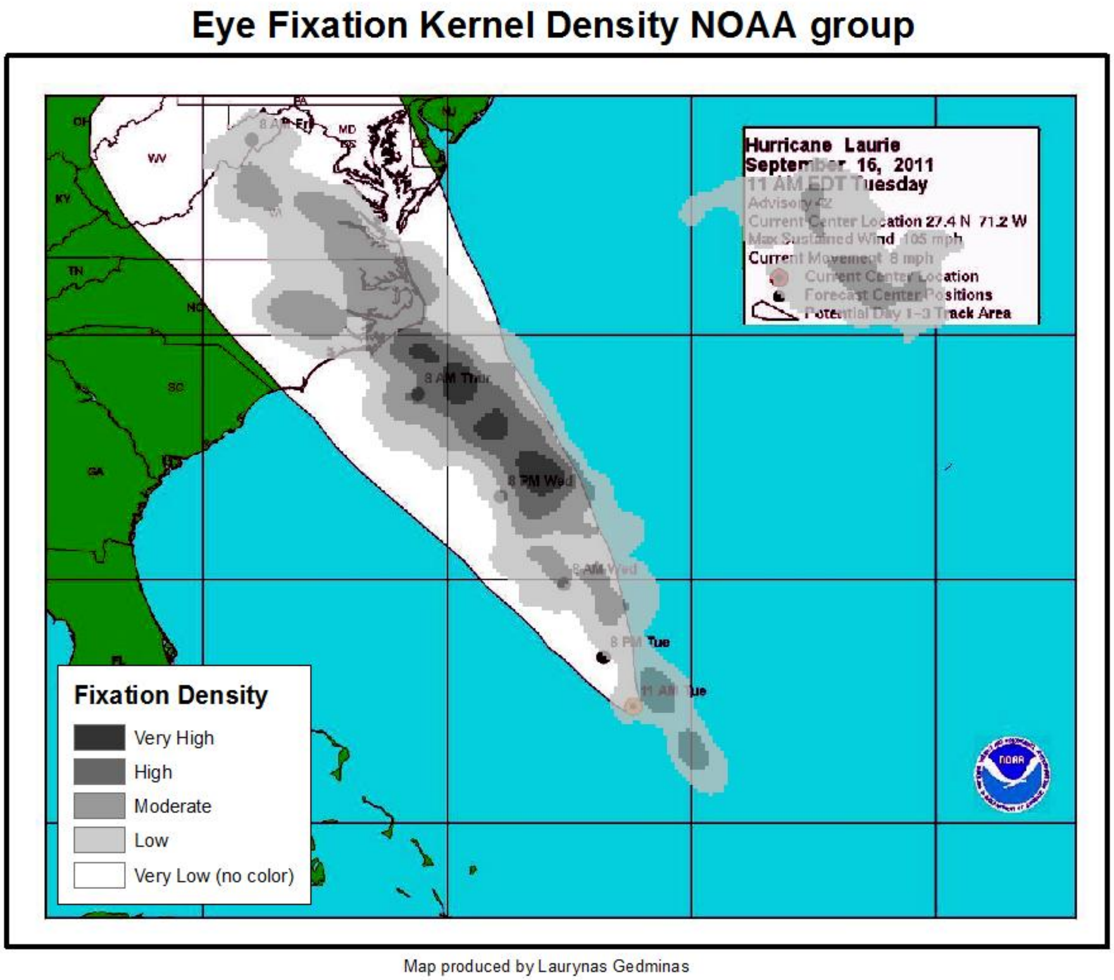


Figure 27: Eye fixation kernel density estimation for NOAA group.

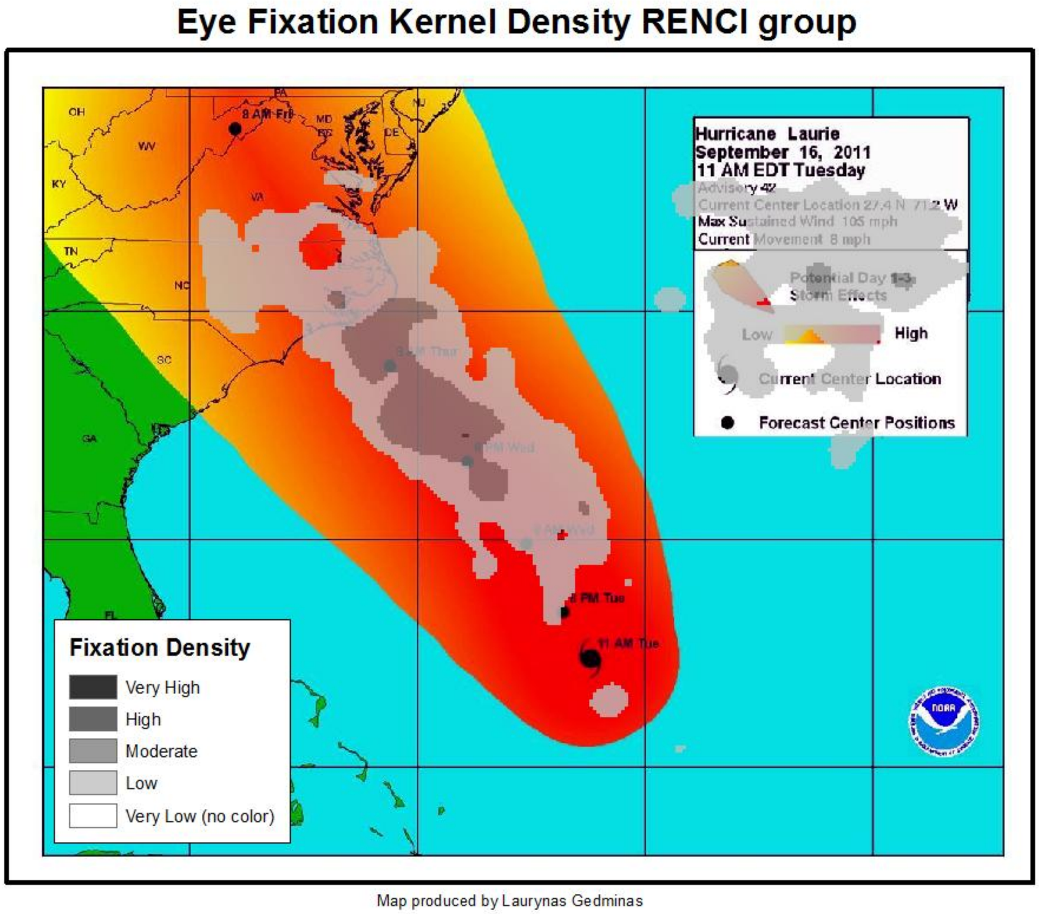


Figure 28: Eye fixation kernel density estimation for RENCI group.

The differences in the two groups' maps are visible, but for more detailed understanding, we can divide the RENCI group fixation density map from NOAA group fixation density map to highlight differential fixation (Figure 29).

The green color in Fig. 29 represents map areas where fixation density in the NOAA group was higher than RENCI group, while red color represents areas where fixation density in the NOAA group was lower than RENCI group.

This map clearly indicates differences in the two maps. The NOAA group had more fixation in the center line area of the cone, while RENCI maps had higher fixation density in outer periphery of cone. In the maps' legends the NOAA group had higher density of fixation in the top left of the legend while RENCI group had higher fixation density in the top right and lower parts of its legend. Differences in the map legend fixations shows that participants in NOAA group were spending more time on the legend's basic information about the storm, while the RENCI group participants were more concentrated in viewing lower part of the RENCI legend, the area where new legend information was attached.

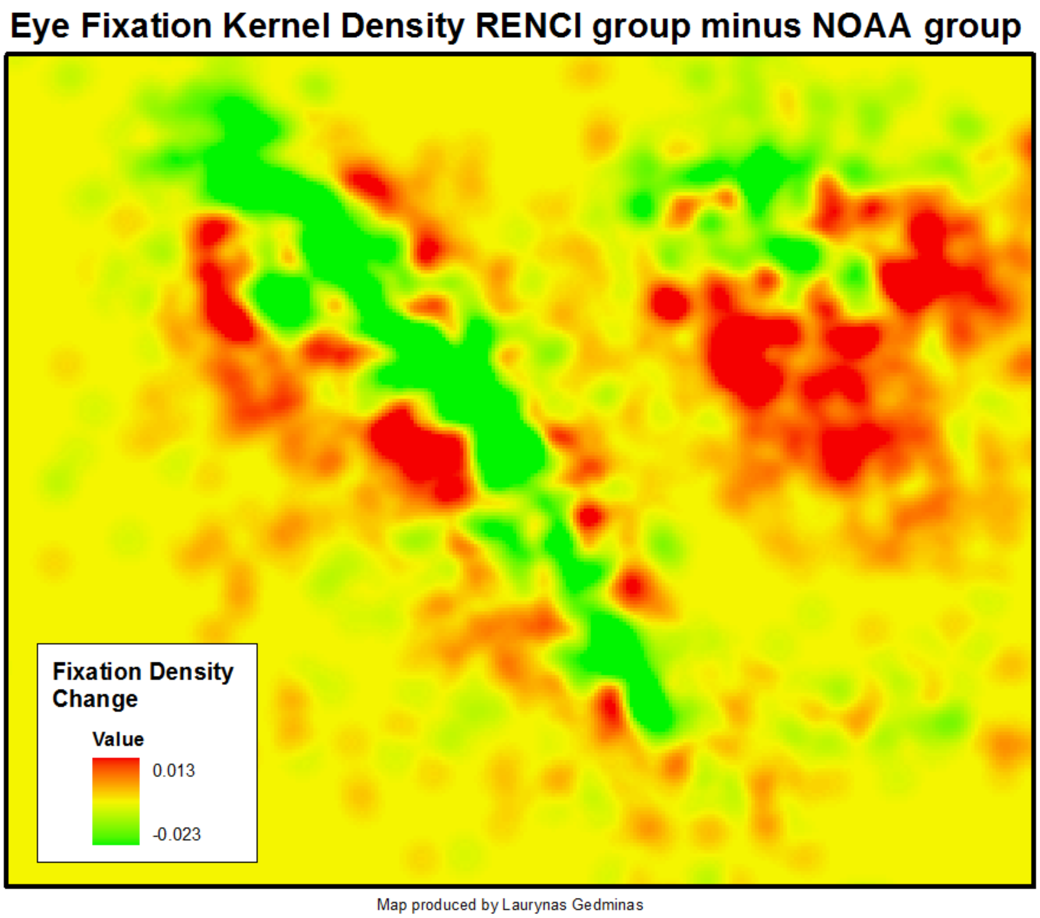


Figure 29: Eye fixation kernel density estimation comparison for two groups.

Geographically weighted regression (GWR) was used to analyze spatially varying relationships of NOAA group fixation heat map and RENCI group fixation heat map. GWR allows for the analysis of the difference in two heat maps with statistical significance.

This regression generates a separate regression equation for every observation analyzed in the study area and presents spatial variation in the results. The GWR model uses Gaussian weights as inverse functions of distance in calculations of spatial relationships between observations. GWR incorporates local spatial relationships into regression (Fotheringham 2002).

GWR fixed spatial kernel was used in this research, because kernel density estimation produces fixation heat map with equal interval cells. Using spatial kernel regression each data point is weighted by its distance from the regression point. "Data points closer to the regression point are weighted more heavily in the local regression than are data points further away" (Fotheringham 2002).

For the purpose of analyzing spatial variation of the heat map with Geographically Weighted Regression (GWR), the following transformations were performed: 1) each group's Kernel density estimation raster (search radius 34, cell size 10) density raster converted to a shapefile; 2) spatial joins of two heat map shapefiles were created; and 3) a final shapefile was created having two attributes, both heat map raster attributes as dependant and independent variables.

The dependant variable for this analysis was the NOAA group density values, with the RENCI group density values as the predictor. GWR analysis correlates both layers and gives estimate of local correlation as local R square. Figure 30 shows R square values for two layers. Both heat map layers are positively correlated, where high positive correlation is in the edges of cone of uncertainty and map legend areas.

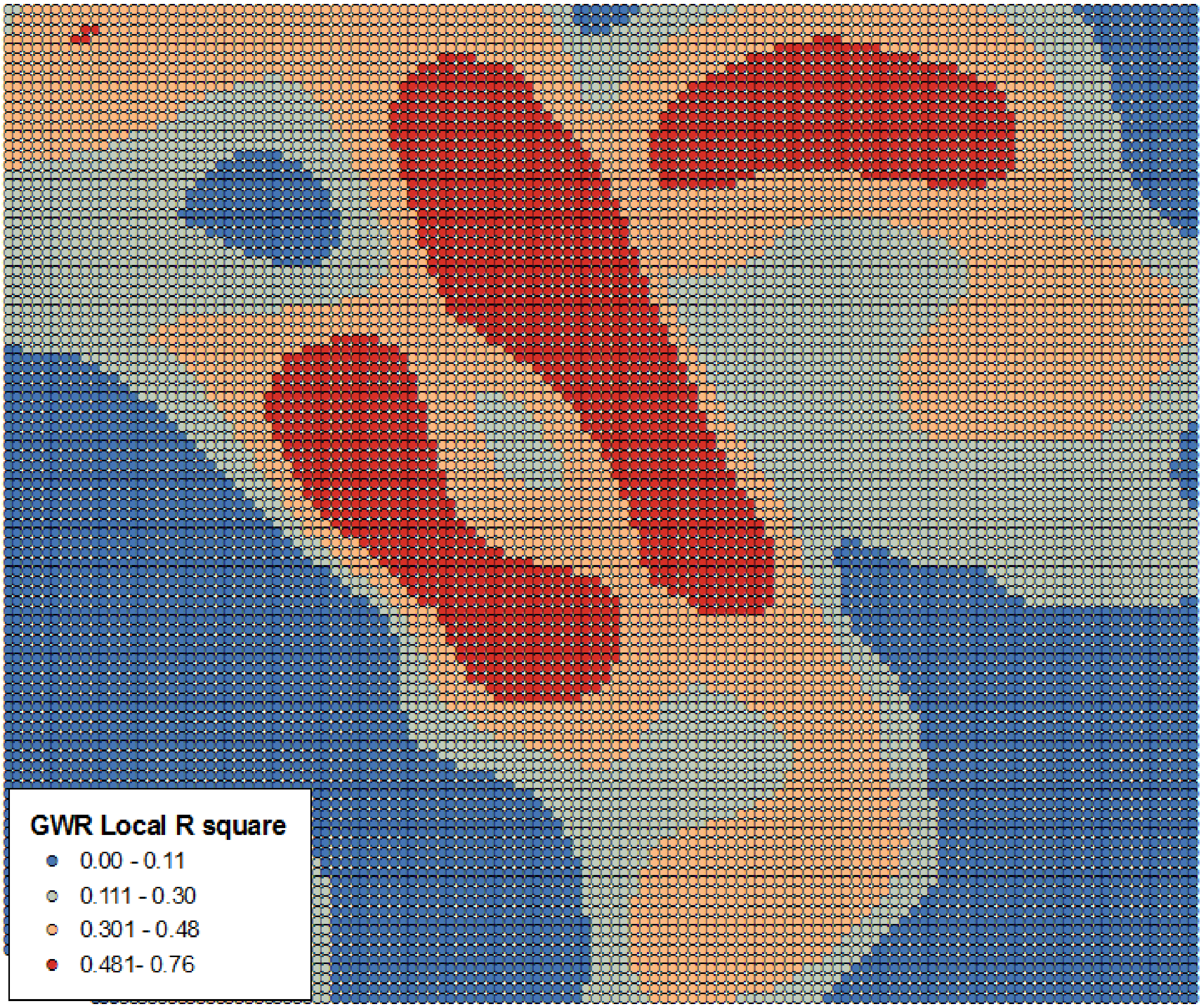


Figure 30: GWR analysis local R square.

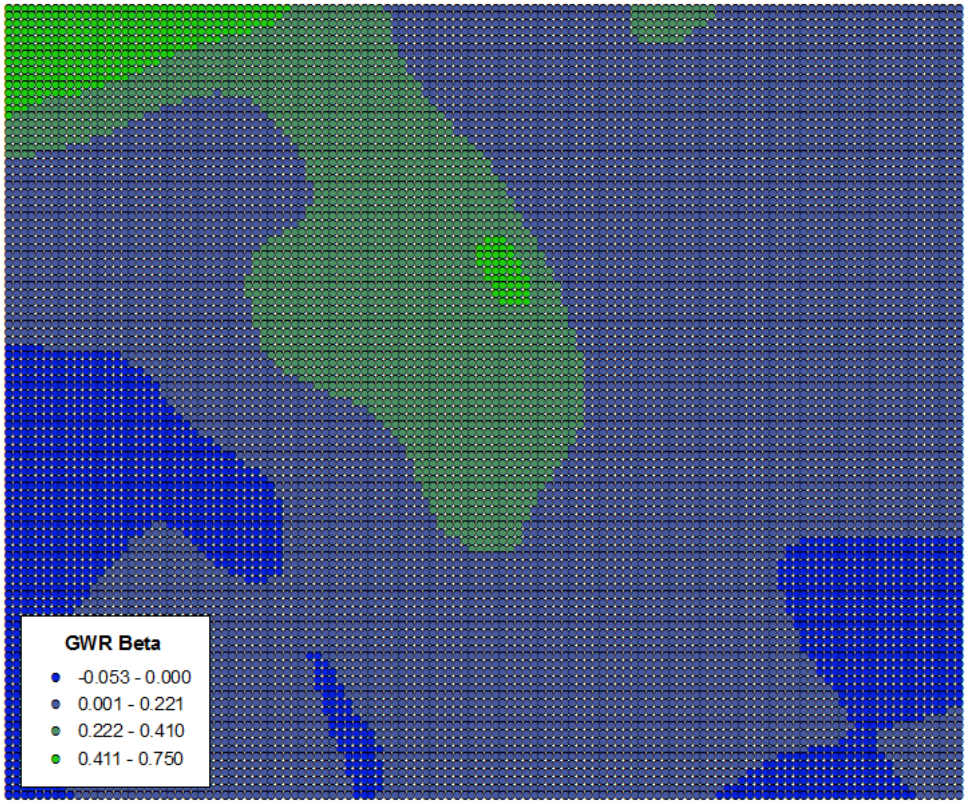


Figure 31: GWR Beta.

GWR coefficient is mostly positive throughout the advisory map (Figure 31.) showing positive relationship between two advisory maps. Weak negative relationship is observed in the lower-right and lower-left corners of the advisory, areas where participants spent the least amount of time. Weak positive relationship is observed across majority of the advisory with stronger relationship in cone of uncertainty area and the upper-left corner of the map.

Figure 32 shows GWR results standardized residuals. The results are similar to RENCI – NOAA heat map difference map in Figure 29. GWR over predicts green areas and under predicts in the red and orange areas of Fig. 32. However, GWR statistics corroborate and affirm that the two heat maps are truly different. The NOAA heat map has higher values in the center of its cone and legend, while the RENCI fixation heat map has higher values spread more widely than the NOAA map in its cone and legend area.

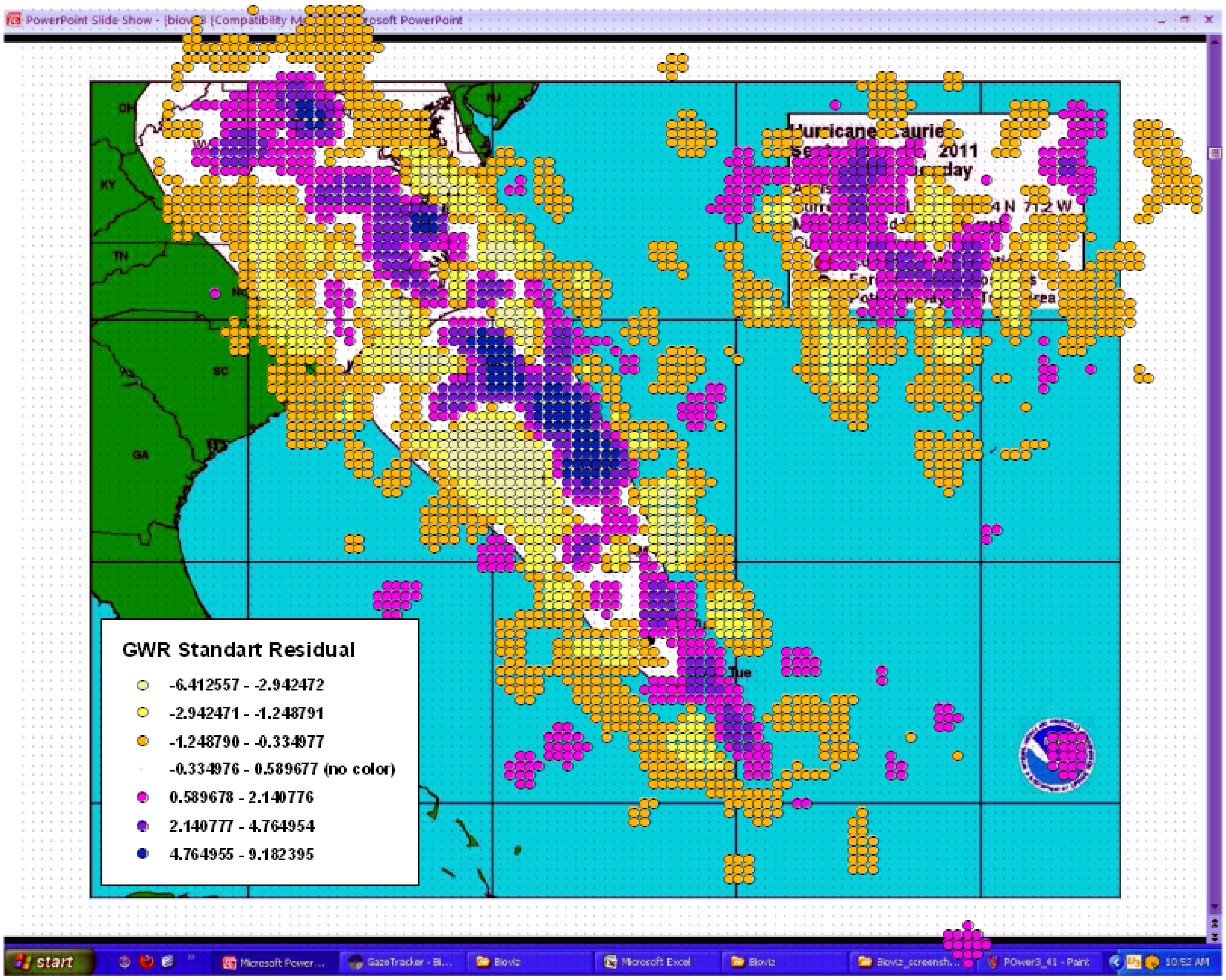


Figure 32: GWR analysis of fixation density for two groups.

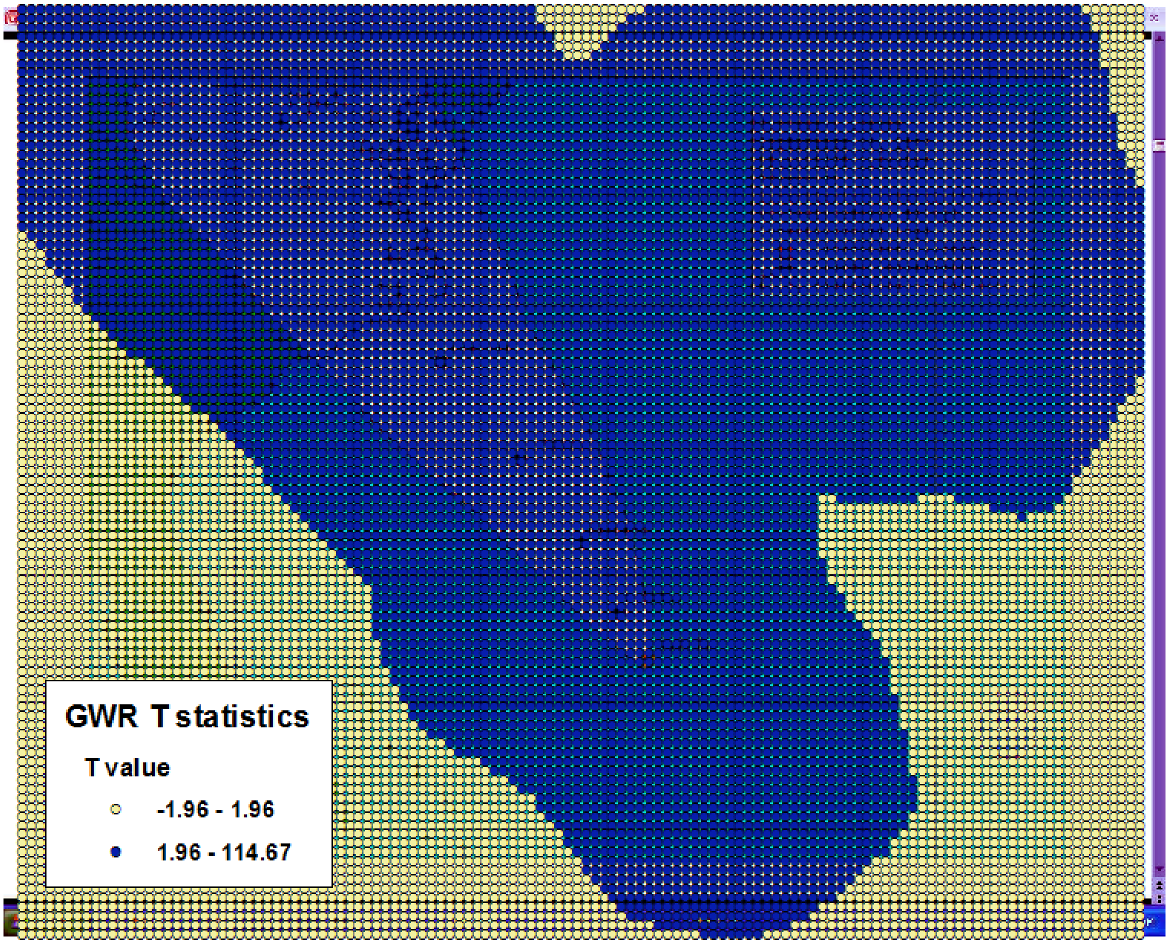


Figure 33: GWR analysis of fixation density for two groups' significance test.

The next step was to estimate the significance of these differences. The GWR coefficient was divided by regression standard error to get the *T* statistic values for this GWR model (C1_GRID_CO/StdErr_C1GRID, or *T* = coefficient/standard error). Figure 33 shows the significance of GWR results. As expected most of the map areas, around the maps cone and the legend, are significantly different.

Spatial Pattern Analysis

Spatial autocorrelation analysis using Moran's I, LISA and nearest neighbor statistics was conducted for the eye fixation points and their duration attribute. Analysis results were compared between the two test groups. Hurricane advisories in this experimental setting are different, and spatial autocorrelation would occur in the different areas and at different intensity. For example, a high interest area of this study is the map legend which in theory should have different number of fixation and fixation duration between two test groups.

The nearest neighbor analysis was conducted for the same dataset. For both groups, the ratio value was lower than 1, indicating clustering of nearest eye fixation points. The RENCI group nearest neighbor ratio is lower than the NOAA group statistic, indicating that fixation points are more clustered in RENCI advisory maps. This result comes unexpected since literature and cartographic design suggested higher clustering of NOAA group fixations.

NNA indicator	NOAA group	RENCI group
Observed mean distance	7.68	6.91
Expected mean distance	10.87	10.67
Nearest neighbor Ratio	0.71	0.64
Z – score	-29.13	-34.38
p value	0.001	0.001

Table 5: Nearest neighbor analysis results.

For both groups, Moran's I is much greater that E(I), which suggests that adjacent fixation points have similar values and are spatially correlated. The NOAA group's Moran's I indicator was larger than the RENCI group, indicating larger spatial correlation.

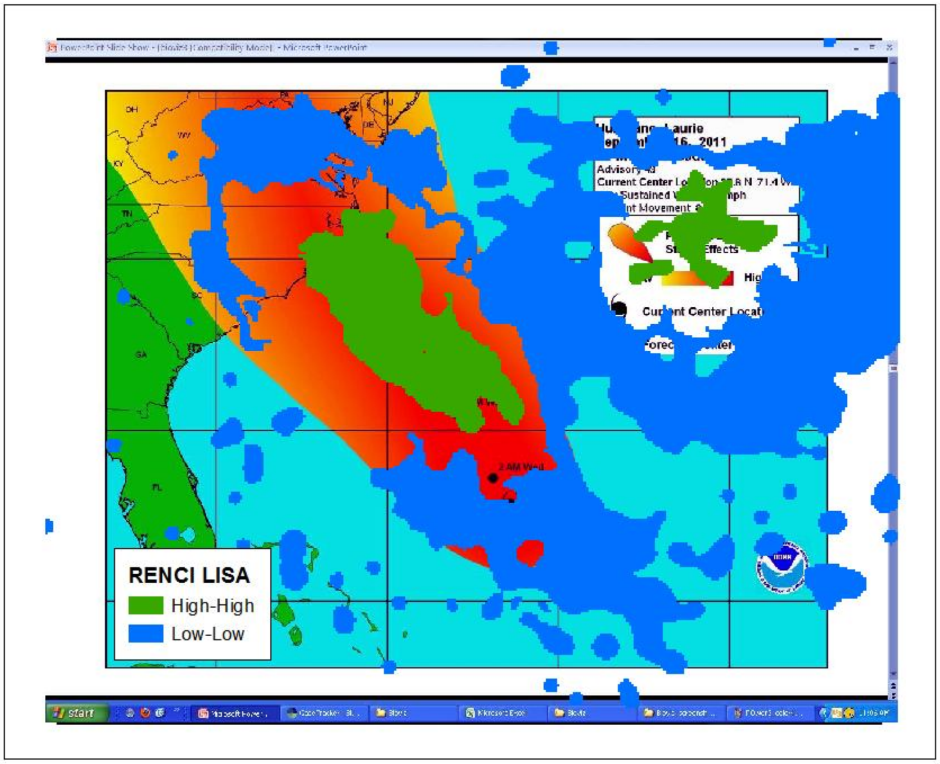
Moran's I indicators	NOAA group	RENCI group
Global Moran's I Index	0.0309	0.0214
Expected Index	-0.000383	-0.000371
Variance	0.000004	0.000005
Z score	15.78	9.85
p-value	0.001	0.001

Table 6: Moran's I analysis results.

LISA analysis revealed clustering of high and low fixation duration values. For the RENCI group, clustering of High-High values occurred in the center of the cone and coastal North Carolina. High-High fixation duration value clustering is also observed in the map legend.

For the NOAA group, the same High-High clustering pattern is observed, except there is no clustering in the map legend, and clustering of High values in notably narrower for this group (Figure 34).

High-High fixation duration clustering pattern is very similar to fixation density patterns. NOAA group having more elongated narrow clustering in the center of the cone and RENCI group having more wider spread of clustering. In RENCI group LISA maps we also observe High-High clustering of high duration fixations. This result is similar with earlier discovered notion that participants find information easier in RENCI map versus NOAA maps or could be that observed patterns in RENCI maps are related to the fact that participants are learning new map cartography.



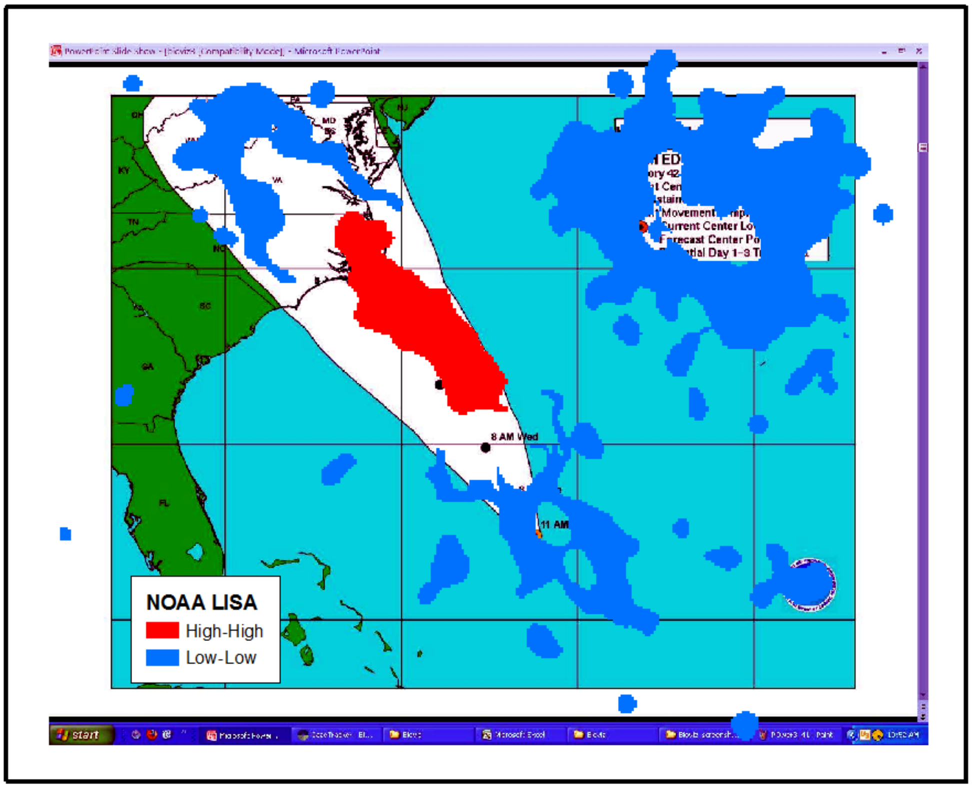


Figure 34: LISA analysis of eye fixations.

Logistic Regression

The final stage of this study is to find biometric and demographic indicators which explain participants' hurricane advisory preference . A logistic regression was constructed using survey answers to the question: Which hurricane advisory map each test subject prefers – NOAA NHC or RENCI@ECU? Survey demographic data and biometric data (EEG, EMG, and ECG) was used as independent variables for this model. 27 out of 32 participants preferred RENCI hurricane advisory in survey questioner, and only 5 out of 32 preferred NOAA hurricane advisory.

For a logistic regression, the predicted dependent variable is a participants' advisory map preference as indicated in Q43 in the model and independent variables are demographic and biometric indicators.

Variable	Description	Data Source
Q43	Hurricane advisory preference	Survey
Brow	Brow Facial muscle movement	VML
Cheek	Cheek Facial muscle movement	VML
EDA	Electrodermel activity	VML
HR	Heart rate in beats per minute	VML
Age	participants age	Survey
Gender	participants gender	Survey
Dist	participants residence place proximity to the hurricane land fall	Survey
EvaExp	participants hurricane evacuation experience	Survey
Knowledge	participants knowledge of weather	Survey

Table 7: Demographic and biometric indicators used in model creation (VML is biometric data collected with instrumentation of the ECU Visual Motor Laboratory).

The author of this research decided to construct two separate logistic regression models; one for biometric data and one for demographic data.

The logistic regression model for the biometric data was developed first. Variables in the final model were selected with a step-down procedure where the decision to remove terms was based on a likelihood-ratio test. All potential predictors were first included in the "full" model, then predictors were sequentially removed if their removal did not result in a significant change in the log-likelihood.

Stepping down for biometric data from this full model resulted in the sequential removal of Brow (p = 0.91), EDA (p = 0.326) and HR (p = 0.12) predictors. Overall success rate in classification was 83.9 %.

Even though the model correctly predicted a high number of participant hurricane advisory preferences, its predictions were emphatically one-sided (predicted *all* RENCI advisory choices, but only predicted 16 percent NOAA advisory choices), and overall model was not statistically significant (p = 0.24).

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1	Cheek	2511.156	2152.123	1.361	1	.243	.
	Constant	-3.131	1.485	4.444	1	.035	.044

Table 8: Variables in step-down model for biometric predictor variables.

Observed		Predicted		
		Q43		Percentage Correct
		RENCI	NOAA	
Q43	RENCI	25	0	100.0
	NOAA	5	1	16.7
Overall Percentage				83.9

Table 9: Classification Table for biometric predictor variables.

Each biometric indictor was also analyzed separately by constructing separate logistic regressions for each biometric indicators. Investigation results produced the following table where multiple model results are presented. Only one biometric indicator out of four produced a significant results (p = 0.048) for predicting user hurricane advisory preference. The brow facial muscle movement indicator had highest overall classification percentage (87.5%), it also had one of the lowest log likelihood indicators, indicating better model performance.

	-2 Log likelihood	B	Wald	Cox & Snell R Square	Predicted percentage correct	Significance	Exp(B)
Brow	26.543	3769.5	3.91	.127	87.5	0.048	
Cheek	26.250	2211.0	1.09	.135	84.4	0.30	
EDA	30.327	0.035	0.14	.004	80.6	0.71	1.036
HR	28.679	-0.035	1.81	.067	84.4	0.18	0.965

Table 10: Logistic regression model output for each biometric indicator.

For demographic predictor variables, the same step-down logistic regression analysis was constructed. Stepping down for demographic data from this full model resulted in the sequential removal of all predictors.

As with biometric predictors, logistic regression models for each demographic variable were also produced. The following table shows model output parameters. All variables produced highly correct prediction classifications, but none of the variables had statistically significant results.

	-2 Log likelihood	B	Wald	Cox & Snell R Square	Predicted percentage correct	Signifi-cance	Exp(B)
Age	34.319	0.08	0.26	0.07	79.4	0.61	1.086
Gender	34.394	0.36	0.18	0.005	79.4	0.67	1.435
Distance	31.660	2.03E-6	1.36E-6	0.082	79.4	0.134	1.0
EvaExp	34.454	0.34	0.12	0.004	79.4	0.725	1.4
Knowledge	34.562	0.07	0.01	0.000	79.4	0.91	1.072

Table 11: Logistic regression model output for each demographic indicator.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

The purpose of this research was to compare NOAA NHC hurricane advisory and an experimental RENCI hurricane advisory cartographic design using biometric, eye tracking, and demographic data recorded during the experiment.

The literature review revealed a need for more objective ways to investigate map cartographic design. In this research the NOAA hurricane advisory maps were changed to address the common cartographic perception issues, such as color and also to explore the hurricane risk perception via a wider cone of uncertainty. The RENCI hurricane advisories were theoretically designed to be more superior than NOAA advisories, incorporating color within the cone of uncertainty to convey a risk gradient, stronger figure-ground contrast, and also an expanded zone of hurricane risk beyond the extent of the standard cone of uncertainty.

Both maps were tested in a laboratory under experimental conditions, and indicators averages were compared. The results for this research did not had many statistically significant results, but some results were promising and should be considered as first steps towards further investigation as well as operational decisions with risk map communication.

Eye fixation data revealed results that were theoretically expected by the author of this research, but did not had statistical significance. Fixations are considered an indicator of the user's cognitive loading. On the other hand, more cognitive loading does not inherently mean better map design. Purpose of experimental RENCI hurricane advisory was to produce more understandable and higher risk perception map leading to more intuitive map which every one could easily recognize and which would produce lesser cognitive loading of the brain. Higher total and average fixation counts were observed for NOAA hurricane advisories proving the raised hyphosesis at the beginning of this research.

The map legend is a key is successful map design. In essence, a more user-friendly map would have less eye fixation in the map legend, because user would not have to spend much time there to understand the map. Fixation metrics indicated that less fixation per square pixels in the map legend were in RENCI hurricane advisories. This observation and the transition matrix indicators were good result, but it did not had no statistical significance to prove the hypothesis posed that for lesser fixation counts in the RENCI maps.

Brow muscle movement is associated with unpleasant stimuli according to Lane and others (Lane et al., 2000). Both groups had similar brow muscle movement, but the RENCI group brow muscle average was higher than the NOAA group, explaining higher negative effect on the map user. On other hand the NOAA group cheek muscle movement was larger than RENCI group by 8 times. This could be explained by the RENCI maps being more pleasing to the user. EDA recordings were also higher for RENCI group, indicating higher arousal to the user. These findings allow us to conclude that the RENCI slides were more plesant for participants and increased their arousal.

Eye fixation sequence analysis indicated that similar sequences arguably exist in the fixation data. EyePatterns software outlined three different sequences based on the hurricane advisory being viewed participants. Transition matrices calculated by EyePatterns confirmed that more NOAA group participants transitioned to the legend of the map, indicating higher map user confusion.

The spatial distribution of eye fixation data revealed the preliminary theories that NOAA hurricane advisory maps have more clustered fixations in the cone of uncertainty. These fixations were positioned along the center line of the cone of uncertainty. On other hand, the RENCI fixations had a wider distribution of fixation in the cone of uncertainty, which was expected during the initial design of the advisory (i.e., wider cone.). Statistical analysis of fixation clustering also affirms these findings, the NOAA group fixations are more spatially autocorrelated then RENCI group fixations.

The final stage of this research aimed to determine the best biometric and demographic predictors of hurricane advisory map preference. This analysis determined that brow muscle movement was the best indicator for predicting the user's hurricane advisory preference. However, prediction was asymmetric, with the logistic model, despite a weak significance level, predicting the vast majority of subjects preferring the RENCI cone versus few choosing the NOAA cone.

Over all the experiment did not produce many strongly statistically significant results. This may have occurred because the experiment did not used completely different hurricane advisories, but instead author used similar, albeit modified, versions of the current NOAA product. In many cases neuroscientists in their research use images from a different spectrum of emotions, like pleasant and unpleasant pictures, so significant responses could be detected. In addition, the low number of participants and the convenience sample of university students used in this research could also have lead to unsatisfactory statistical significance. The author believes that higher number of participants and a wider cross-section of population would have produced statistically significant results for both hurricane advisories. Another factor influencing statistically insignificant results is that this experiment is far from a real-life situation, wherein the majority of experiment executed during the months of March and April or outside the peak hurricane season. In addition, the experiment was conducted in a synthetic laboratory setting with little real danger experienced.

Nonetheless, the research affirms many expected relationships, such as large differences in biometric indicators for EDA, cheek and brow muscle movement. Eye fixation density was visibly and statistically different from each other. This is a significant result, since the density and some biometric measurement differences where anticipated before the experiment has begun. This research provided other results which were anticipated like higher heart rate, lower fixation count in the map and higher electro dermal activity.

This research did not included survey questions about actual risk perception of the participant. To investigate relationships between biometric data and other survey answers is beyond the scope of this study and future research is highly needed to unlock new findings.

The next step in conducting more successful cartographic design comparison and hurricane risk perception evaluation would be the design of a completely different hurricane advisory and comparing it to the NOAA NHC design. The author of this research would also suggest the use of baseline stimuli, internationally recognized as neutral, pleasant, or unpleasant. This would allow the comparison of both maps to the known stimuli and achieve clarification were these maps stand on a benchmark scale in comparison to documented emotions. Another suggestion is to conduct such experiments during the hurricane season, and preferably in the peak August and September months. Finally, this research included only a small number of participants, and a next step would be to expand to more participants and especially a population with higher home state and hurricane experience variation. Future cartographic design and hurricane risk perception studies using the described methods could also investigate the indicators at a finer scale where differences could be compared between participants or predictively at the individual level based on gender, age and experience.

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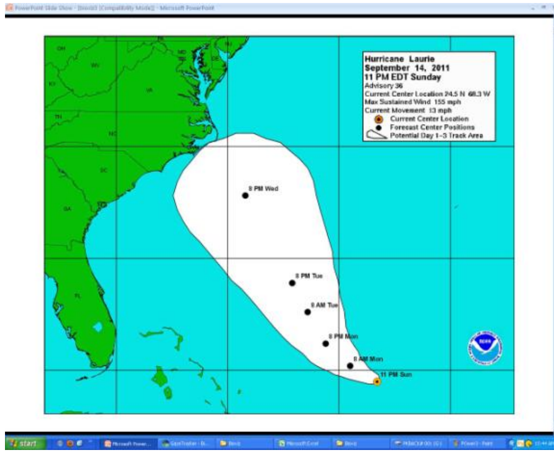
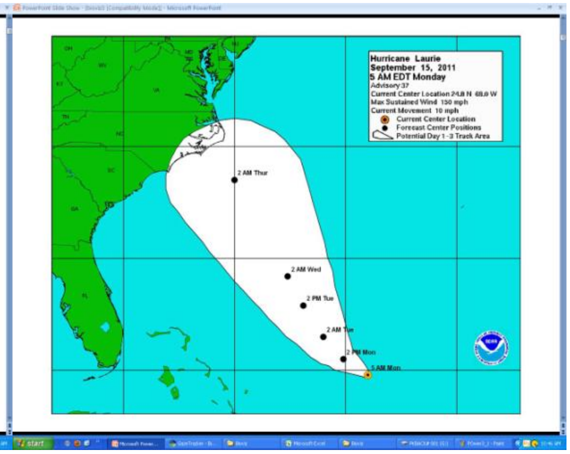
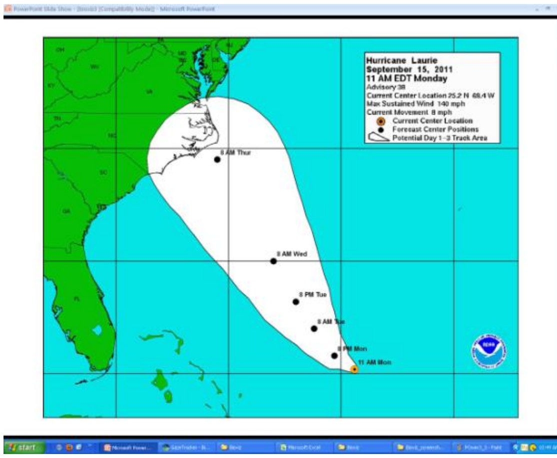
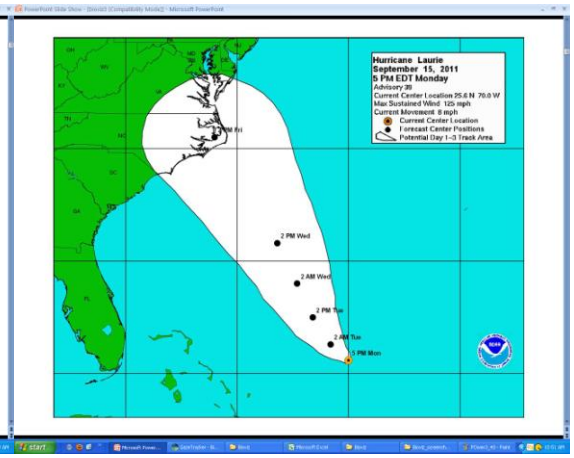
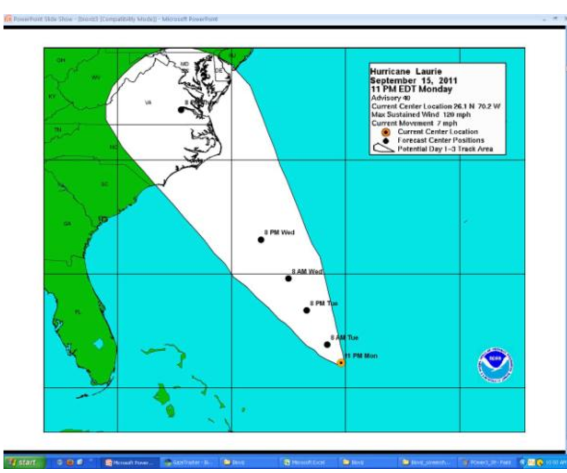
APPENDIX A: NHC HURRICANE ADVISORIES USED IN RESSEARCH

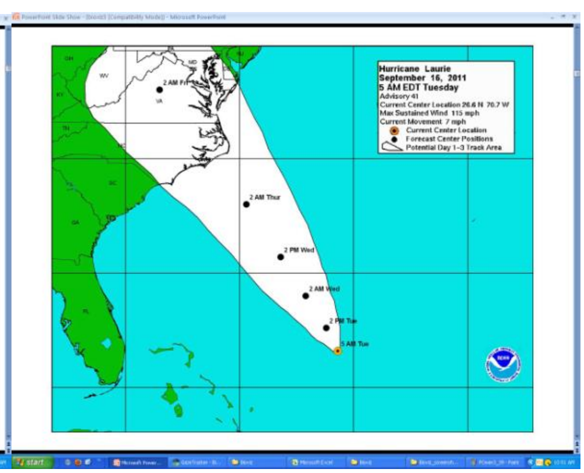


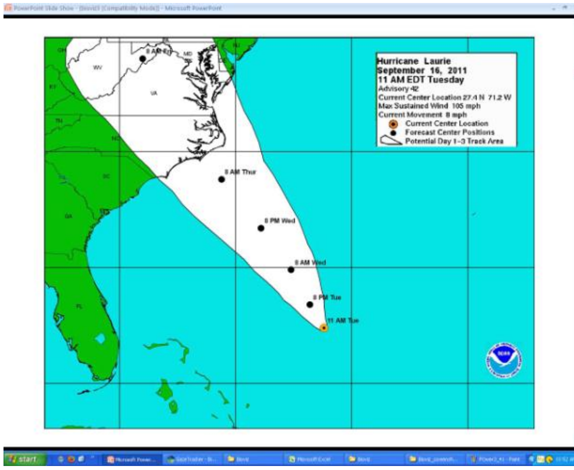


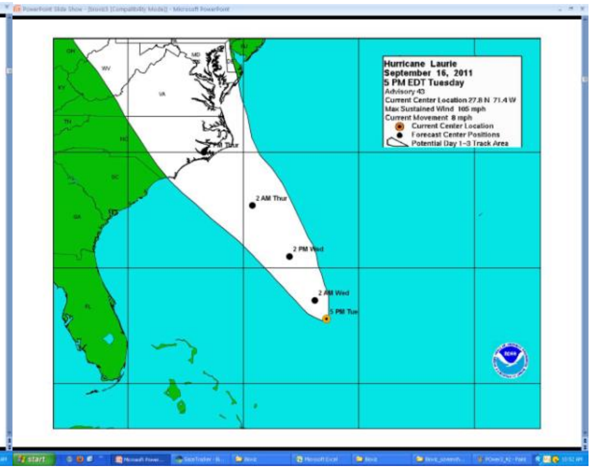


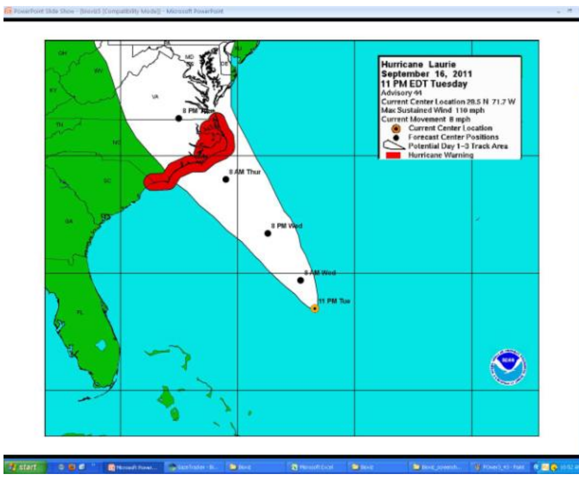







Hurricane Laurie
September 16, 2011
11 AM EDT Tuesday
Advisory 42
Current Center Location 27.4 N 71.2 W
Max Sustained Wind 105 mph
Current Movement 8 mph
Current Center Location
Forecast Center Positions
Potential Day 1-3 Track Area
8 AM Thur
8 PM Wed
8 AM Wed
8 PM Tue
11 AM Tue


Hurricane Laurie
September 16, 2011
5 PM EDT Tuesday
Advisory 43
Current Center Location 27.8 N 71.4 W
Max Sustained Wind 105 mph
Current Movement 8 mph
Current Center Location
Forecast Center Positions
Potential Day 1-3 Track Area
2 AM Thur
2 PM Wed
2 AM Wed
5 PM Tue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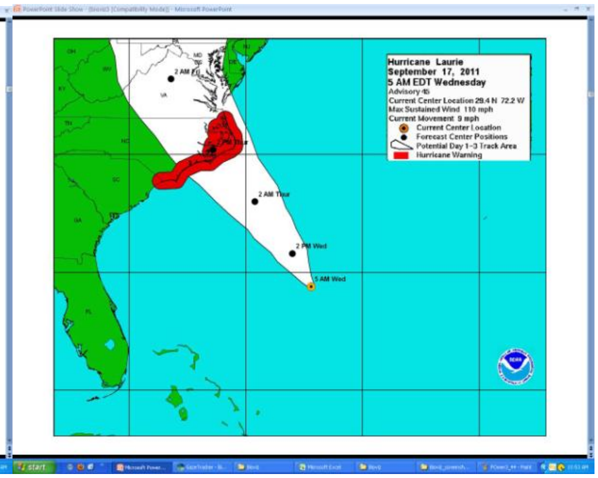
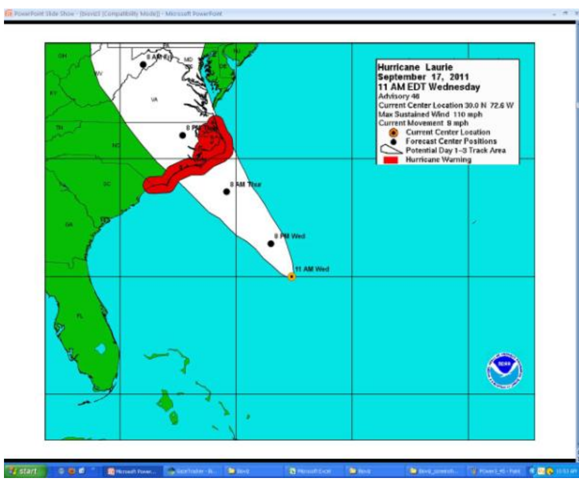
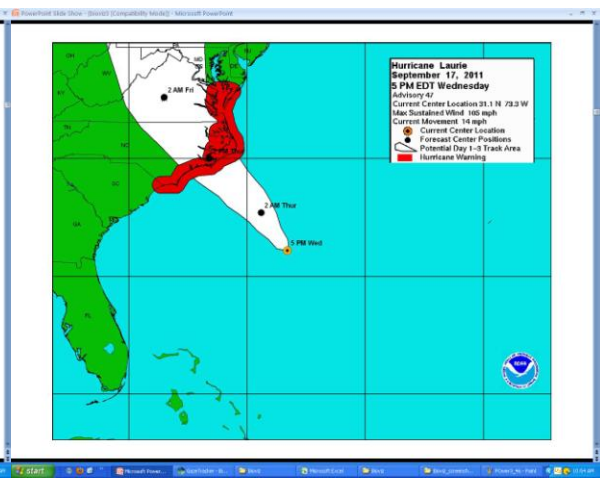
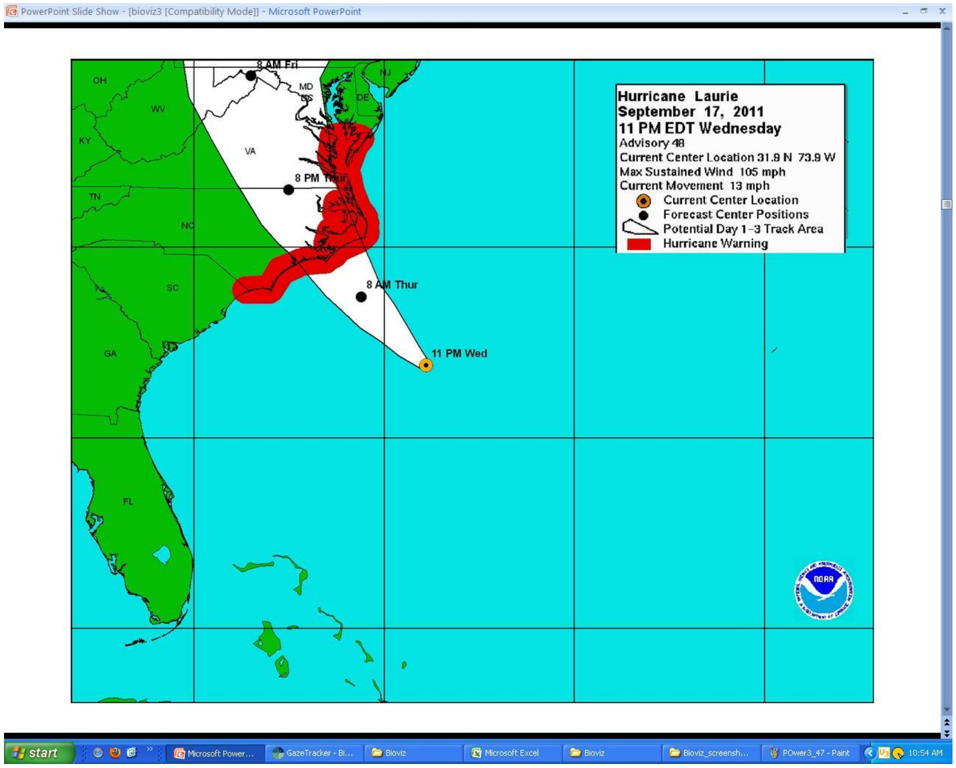
September 16, 2011
11 PM EDT Tuesday
Advisory 44
Current Center Location 28.5 N 71.7 W
Max Sustained Wind 110 mph
Current Movement 8 mph
Current Center Location
Forecast Center Positions
Potential Day 1-3 Track Area
Hurricane Warning
8 AM Thur
8 PM Wed
11 PM Tue


Hurricane Laurie
September 17, 2011
5 AM EDT Wednesday
Advisory 45
Current Center Location 29.4 N 72.2 W
Max Sustained Wind 110 mph
Current Movement 9 mph
Current Center Location
Forecast Center Positions
Potential Day 1-3 Track Area
Hurricane Warning
2 AM Thur
2 PM Wed
5 AM Wed


Hurricane Laurie
September 17, 2011
11 AM EDT Wednesday
Advisory 46
Current Center Location 30.0 N 72.6 W
Max Sustained Wind 110 mph
Current Movement 8 mph
Current Center Location
Forecast Center Positions
Potential Day 1-3 Track Area
Hurricane Warning
8 AM Thur
8 PM Wed
11 AM Wed


Hurricane Laurie
September 17, 2011
5 PM EDT Wednesday
Advisory 47
Current Center Location 31.1 N 73.3 W
Max Sustained Wind 105 mph
Current Movement 14 mph
Current Center Location
Forecast Center Positions
Potential Day 1-3 Track Area
Hurricane Warning
2 AM Fri
2 AM Thur
5 PM Wed



PowerPoint Slide Show - [bioviz3 [Compatibility Mode]] - Microsoft PowerPoint
Hurricane Laurie
September 17, 2011
11 PM EDT Wednesday
Advisory 48
Current Center Location 31.9 N 73.9 W
Max Sustained Wind 105 mph
Current Movement 13 mph
Current Center Location
Forecast Center Positions
Potential Day 1-3 Track Area
Hurricane Warning
8 AM Fri
8 PM Thur
8 AM Thur
11 PM Wed
OH
WV
KY
VA
MD
DE
NJ
TN
NC
SC
GA
FL
start
Microsoft Power...
GazeTracker - Bi...
Bioviz
Microsoft Excel
Bioviz
Bioviz_screensh...
POwer3_47 - Paint
10:54 AM

APPENDIX B: IRB FORM

Unique Identifier:

UNIVERSITY AND MEDICAL CENTER INSTITUTIONAL REVIEW BOARD
HUMAN BEHAVIORAL AND SOCIAL SCIENCE INTERNAL PROCESSING FORM
SUBMISSION FOR UMCIRB REVIEW
FULL AND EXPEDITED RESEARCH

DEMOGRAPHIC INFORMATION

Type of application: ☒ New ☐ Modification Date: UMCIRB #:

Title of proposed research (this title must match protocol, funding application and consent form):: Assessment of Geospatial Visualization Response and Effectiveness for Coastal Hazards Risk Communication

Principal Investigator, credentials, department, section and school: Nicholas P. Murray, PhD, EXSS, HHP, ECU

Check the institutions for which the principal investigator is associated: ☒ECU ☐PCMH ☐Other

Subinvestigators, credentials, department, section and schools: Tom Crawford, PHD, GEOG, Harriot College of Arts and Sciences, ECU

*** Investigators not associated with ECU or PCMH require submission of an Unaffiliated Investigator Agreement.

List of all items related to this research study submitted for UMCIRB review and approval: IRB, Informed Consent, and Participant advertisement.

SOURCE OF FUNDING

☒ Government Agency, Name: Renaissance Computing Institute (UNC-General Administration)
☐ Private Agency, Name:
☐ Institution or Department Sponsor, Name:
☐ No funding
☐ Grant: include 3 copies of the final grant application for full committee reviews or 1 copy for expedited reviews

NOTE: The UMCIRB Conflict of Interest Disclosure Form needs to be submitted for expedited and full review.

CHECK ALL INSTITUTIONS OR SITES WHERE THIS RESEARCH STUDY WILL BE CONDUCTED:

☒ East Carolina University
☐ Other

CHECK ALL OF THE FOLLOWING INVOLVED IN THIS STUDY

Population Specifically Targeted

☒ Normal volunteers
☒ Adults (> 18 yrs old)
☐ Minors (< 18 yrs old)
☐ Institutionalized Participants
☒ Students
☐ Participants at other Institutions
☐ Mentally Impaired Participants
☐ Prisoners
☐ Wards of the State
☐ Minorities
☐ Participant pools
☐ Staff Participants
☐ Non-English speaking

Methods/Procedures

☒ Surveys / Questionnaires
☒ Interviews
☒ Standardized Tests
☐ Non-standardized Tests
☐ Focus Groups
☐ Deception
☐ Databank Information
☐ Videotaping / Voice Recording / Photography
☐ Public observation

Unique Identifier:
☐ Public School System
☐ Day care facilities

RESEACH RISK AND LEVEL OF REVIEW REQUIRED

Research participants will be placed at as defined below:
☒ No more than minimal risk
☐ More than minimal risk

Minimal risk means that the probability and magnitude of harm or discomfort anticipated in the research are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests. 45 CFR 46.102(i) The definition for prisoners differs and is located at 45 CFR 46

What level of review does your proposal require?
☒ Expedited
☐ Full

Those research studies utilizing Pitt County Memorial Hospital resources, Brody School of Medicine resources or involving ionizing radiation should complete the Institutional Approval for Research Form.

RESEARCH QUESTIONS

1. Subject Selection
   - Describe how participants will be selected or recruited for the research, including enrollment procedure. Participants will be recruited from classes taught at East Carolina University as well as from the general public. Participants will be enrolled after the study investigator has described all aspects of the proposed study to the students. Informed consent will be obtained
   - Identify the projected number of participants to be enrolled. 40
   - Outline the inclusion and exclusion criteria for this research study. Participants will be 18 years of age with normal or correct normal vision, and able to use a typical keyboard and mouse.
   - Provide a justification for the sample size selected. In order to detect a medium-sized difference between two groups for $\alpha = .10$ a sample size of 40 is required (Cohen, 1992).
   - Describe the safeguards in place to protect the rights and welfare of any vulnerable participants enrolled in this research study. In order to protect the rights and welfare of any vulnerable participants, we will ensure that participants are aware.

Are there any advertisements (public display in written, radio, or TV form) for participant recruitment?
☐ Yes ☒ No If yes, attach the advertisements to the processing form.

Does the research include any monetary inducements, compensation or reimbursement for participation in this research study?
☒ Yes ☐ No If yes, attach the payment schedule to the processing form or provide specific protocol reference.
They will receive a $20 Food Lion Gift Card immediately upon completion or voluntary withdraw from the study.

Will the sponsor reimburse for any items or procedures or supply any items at no cost involved in this research study?
☒ Yes ☐ No If yes, attach written documentation of the items that will be reimbursed or supplied by the sponsor unless this information is specifically noted in the research protocol.

Are there any associated costs that participants will incur in as a result of participating in this research study?
☐ Yes ☒ No If yes, describe these costs.

2. Researcher Qualifications

Name and list the duties of the research team members and describe the qualifications of each member to perform their duties.

Dr. Murray will be responsible for assisting in data collection and analysis. Dr. Murray has been trained in psychophysiologcal assesment and has conducted research examining emotionality and Dr Tom Crawford will assist in data collection and analysis

- **Include the completion date of the human protections modules located on the UMCIRB web site.** Dr. Murray completed the human protection modules on 5/29/09. Dr Crawford completed the human protection modules on 2/24/10

3. Risk Determination

Describe the research setting, listing any safeguards in place for participant safety. The data collection will occur in the Visual Motor Laboratory (Minges Coliseum 164, East Carolina University). This laboratory is specifically designed to ensure the safety and comfort of research participants. All laboratory materials will be new for each participants and laboratory protocols including wearing of gloves, maintaining a sanitary environment and properly disposing of any waste materials will be followed.

4. Risk Determination

- **Describe all foreseeable physical, psychological, economic, social, legal and dignitary risks to the participants, with steps outlined to minimize those risks. Risks should be described in terms of probability or likelihood, magnitude and duration when possible.**

  There are no foreseen psychological, economical, social, legal or dignitary risks. There are no risks associated the use of the EEG and QuikCap system with exception of possible discomfort from wearing the head gear. This discomfort general ends as soon as the equipment is removed. The QuikCell system utilizes a saline solution that is injected into a spongy type material consequently only a small amount of the saline solutions is left on the subject once the cap is removed. The saline solution poses no risk to the subjects. Heart rate variability will also be examined by placing small electrodes on the participants' chest. No risk or discomfort is expected with the heart rate measure.

- **Outline the mechanism for reporting adverse events or unanticipated risks to participants or others for this study.** Any adverse events or complications will be immediately addressed and reported to the UMCIRB within 24 hours.

5. Data/Safety Monitoring: Data monitoring includes activities such as interim analysis or other opportunities for both individual and aggregate study data to be reviewed to ensure the safety of participants. A plan for this type of data monitoring may be required to meet the criteria for IRB approval in order to ensure the protection of participants involved in the research, to review the risk-benefit analysis, and to ensure there are no new findings for which current or future participants should be apprised.

If applicable, describe how data will be reviewed to determine if the study procedures should be changed during the course of the study.

Typically the PI will be on the premises when data is collected, however, if the PI is not on-site, sub-investigators will inform the PI that data collection will be occurring and to contact the PI or his designated faculty alternate with any problems.

6. Anticipated Benefits

- **Describe the benefits of the research study to participants or others.**

The primary purpose of the study is to learn how people respond biologically to map products depicting hurricane hazard risk. Emergency planners desire to produce and disseminate maps to the public that are the most effective at communicating hurricane risk. This research helps us learn what map types and formats are the most effective.

7. Data Confidentiality and Subject Privacy

Unique Identifier:

- **Describe how confidentiality will be maintained by providing details about the storage facility, duration of storage, data destruction method, and persons with access to the data.**

  Hard data will be stored in a locked filing cabinet in a locked office (the PI's) for a period of five years. Soft data files will be stored in a secure computer file on the PI's computer for a period of five years. Hard data will be shredded and computer files deleted at the end of the five year period.

- **How will subject privacy be maintained during recruitment, data collection and data analysis?**

  Study data will be identified only by study identification numbers. No names will be used. Only the investigators will have access to the study records and data.

- **If the participants data or samples will be used for future research, describe how their privacy will be protected?**

  Data will not be used for future research at this time.

- **Describe any additional safeguards in place to manage illegal, significantly intimate or potentially embarrassing information gathered in this research study.**

  All data will be kept in the PI offices. Data will be identified with code numbers.

- **Include steps to handle information that requires mandatory reporting to officials, for example physical abuse, emotional abuse or health problems.**

  It is unlikely that cases of physical abuse or emotional abuse among participants will become evident during the course of the trial. If, however, the research team does discover cases of physical and emotional abuse that requires mandatory reporting to officials we will work with the participant to report them. Health problems that become evident will be reported to the participant.

- **If the research study involves HIV testing, describe the plans for pre/post-test counseling and other related considerations.**

  n/a

6. Obtaining Consent or Parental Permission

- **Describe the consent process, including members of the research team that will be obtaining informed consent from study participants.**

  Participants will be told about the study at the initial recruitment meeting. Participants will be allowed to ask questions during the initial recruitment meeting, the telephone call to schedule an appointment and immediately prior to signing the consent form during the scheduled test session. Informed consent will be obtained at the scheduled test session immediately prior to any testing. Dr. Murray and/or a research assistant will explain the procedure and obtain consent.

- **Describe the setting in which the consent will be obtained.**

  Consent will be obtained in Minges Coliseum in the Visual Motor Laboratory (Rm 164)

- **Describe the process to minimize undue influence and coercion during the consent process.**

  Participants will be told during the initial meeting that participation is voluntary and that they do not have to participate. The PI and/or research assistant will reiterate the voluntary nature of the study during the subsequent telephone call and prior to obtaining informed consent at the testing session.

- **Outline procedures for obtaining informed consent from participants with limited or low literacy based on the specific circumstance.**

Participants with impairments to mental capacity will be permitted to participate if the research team believes informed consent can be obtained and that the impairment does not interfere with the participant's ability to complete the task.

- **Describe the process for determining cognitive impairment or other conditions that may make a participant more vulnerable.**

The initial meeting during recruitment will allow an opportunity for the PI or research assistant to detect vulnerabilities such as cognitive or emotional impairment. Additional safeguards will include (a) stressing that participation is voluntary and (b) stressing the confidentiality of the study.

- **Describe the process for identifying the legally authorized representative and the process to debrief and subsequently obtain consent from the study participant, when feasible.**

n/a

9. Minor Assent Related Issues

- Describe the assent processes given the range of ages intended for this research study. n/a
- **If a separate assent is not being used, how will assent be documented?** n/a
- How will custody changes during participation in the study be determined? n/a
- **Describe the processes as required for enrolling wards of the state if they are a target population for this study. Note: If a child becomes a ward of the state, the IRB must be notified immediately to seek advice on further protections that may be required.**

n/a

10. Background

a. **Describe the current state of knowledge surrounding the research questions to be addressed in this study.**

Hazards risk and vulnerability is communicated to the public by emergency managers using various media and technologies. We propose to test the usability and communication effectiveness of products developed and delivered using digital geospatial technologies. We will initially focus on media products developed by the Storm Surges and Flooding featured project that include static and animated map simulations of surge-related hurricane impacts for Dare County. Our key objective is to assess the benefits and effectiveness of geospatial simulation products including threat awareness, learning, and decision-making. Do viewers actually respond to products in ways intended by product designers? There is a lack of empirical studies that examine this issue for geospatial media communicating coastal hazards risk. Nonetheless, we increasingly see such media displayed on major networks during hurricane events. We will examine hazard risk visualizations geared to the general public utilizing psychophysiological measures. More specifically, do objects of high interest and information content in the x,y space of the visualization (row/column pixel space) correlate with human eye tracking measures and for how long and to what effect? How are other biometric measures correlated (galvanic skin response, heart rate, EEG measures of brain activity) with the content and spatio-temporal sequencing of visualizations? Do visualization products alter risk perception and do they promote learning?

b. **Describe the uncertainty to be addressed by this research study (research question).** What are the usability and communication effectiveness of products developed and delivered using digital geospatial technologies?

c. **Describe the rationale for the type of research design chosen for this study.** **Design:** This research design chosen for this study is optimal for examining the variables outlined above. In order to adequately examine the temporal sequence of these relationships.

Measures:

Survey measures is a self-designed questionnaire (See attached)

Psychophysiological Measures:

- Electroencephalogram (EEG) will be measured from the scalp at 64 electrode sites. A fast Ag/AgCl electrode positioning system consisting of an extended 10–20 system, in a 68-channel montage

(Quik-Cap, Neuromedical Supplies®). Two bipolar channels out of the 68-channels in the montage were used for recording both horizontal (HEOG) and vertical eye movements (VEOG). Bilateral mastoids served as non-active reference sites for data collection. The ground electrode will be located 10% anterior to FZ. One 64-channel DC amplifiers (Synamps, Neuroscan Inc.) and the Scan 4.3 software package (Neurosoft Inc.) will be used for data collection and analysis. The filter settings for acquisition will be from DC to 30 Hz, and the digitization rate will be 1000 Hz. EEG activity will be collected continuously during video game play.

- Heart rate variability (HRV) is oscillations in the interval between consecutive heart beats as well as the oscillations between consecutive instantaneous heart rate. HRV provides a quantitative multidimensional measure of autonomic, sympathetic (SA) parasympathetic (PS) modulation of cardiac function. HRV is a nonspecific marker of autonomic nervous system function and therefore is a good measure of stress. Heart Rate Variability (HRV) will be assessed using Biopac Student Lab System. The manufacture's instruction for data collection will be followed.
- Galvanic skin conductance which provides an indicator of arousal will be recorded by placing small electrodes on the second and third toe through a Biopac Student lab system. In addition, the Biopac Student lab system will also collect electro-ocular activity through electrodes place above and below the participants' right and left eye. The manufacture's instruction for data collection will be followed.
- The participants will be outfitted with a visual search collection instrumentation, which will be used to collect eye movement information. Their eye movements will be recorded with an Applied Science Laboratories (ASL, Waltham, MA) 5000 SU eye movement system with Eyehead Integration software. The 6000 SU eye movement system is a video based monocular corneal reflection system that accurately measures line of gaze with respect to the orientation of the head.

PROTOCOL SUMMARY

Provide a brief, one page description of the research study. All more than minimal risk research studies or research requiring full UMCIRB review must have a separate protocol.

Design and Procedure

The participants will complete an approximately *1 hour* testing session. The experiment will be run in a dimly lit room to reduce visual distracters. The images will be viewed on a standard PC using a 19 inch LCD monitor. The participants will be given the informed consent to read and sign. The participants will be allowed to visually inspect the QuickCell cap before it is place on their head and will be familiarized with other data collection equipment. Following the Society for Psychophysiological Research guidelines (Putnam, Johnson, & Roth, 1992) the QuickCell cap will be placed on the head of the participant and saline solution will be injected into the cap in which the majority will be absorb by the QuickCell electrodes (a spongy type material). In addition, small QuickCell electrodes will be placed above and below the left eye, one on the right side of the right, and one on the left side of the left eye. In addition, two QuickCell electrodes will be placed on the mastoids (just behind the ears). Two disposable electrodes will be placed on the participants' chest to record heart rate. The eye tracking will be placed on the participants head and the participant will follow a standard calibration sequence. Participants will be asked a series of questions related to their impression of images detailing coastal hazards.

Unique Identifier:

REQUIRED RESEARCH APPROVALS

Does the study involve enrolling participants at another site, institution or department outside of the principal investigator's department?

☐ Yes ☒ No If yes, attach the IRB approval letter (if any) or approval letter for institutional or departmental participation to the processing form.

CHIEF OF SERVICE OR DEPARTMENT CHAIR APPROVALS STATEMENT

I have reviewed this project. I believe that the research is sound, the goals are scientifically achievable, and does not involve any significant human rights issues. There are appropriate departmental resources (financial and otherwise) available to conduct the research. The investigator is qualified to conduct all aspects of this research project based on education, training or experience, and has the necessary authorizations or privileges to conduct all outlined procedures. I endorse the investigator and outlined research project as indicated by my signature below.

I have reviewed the UMCIRB Conflict of Interest Disclosure Form and evaluated the principal investigator of this project for risk related to conflict of interest according to the UMCIRB Standard Operating Procedure Manual. I endorse the investigator and the attached plan (if required) for managing conflict of interest related to this research study as indicated by my signature below.

NOTE: (1) A department chair may not sign this statement if listed as an investigator, and should seek the signature of the division chair/dean. (2) If you don't have a department chair (such as a private practice investigator) then attach a current CV.

Stacey Alt [signature] Stacey Altman 2/25/2010
Signature of Chief of Division/Department Chair Print Date

CONTACT INFORMATION

Mailing address for all correspondence: 166 Minges, East Carolina University, Greenville, NC 27858
Telephone Number: 252-737-2977 **Fax Number:** 252-328-4564 **e-mail:** murrayni@ecu.edu
Research assistant: Danielle Zebroski **Telephone number:** 252-737-4680

RESPONSIBLE FACULTY MEMBER: For any Principal Investigator that has an undergraduate, graduate, post-graduate student status including residents and fellows, or visiting status to serve as a responsible individual in the oversight of the research study.

Responsible Faculty: Nicholas P. Murray
Mailing address: 166 Minges, East Carolina University, Greenville, NC 27858
Telephone Number: 252-737-2977 **Fax Number:** 252-328-4564 **e-mail:** murrayni@ecu.edu

I have reviewed the study proposal and all documents and materials to be used in the study.

Nicholas P Murray [signature] Nicholas Murray 2/24/10
Signature responsible faculty as above Print Date

INFORMED CONSENT DOCUMENT

Title of Project: **Assessment of Geospatial Visualization Response and Effectiveness for Coastal Hazards Risk Communication**

Principal Investigator: Dr. Nicholas Murray
Co-Investigator: Dr Tom Crawford
Institution: East Carolina University
Address: 164 Minges Coliseum, ECU, Greenville, NC 27858
Telephone #: 252-737-2977

This consent form document may contain words that you do not understand. You should ask the principal investigator to explain any words or information in this consent form that you do not understand.

INTRODUCTION

You have been asked to participate in a research study being conducted by Dr. Nicholas Murray and Dr. Tom Crawford. The primary purpose of the study is to learn how people respond biologically to map products depicting hurricane hazard risk. Emergency planners desire to produce and disseminate maps to the public that are the most effective at communicating hurricane risk. This research helps us learn what map types and formats are the most effective.

PLAN AND PROCEDURES

You will be asked to complete an approximately 1-hour testing session. During this session, you will be asked to view some map products on a computer screen and complete measurement questionnaires before and after you view the map products. You will wear a special cap with eyelet holes and surface electrodes placed on your scalp to record your brain signals. A saline solution will be injected into the electrodes in which the majority will be absorbed by a spongy type material in the actual electrodes; however, some moisture from the saline solution (essentially salt water) will remain on your scalp. This is easily removed with a towel or washing of your hair. In addition, there will be small surface electrodes placed above and below your eyes using tape. These electrodes will measure your eye muscle activity. Next, you will be outfitted with a video based eye tracking system, which will be used to collect eye movement information while you view the map products. You will also be asked place two small electrodes on your second and third fingers on your left hand. In addition, two electrodes will be placed on your chest Data collection wires will be attached to all electrodes and connected to a data collection device. Following placement and calibration of the data collection equipment, you will be asked to view the map products and complete measurement questionnaires before and after the visualization.

POTENTIAL RISKS AND DISCOMFORTS

There are no health risks associated with participation in the study.

POTENTIAL BENEFITS

Following completion of the experiment, you will be given the opportunity to view your own data output which would shows how you responded biologically (e.g. heart rate, brain activity, etc.) to map stimuli and how this type of research can help researchers to produce maps that have greater effectiveness.

TERMINATION OF PARTICIPATION

Your participation in this research study may be terminated without your consent if the investigators believe that these procedures will pose unnecessary risk to you. You may also be terminated from participation if you do not adhere to the study protocol.

COST AND COMPENSATION

The policy of East Carolina University does not provide for the compensation or medical treatment for subjects because of the physical or other injury resulting from this research activity. However, every effort will be made to make the facilities of the School of Medicine available for treatment in the event of such physical injury.

CONFIDENTIALITY

Only the investigators associated with this study will have access to the data obtained. Numeric coding will protect the identity of the subjects. No identifying information will be released.

VOLUNTARY PARTICIPATION

Your participation in this study is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you're otherwise entitled. Furthermore, you may stop participating at any time you choose without penalty, loss of benefits, or without jeopardizing your grade in the course.

PERSONS TO CONTACT WITH QUESTIONS

The investigators will be available to answer your concerns regarding this research, now or in the future. You may contact the principle=investigator, Nicholas P. Murray, Ph.D. (days: 737-2977, nights: 215-0418 or murrayni@ecu.edu). Also, if questions arise about your rights as a research subject, you may contact the Chairman of the University and Medical Center Institutional Review Board at 252-744-2914 (days) or umcirb@ecu.edu.

CONSENT TO PARTICIPATE

I certify that I have read all of the above information, asked questions, and received answers concerning areas I did not understand, and have received satisfactory answers to these questions. I willingly consent for participation in this research study entitled: "**Assessment of Geospatial Visualization Response and Effectiveness for Coastal Hazards Risk Communication**". (A copy of this consent form will be given to the person signing as the subject).

____
Subject's Name (Print)

____
Subject's Signature

____
Principal Investigator's Name (Print)

____
Signature of Principal Investigator Date

East Carolina University

Authorization for the Purchase of Gift Cards/Gift Certificates, Incentives, or Prizes

Intended Payment Method (check one): __X__ ECU ProCard _____ PORT PO _____ Employee Reimbursement

Upon completion this form must be attached to the appropriate payment mechanism.

Requestor's Information: Requestor/Principal Investigator: __Nicholas P. Murray__________ (please print)

Department: ___EXSS, HHP______ Campus Phone: __252-737-2977______

Cardholder (for purchase by ProCard): __Kevin R. Mills__________ (please print)

Banner Fund ___211579___ Orgn ___780101___ Acct ___ ___ ___ ___ ___ Prog ___0000___

Grant Title (if applicable): Renaissance Computing Institute ECU Engagement Center (Renci at ECU)

Detailed description and business purpose/Purpose of event or research project (attach additional sheet if necessary): Cards will be used as payments to research participants. The purpose of the study is to learn how people respond biologically to map products depicting hurricane hazard risk. Emergency planners desire to produce and disseminate maps to the public that are the most effective at communicating hurricane risk. This research helps us learn what map types and formats are the most effective.

Purchase Information: Type of incentive or prize (check one): __X__ Store card _____ Mall card _____ Gas card

_____ Other (please specify): ______________________

Vendor Name: __Food Lion__________ Est. Date of Purchase: ___3-1-2010______

Total Amount of Purchase: $_900.00___ Quantity 45 Cost per unit/Amount of each card $__20.00____

Month/Year Disbursement(s) to be made: _March-May 2010_ Project expiration: May 30, 2010___

I verify that the gift cards/gift certificates or other noted incentives purchased will be used solely for the intended purpose listed above. I further agree to comply with University and Sponsor policies regarding documentation and distribution of gift cards/gift certificates, incentives, and prizes, and will abide by the University policies related to the possession of confidential information, if applicable.

Requestor/Principal Investigator's Signature: [signature] Date: 2/24/10

Cardholder Signature (if applicable): ______________________ Date: __________

****

I hereby authorize the use of departmental funds to purchase gift cards/gift certificates, incentives, or prizes for the intended purpose listed above.

Dean/Department Head Signature: ______________________ Date: __________

Printed Name of Dean/Dept Head: _Thomas R. Allen, Director, Renci at ECU_______ Phone: __252-737-1771___

Funding Source (Special Funds, Student Affairs, Grants, Foundations, etc.):	Date:
Sign: ______________________	______________
Print: __Wanda Sandeford__________	
Materials Management:	Date:
Sign: ______________________	______________
Print: ______________________	

NOTE: The Division of Research & Graduate Studies Office of Grants and Contracts Policies and Procedures titled: *Payments to Research Participants (Human Subjects)* applies. See http://www.ecu.edu/purchasing/ for more information.