SMALL-MULTIPLES AND ANIMATION: MEASURING USER PERFORMANCE WITH WILDFIRE VISUALIZATION

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A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Geography

2011

ABSTRACT

SMALL-MULTIPLES AND ANIMATION: MEASURING USER PERFORMANCE WITH WILDFIRE VISUALIZATION

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Recent investigations in cognitive psychology and cartography have examined the communicative efficiency of animation and static small-multiple visualizations on knowledge construction and apprehension. In theory, animation may be the most congruent method to represent a dynamic geographic process. However, some have suggested that cartographic animations are too complex and transient, making them difficult to comprehend. Others have demonstrated that static small-multiples facilitate comprehension, inference and learning and afford map-readers interactive capabilities that are unavailable in most conventional animations. This thesis empirically investigates the influences of map-design and temporal resolution on apprehension and inference affordance, in the context of wildfire visualization. A human-subjects experiment was conducted to measure task accuracy, response time, and confidence between animated and small-multiple maps. The results reveal the importance of both map design and temporal resolution; small-multiples and fine temporal resolution maps elicit more accurate and more confident responses from readers. While participants performed better with the small-multiple maps, they prefer animated maps. The results of this research suggest that map type is an important factor that influences accuracy and response time, while temporal resolution is significant for accuracy and confidence yet inversely related to participants overall map preference.

ACKNOWLEDGEMENTS

This thesis could have been possible without the support and guidance from many individuals. First and foremost, a sincere thank you to Dr. Kirk Goldsberry for your advice, guidance, and encouragement over the past two years. This project would not have been a success without your help. Thank you Dr. Olson and Dr. Shortridge for your advice on everything from the map-design, statistics, and writing. Thank you, Mom and Dad for everything you have done to help me reach my goals. I sincerely appreciate all you have done for me. Thank you Eric and Julie for your encouragement and support. Thank you, Carolyn and Josh for your help and effort guiding me through Flash difficulties and Mahalakshmi for always being there for me. Thank you Marissa, Christine, Anita and Molly for being such caring friends and helping me achieve this goal. I could not have done it without your love and encouragement. Thank you Chris Leavitt, for standing by me, supporting me, and keeping my spirits up through the stressful times. I could not have completed this project without your help.

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Chapter 1.
INTRODUCTION

1.1 Introduction

When it comes to representing change over time on a map, cartographers have several options for choosing a design. Animated maps enable cartographers to congruently depict the passage of time, and static sets of small-multiples enable a more stable, less fleeting depiction of temporal changes. While each of these representational strategies are valid, each has its own particular strengths and weaknesses, and functionally, each may support different kinds of map tasks.

As a means to determine effective visualization methods that enable people to comprehend information accurately, it is necessary to investigate the benefits and limitations of current cartographic methods depicting dynamic geographic processes. This thesis will explore different map designs for wildfire visualizations. Wildfire is a complex spatio-temporal, geographic phenomenon that threatens the safety of millions of people each year. Unfortunately, to date, most cartographic representations of wildfire fail to help people understand how and why fires spread over time. Using the outputs of fire prediction models or perimeter data we can cartographically visualize a wildfire progression using both small-multiple maps and cartographic animation.

Recent investigations in cognitive psychology and cartography have examined the communicative efficiency of animation and static small-multiple visualizations on knowledge construction and apprehension (Koussoulakou, A., & Kraak, M., 1992; Griffin et al., 2006; Fabrikant et al., 2008; Archambault et al., 2011). Animated maps illustrate dynamic processes by showing time directly, while static small-multiple maps have been proven to facilitate learning, inference, and apprehension (Hegarty, 1992; Hegarty & Sims, 1994).

According to the *congruence principle* of graphics, animation should theoretically be the most effective way to represent a dynamic geographic process (Tversky et al., 2002). However, some have suggested that animations can be too complex and transient, making them difficult to comprehend (Tversky et al., 2002). Others have demonstrated that static small multiples afford map readers interactive capabilities that are unavailable in most conventional animations (Fabrikant et al., 2008). Small-multiple displays enable users to make comparisons, look for differences, and revisit specific maps at their own pace compared to animations where it is more difficult to memorize and compare features (Tufte, 1995).

The number of small multiples or scenes in an animation is partially dependent on the temporal resolution of the mapped data. The coarseness of the temporal resolution may be an important factor that affects inferences from both fine and coarse temporal resolutions on small-multiple displays and animated maps. Although previous research on the influence of temporal resolution is limited, some results have suggested that map readers prefer smoother, finer resolution animations (Harrower, 2009) and coarser resolution small-multiples (Slocum et al., 2004). An effective number of small-multiple maps or animation scenes to display has not been determined.

Task accuracy, response time, confidence, and preference are key response variables that could be used as proxies to measure the efficiency of both animated maps and small-multiple maps. Previous research on animated maps has produced mixed results regarding participants' accuracy and response times. Koussoulakou and Kraak (1992) found that participants had faster completion times with animated maps compared to small-multiple maps of cartographic symbolizations. Cutler (1998) found that participants take longer and are less accurate with animations. Previous research by Reiber and Parmley (1995) investigating children's confidence with animated maps revealed that children have less confidence when answering questions about animations than when answering about static graphics. Research investigating participants' map preferences is limited; however, a study by Linn (1996) found that children preferred to use interactive maps rather than static maps to learn about geography.

This thesis examines differences between static small multiples and animated maps. More specifically, it investigates the differences between the design variables of map type and temporal resolution in the context of wildfire visualization in order to understand the influence of each on map-reader accuracy, response time, confidence, and preference.

1.2 Research Goals

My goals in this thesis are to:

1. Evaluate how variations in map type affect map-reader ability to apprehend information encoded within both animated maps and small-multiple displays of wildfire.
2. Evaluate how variations in the temporal resolution of animated maps and small-multiple displays affect map-reader ability to apprehend information.

1.3 Research Questions

In order to achieve these goals, I will attempt to answer the following eight questions with respect to map type and temporal resolution:

Map Type

1. Do animations or small multiples evoke higher accuracy rates for completing wildfire-related map tasks?

2. Do animations or small multiples elicit faster response times to complete wildfire-related map tasks?
3. Does the type of map affect map-readers' confidence in their answers?
4. Is there a difference in map-readers' preferences between animated maps and small-multiple maps?

Temporal Resolution

5. Does temporal resolution influence map-reader ability to accurately complete wildfire-related map tasks?
6. Does temporal resolution influence map-readers' response time to complete wildfire-related map tasks?
7. Does temporal resolution influence map-readers' confidence of their responses?
8. Is there a difference in map-readers' preferences based on the temporal resolution of a map?

1.4 Hypotheses

Map Type:

Hypothesis 1. Small-multiple maps will elicit more accurate responses.

According to Tufte (1995), the compactness and repetition of small-multiples allow our eyes to view many images at the same time, helping make comparisons between maps easier and making changes and patterns more evident compared to an animation. Small multiples may elicit more accurate responses because readers can interpret the maps according to their own viewing preferences and strategies.

Hypothesis 2. Small-multiple maps will elicit faster response times.

The dynamic attributes of animated maps can add an overwhelming cognitive load on working memory (Hegarty, 2004). To make comparisons between maps, readers need to remember and recall a great amount of information from previous scenes, or replay the animation over in order to answer a question, which in turn may slow their response time.

Hypothesis 3. Small-multiple maps will elicit more confident responses.

Small-multiples afford map-readers the ability to view the map at their own pace and for any duration, which will help reassure themselves of their answer and in turn, increase confidence in their answer choice.

Hypothesis 4. Map-readers will prefer animated maps.

With the power of the Internet and interactive and immersive applications, people are becoming accustomed to dynamic applications. Animation provides an intuitive way to depict changes over time and provides a tangible way for users to interact with data in their own ways. Slocum et al. (2004) found that participants preferred using small-multiples and animations for different kinds of map tasks.

Temporal Resolution:

Hypothesis 5. Fine temporal resolution maps will elicit more accurate responses.

The fine resolution maps illustrate the finest level of detail available, thereby affording readers more scenes and eliciting more accurate responses. Investigations of the influence of temporal resolution on accuracy have not been conducted.

Hypothesis 6. Fine temporal resolution maps will elicit faster response times.

Coarse temporal resolution maps require map readers to interpolate between known timestamps in order to answer specific questions, which may delay responses. Investigations of the influence of temporal resolution on response time have not been conducted.

Hypothesis 7. Fine temporal resolution maps will elicit more confident responses.

Map readers may feel more confident in their responses when more scenes are present and they do not have to interpolate between scenes. Investigations of the effects of temporal resolution on participant confidence level have not been conducted.

Hypothesis 8. Map-readers will prefer fine temporal resolution maps.

Harrower (2009) found that people prefer smooth animations. Because the fine temporal resolution maps contain more information than the coarse temporal resolution maps, they present a smoother progression over time, which participants might prefer. Investigations on the level of temporal resolution people prefer are limited.

1.5 Research Relevance

This research will fill an important gap in our understanding of visualization by further investigating the information affordance of small-multiple maps and animated maps within the context of wildfire visualizations. In order to accomplish such a task it is important to understand the effect of map design on readers' ability to accurately comprehend wildfire behavior using small-multiple displays and animation, which is currently unknown. The influence of temporal resolution on map type is also undetermined. Without this understanding, cartographers may have a difficult time determining the most effective way to illustrate a geographic process changing over time, not only with respect to map design but also with the level of temporal granularity to depict. This thesis aims to evaluate how critical design variables influence map-readers' abilities to understand information encoded within displays of a dynamic geographic process.

Chapter 2.
LITERATURE REVIEW

While maps are designed to communicate a vast amount of information, it is important to understand how humans interpret the information that cartographers try to convey. In the twentieth century cartographers began to realize how their design decisions affected what readers interpreted from maps. The idea that psychology could help cartographers understand how human cognition could be used to facilitate map design research generated a new area of interest called, *cognitive cartography*. It encompasses the perception, learning, and communication of maps. While many studies have compared the effectiveness of animation to small-multiple displays, few have used dynamic geographic processes as the stimuli measure. Furthermore, the influence of temporal resolution on map-readers abilities to complete basic map tasks has not been determined. This literature review aims to outline the principles of cartographic animation, small-multiple displays, and other cartographic works as it relates to the techniques of representing dynamic processes on maps.

2.1 Experimental Cartography

According to Montello (2002), map-design research, also known as experimental cartography, could be said to have began in the late twentieth century with the development of scientific psychology, shaded relief maps, and thematic maps. These areas greatly affected the direction of cartography in academia as well as influenced geographer, Arthur Robinson to evaluate the role of maps as communication devices in society.

Robinson (1952) published *The Look of Maps,* a book that played a seminal role in the concept and development of cognitive map-design research. Robinson (1952) believed that the main function of a map was to communicate information to people, and the design decisions used to communicate ultimately influence what people discern from a map. In order to determine and improve the effectiveness of maps, cartographers must understand what and how map-readers apprehend and perceive information from a map. Koussoulakou and Kraak (1992) argue that cartographers not only design maps, but also assess the performance and effectiveness of maps.

Arthur Robinson called for empirical and scientific investigations on the influence of map design decisions and how people perceive information on maps (Robinson, 1952). Robinson's concepts for map-design research have had lasting effects on cartographic research today and have inspired many cartographers to look at the cognitive aspects of many different types of maps to help improve their effectiveness as visual communication tools.

The Look of Maps set a foundation for experimental cartographic research including a popular empirical investigation conducted by Flannery (1971) on the psychophysics of graduated circles. Other map-design research by Dobson (1975, 1977) and Steinke (1979) focused on using eye-tracking devices to examine map-readers eye movements while they read a map. During the 1970's map-design research progressed at a rapid rate until its resultant work became questionable in the applicability and usability to incorporate findings in actual map designs (Montello, 2002). In the early 1980's the rise of GIS brought about automated cartographic methods and GIS projects became more popular over map-design research. In the late 1990's GIS and computers helped bring map design research back to the forefront and inspired many uses and new technologies for experiment stimuli and data recording.

2.2 Representation of time series data

Time-series data can be represented spatially or non-spatially, with single or multiple views, or as static or dynamic depictions. Monmonier (1990) divided temporal graphic representations into two groups, those occurring in time-attribute space and those in geographic space. Time-attribute space typically involves using diagrams with a horizontal and vertical axis while geographic space is used to represent one attribute over many places with multiple maps or with a sequence of maps. Time can also be represented on maps with isochrone lines, flow lines, variations in point symbols, and directional arrows.

Static maps can depict change indirectly such as with snapshots in time (Thrower, 1959) or as a series of maps known as small-multiple maps (Tufte, 1995). Static maps have existed for 5000 years (Harrower, 2009), and they have been subjected to many empirical investigations. Because static maps have existed so long, we are versed in their designs, conventions and uses. Single, static maps can illustrate change over time; For example, the USGS depicts change on a single map by using different hues to differentiate the growth of urban areas between map revisions (Campbell and Egbert, 1990). Cartographers also depict change on a single static map by employing the use of visual variables, such as hue, size, shape, and orientation.

2.4 Principles and Characteristics of Cartographic Animation

Animated maps utilize Bertins' visual variables, as well as make use of the dynamic visual variables of duration, rate of change, and order. By employing the dynamic variables in conjunction with the visual variables, animated maps can emphasize specific locations or attributes, as well as visualize changes in an attribute over space and time.

2.4.1 Animated Maps

Animated maps are still a relatively new form of cartography. The earliest examples of animated maps include Waldo Tobler's (1970) simulation of urban growth in Detroit and Moellering's (1976) study of traffic accidents. During that time cartography was more concerned with production methods and the visualization techniques that animated maps could provide (Koussoulakou, A. and Kraak, M., 1992). Due to the high production costs associated with animation, few people focused on designing animated maps during the late 1970's and early 1980's therefore slowing the development of cartographic animation. As technology advanced and the computational and monetary constraints of the production of animated maps decreased over the years, animated maps became increasingly popular. With the onset of GIS, more people became interested in the uses and visualization capabilities of animated maps; however cognitive research about their effectiveness over static displays lagged behind (Fabrikant, 2008). Cartographic research on map design is now on the rise again and the educational uses and development of animation software continue to progress (Lobben, 2003).

Several classification schemes exist to distinguish between the different types of animation. Lobben (2003) classified animation into four broad categories: time-series areal, thematic and process animation in the context of time, and variable and space. This thesis examines the inference affordances of a time-series animation, by highlighting the changing variable and holding the basemap constant while time remains dynamic.

2.4.2 The Congruence Principle

The benefit of graphics is apparent in their ability to communicate large amounts of information. The type of graphic and the information it communicates to people should correspond to the characteristics of what is being represented. Tversky et al. (2002) describe this concept as the *Congruence Principle.* According to the Congruence Principle, for graphics to be effective, the internal representation of the phenomenon in the graphic should naturally correspond with the external representation of the phenomenon being conveyed. For example, illustrating a dynamic process such as the progression of a wildfire should be represented congruently with an animated graphic. Graphics that adhere to the congruence principle depict change over time directly, such as animations.

2.4.3 The Apprehension Principle

For a graphic or visualization to be effective, the reader must be able to successfully understand the information presented. For this to occur, Tversky et al. (2002) suggest the structure and external representation of a graphic also follow the *Apprehension Principle*, which states that people should be able to accurately comprehend and perceive the information presented. Experimental research in psychology by Hegarty (1992) and Hegarty and Simms (1994) has demonstrated that small-multiple maps of dynamic processes facilitate comprehension, inference, and learning. However, in a comprehensive review, Tversky et al. (2002) failed to find conclusive evidence that animation facilitates learning.

2.4.4 Informational Equivalence

Measuring the communicative efficiency between different visualizations or graphics requires that each graphic contain the same information content, in order to make a fair comparison. Larkin and Simon (1987), state that two graphics are informationally equivalent if all of the information encoded in one representation is also inferable from the other, and vice versa. This concept of *informational equivalence* refers to the quality of the content encoded within the graphic. Tversky et al. (2002) argue that animations illustrate the fine changes between scenes and are therefore not informationally equivalent to static graphics, which illustrate the coarse changes between scenes.

2.4.5 Computational Equivalence

Fair comparisons between different representations require the representations be computationally equivalent. According to Larkin and Simon, (1987), two graphics are said to be computationally equivalent if they are informationally equivalent *and* the information encoded in one representation can be easily and quickly inferred from the other representation, and vice versa. The quality of the inferences based on the design of the graphic should facilitate the opportunity for knowledge construction. Fabrikant et al. (2008) believe computational equivalence is a valuable concept to use for comparison studies of interactive and complex graphics. Fabrikant et al. (2008) found that participants do not view small-multiple maps in sequential order; they suggest future studies provide users with play, stop, and rewind buttons on the animation to maintain a computationally equivalent design.

2.4.6 Inference Affordance

Due to the similarity between computational equivalence and informational equivalence, Fabrikant et al. (2008) coined the term *inference affordance*. Inference affordance essentially combines computational and informational equivalence into one term. It can be used to describe both the amount of the content as well as the how design influences the quality of the inferences. Comparing two computationally and informationally equivalent representations would allow participants to make equally efficient inferences (Fabrikant et al., 2008).

2.5 Limitations of Cartographic Animation

2.5.1 Interactivity

Interactive displays afford readers the opportunity for data exploration in their own ways. Interactive graphics have been proven to facilitate learning, comprehension, and data exploration

(Harrower, 2007; Tversky et al., 2002) whereas non-interactive displays play at a constant rate and do not provide user control (Hegarty, 2004). Without interactive elements, the viewer must be able to remember and recall changes in earlier scenes and integrate them with changes from later scenes to make comparisons, which can overload working memory (Hegarty, 2004). While traditional animations only provide the user with play and stop features, the addition of other interactive controls afford the user greater control over the animated display and become more active in the learning process. Interactivity is not limited to animations; static small-multiple maps afford readers interactive capabilities as well. Fabrikant et al. (2008) believe small-multiples afford interactivity because readers can view the maps at their own pace, for any duration, and in any order.

Animated cartography has become a common method for portraying temporal data; however there are no clear guidelines as to the kind of functionality a visualization should have to support a users' needs. The basic functionality within a conventional animation is limited to the play and pause buttons. Sweller (1994) found that animations without interactivity may increase users' cognitive load and ultimately limit the amount and quality of information apprehended. In a study by Slocum et al. (2004) interviewing participants about the level of interactivity an animation should afford, found that participants preferred a non-interactive animation to look for overall trends and patterns, while the ability to control the animation was better when the map-task required the user to look at specific details. Testing has proved that users get frustrated with animated maps that they cannot control, which was also found to affect their accuracy (Harrower, 2003).

To provide users some control over an animation, Monmonier (1990) suggests adding an interactive temporal scrollbar to animations to allow the user to view the information at their own pace. Fabrikant et al. (2008) suggest designing an interface for small-multiples that allows users to rearrange the maps according to their map-task goals. In an evaluation of various kinds of interactive techniques by Ogao and Kraak (2002), found that the tools and controls of the animation interface should correspond directly to users' needs and in doing so, would provide for a wider range of queries and ultimately the discovery of new information.

2.5.2 Split Attention

Animations are often fleeting and transient by nature with multiple symbols and map elements simultaneously changing. With the dynamic features of animated maps presented in a layout similar to a static map, it is impossible for a reader to simultaneously direct their attention to all the elements at the same time. Harrower (2007) defined this limitation as the *split attention effect.* It occurs when a reader must attend to different elements in order to understand them, such as viewing a map and a legend (Harrower, 2007). If a reader is viewing the movement of a temporal legend, then they are missing the changes occurring during the animation because their attention was directed at the legend. Split attention is a weakness of animated maps, specifically with use of temporal legends and other dynamic elements (Harrower, 2007).

It is possible to limit the effects of split attention by employing different representational strategies. The biggest obstacle to overcoming spilt attention is to reduce the space or distance between the map elements. Mayer and Moreno (2002) suggest that whenever possible, items be integrated on a map. For example, labels might be placed on the map, eliminating the need for a legend. The less time the reader spends looking back and forth between items, the more time they can focus on the animation. Digital *brushing,* or linked views of the same data represented different ways also alleviates the cognitive load associated the split attention effect (Harrower, 2007).

2.6 Small-multiple Maps

Edward Tufte (1995) coined the term “small-multiples” to describe a series of small, static maps closely arranged next to each other used to illustrate change over time or multiple attributes over the same time. Small-multiples have their own type of interactivity in which users can view the maps in any sequence and at their own pace, something that most conventional animations do not allow. Small-multiples have inherent limitations, both for print and digital graphics. While they have been proven to facilitate learning, experiments using small-multiple displays have used a limited number of small maps. Many studies (Fabrikant et al., 2008; Griffin et al., 2006; and Slocum et al., 2004) that have investigated small-multiples used map sequences ranging from 6-20 maps. In an interview and focus group study by Slocum et al. (2004), participants claimed that viewing twenty small multiples simultaneously on the screen made it difficult to compare scenes due to their small sizes. From the same study, participants suggested using larger maps and incorporating a scroll bar into the design. For large datasets, Fabrikant et al. (2008) advocates using small multiples only to highlight or illustrate significant changes or scenes.

2.7 Temporal Resolution

Temporal resolution or temporal granularity is “the finest temporal unit resolvable ” (Harrower, 2009). Temporal granularity is the resolution used to illustrate the amount of change over time. The temporal resolution of an animated map could range from hours to days, or weeks; and it is this level of granularity that affects what map-readers see changing on the map (Harrower, 2009). The way changes are depicted is largely dependent on the temporal granularity. Harrower (2009) has discussed the potential of using temporal interpolation to create smooth animations by taking a coarse temporal resolution dataset and interpolating between the known timestamps.

Koussoulakou and Kraak (1992) argue that static maps cannot illustrate changes using a fine temporal resolution and therefore are not as effective as animations for displaying spatio-temporal data. This thesis aims to examine temporal resolution as used in animation and static small-multiples, by aggregating the data at two different resolutions.

2.8 Wildfire Visualization

Wildfires cost hundreds of lives, and billions of dollars in property damage and suppression efforts each year in the United States alone (McCormick & Ahrens, 1998). Yet current visualizations fail to help people understand the dynamics of a wildfire event. Wildfire is a dynamic, geographic phenomenon that is difficult to accurately and effectively portray cartographically. It presents perplexing issues to the cartographer as far as mapping its movement and creating realistic and intelligent visualizations. Using the outputs of fire prediction models or fire perimeter data we can simulate and visualize a wildfire progression using various cartographic techniques to help us understand and learn about fire behavior.

There has been considerable research done on the development of wildfire visualizations, prediction models, and tools attempting to accurately visualize fire (Ahrens et al., 1997; Black et al., 2007; McCormick & Ahrens, 1998). The research has primarily focused on developing realistic and immersive visualizations for training firefighters and for fire scientists to assess the quality of the simulations (Ahrens et al., 1997). Representations of wildfire events and other dynamic geographic processes are commonly captured in discrete temporal snapshots (Kim et al., 2006).

There are a variety of methods that can be used to map and illustrate the movement of fire. Fire perimeter or progression maps are most commonly found as a single, static representation of perimeters consisting of colored polygons layered over a shaded relief, topographic map or a satellite image. The perimeters are aggregated to illustrate the extent of the entire fire with each daily or hourly perimeter shaded a different hue. This type of design requires the map-reader to mentally picture each timestamp and visualize the progression in their mind.

The second type of representation utilizes animation to convey the movement of fire over time. Many interactive fire mapping software programs and tools such as BehavePlus, and FARSITE, were designed for fire specialists and fire officials to study wildfire behavior, fuels, and weather (Missoula Fire Sciences Laboratory, 2010). However, the specialized tools require the user to have advanced knowledge about wildfire in order to use them. Little research has focused on developing educational tools for novices to learn the basic principles of wildfire behavior. Based on these ideas the question remains as to whether an animated or static representation of wildfire would be more effective for novices to comprehend information about a wildfire event.

2.9 Summary

Advances in technology and the affordability of computers have made creating animated maps more popular than ever; however, their effectiveness remains uncertain. Tversky et al. (2002) suggest animation is better suited for illustrating continuous changes and to improve on conventional animations by allowing users to play, pause, stop, and select scenes. Fabrikant et al. (2008) suggest animations depict change with smooth transitions between scenes to reduce the possibility of users overlooking the changes and thereby reducing response time and increasing accuracy. Small-multiple maps appear to be a practical alternative to animated graphics by affording map-readers greater control over the pace, duration, and sequence of viewing the maps. However, when used with large datasets, their effectiveness remains unknown. This thesis aims to incorporate the principles and ideas discussed here to conduct a computationally and informationally equivalent comparison between map-readers' abilities to comprehend information from animated and static graphics.

Chapter 3.
METHODOLOGY

3.1 Overview and Goals

A human-subjects experiment was used to investigate and compare the influences of two design variables: map type and temporal resolution. The resulting stimuli included four unique maps each illustrating the same wildfire event. Task accuracy, response time, confidence, and user preference were measured to evaluate the conditional differences.

Map-readers viewed the four different maps and completed basic wildfire-related map tasks. The experiment design attempted to address some of the inconsistences Tversky et al. (2002) found in previous research comparing animated and static graphics by designing and adhering to the concept of informational equivalence.

3.2 Design Conditions

Animation may be the best way to visually represent large datasets, while small multiples may be better suited for small datasets. With large scientific datasets widely available, cartographers now have the ability to choose the level of temporal granularity to display when using time-series data. Animating a fine temporal resolution dataset such as the hourly progression of a hurricane over a week long period would generate a smooth animation. However, an informationally equivalent small-multiple map would require 168 scenes in the map sequence! For this experiment, each condition contained a small-multiple map and an animated map. One map type for each temporal resolution was used, to create a total of four different maps:

1. Fine temporal resolution animation
2. Coarse temporal resolution animation

3. Fine temporal resolution small-multiple map

4. Coarse temporal resolution small-multiple map

3.3 Map Data

Fire perimeter data from a fire model simulation output was used to create the animated and small-multiple maps used in the experiment. The following sections provide details about the fire perimeters and basemap data used to create the maps for the experiment.

3.3.1 Fire Perimeter Data

Wildfire perimeter data was used to illustrate a fire progression over time. Fire perimeters are the recorded or predicted geographic extent of a fire at a specific point in time. The perimeter data was modeled data obtained from the fire prediction model, HFire (Peterson, 2008). HFire is a raster-based model of surface fire spread that was used to predict and mimic the hourly progression of the 2003 Cedar Fire in southern California (Peterson et al., 2008). The model output data was in ASCII format, which was later transformed into vector for design enhancements and used in Adobe Illustrator. The perimeter data also contained the wind azimuths associated with each perimeter, which was used to create a wind direction arrow for each timestamp.

3.3.2 Basemap

A shaded relief basemap of southern California was used as the foundation to illustrate the fire progression across a mountainous landscape. The terrain layer was downloaded as part of the World Shaded Relief dataset created by ESRI (ESRI ArcGISOnline, 2009). The major roads were downloaded from the San Diego County Website (SanGIS, 2007) and overlaid on the shaded relief. Cities within the bounding rectangle and near the fire perimeter were selected randomly from the California geographic names dataset (Cal-Atlas, 2006) and labeled for incorporation into the test questions.

3.4 Map Design

The stimuli consisted of informationally equivalent maps. To make accurate and fair comparisons between the maps, they needed to contain the same information content and afford map-readers the ability to complete similar tasks. Each map illustrates the same identical wildfire event and differs only in the map type and temporal resolution. All the maps contained the same basic design and layout, including the same map scale and rotating wind arrow. The wildfire event shown in each map was depicted by illustrating the hourly progression of the changing fire perimeter. The two fine resolution maps illustrated the same 31 timestamps; while the coarse resolution maps each contained the same nine timestamps. These stimuli will each be described in detail in the following section.

3.5 Test Stimuli

3.5.1 Small-Multiple Map Stimuli

The small-multiple maps were designed by exporting the map data and fire perimeters from ArcMap 9.3 (ESRI Inc., 2008) into Adobe Illustrator CS4 (Adobe Systems Inc., 2008). The maps were resized and arranged into equally spaced rows and columns. Each map scene had screen dimensions of 12.0 x 8.5 centimeters. Each individual map contained a title above the map stating the day and time of the current perimeter. The time sequence read from left to right in each row of maps.

Coarse resolution small-multiple map

The coarse resolution small-multiple map sequence contained nine individual maps, each representing a timestamp 3-hours apart within a 31-hour timeframe. The entire small-multiple map layout measured 1152 x 830 pixels and filled the screen with nine individual maps arranged into three columns and three rows. Figure 1 illustrates the coarse resolution small multiple used in the experiment.

Fine Resolution Small-Multiple Map

The fine resolution map sequence contained 31 individual maps, each representing a 1-hour timestamp within a 31-hour progression of the same wildfire event. The maps were arranged into three columns and ten rows with one row containing one map. The individual maps were the same size as the maps used in the coarse resolution small-multiple map. Due to the large number of maps, not all 31 maps fit on the screen at the same time, therefore to accommodate digital display and allow subjects to clearly read the maps, the fine resolution small-multiple map display contained a scroll bar. The scroll bar allowed the subject to vertically scroll through the maps on the display and view nine maps on the screen at a time, exactly like the coarse resolution small-multiple map.

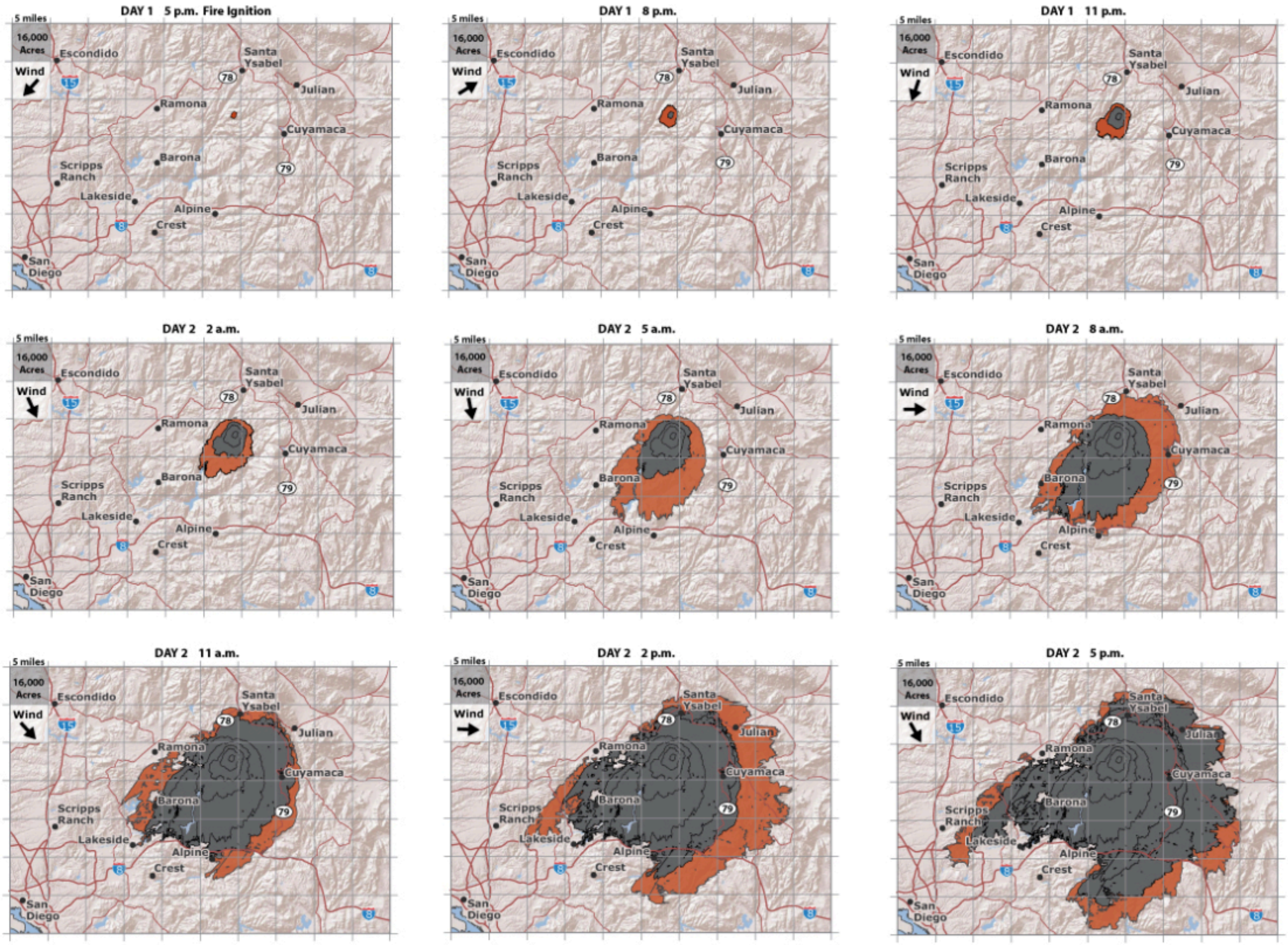


Figure 1. A screenshot of the coarse resolution small-multiple map used in the experiment.
For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

3.5.2 Animated Map Stimuli

The animated map stimuli presented the same information and utilized the same data as the small-multiple maps. The animations and small multiples were designed to be informationally equivalent in order to make fair comparisons between the different maps. The animations employed *motion tweening* to create smooth transitions between scenes. The motion tween was accomplished by varying the alpha value of the actively burning fire perimeter; the changing fire perimeters slowly appeared on the screen as the alpha value of the fire perimeter increased from 0% to 100% during scene transitions. After the polygon reached 100% alpha value the transition was complete and the previously orange perimeter turned grey while the alpha value of the new, current perimeter began to increase. The goal of the motion tweens was to create the illusion of the fire progressing over time as well as to mitigate the effects of change blindness by utilizing smooth and slow tweens as suggested by Fabrikant et al. (2008). The motion tweens did not add any additional information to the map because they did not show how the perimeter moved between known scenes. They presented the same timestamps as the small multiples, except the perimeters slowly and smoothly appeared on the screen.

The animated fire progression maps were created using Adobe Flash CS4. Both animated maps were set to a frame rate of 12fps and motion tweens spanned 24 frames. Each animation used the same interface design consisting of play and pause buttons as well as an interactive temporal legend that allowed the user to select and view the animation at specific timestamps. Figure 2 illustrates the animated map interface used in the experiment.

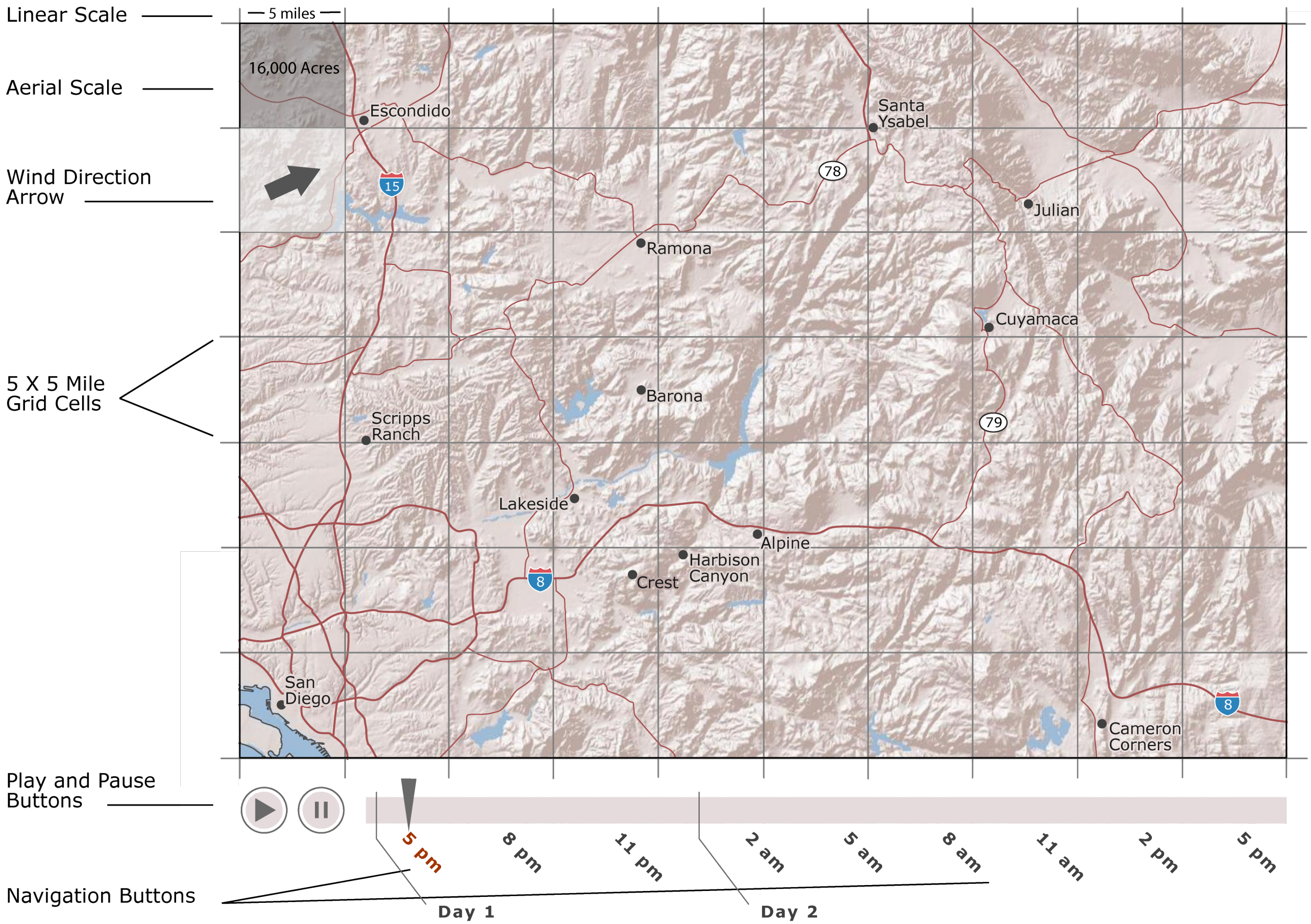


Figure 2. The animated map interface used in the experiment.

Coarse Resolution Animation

The coarse resolution animation consisted of an animated map illustrating the hourly progression of the same wildfire event over the same 31-hour period as the small-multiple stimuli. Similar to the coarse resolution small multiple, it depicted the progression in 3-hour increments, a coarser temporal resolution than illustrating the fire in hourly increments. Figure 3 shows a screenshot of the coarse resolution animation used in the experiment. The same timestamps were used in the coarse resolution animation as in the coarse resolution small-multiple map. The coarse resolution animation had a total play length of 18.8 seconds.

Fine Resolution Animation

The fine resolution animation consisted of an animated map illustrating the hourly progression of the wildfire event over a 31-hour period. The temporal resolution is considered fine resolution because the animation depicts each hour of the fire's progression over the entire 31-hour timeframe. Figure 4 provides a screenshot of the fine resolution animation used in the experiment. The fine temporal animation had a total play length of 64.5 seconds.

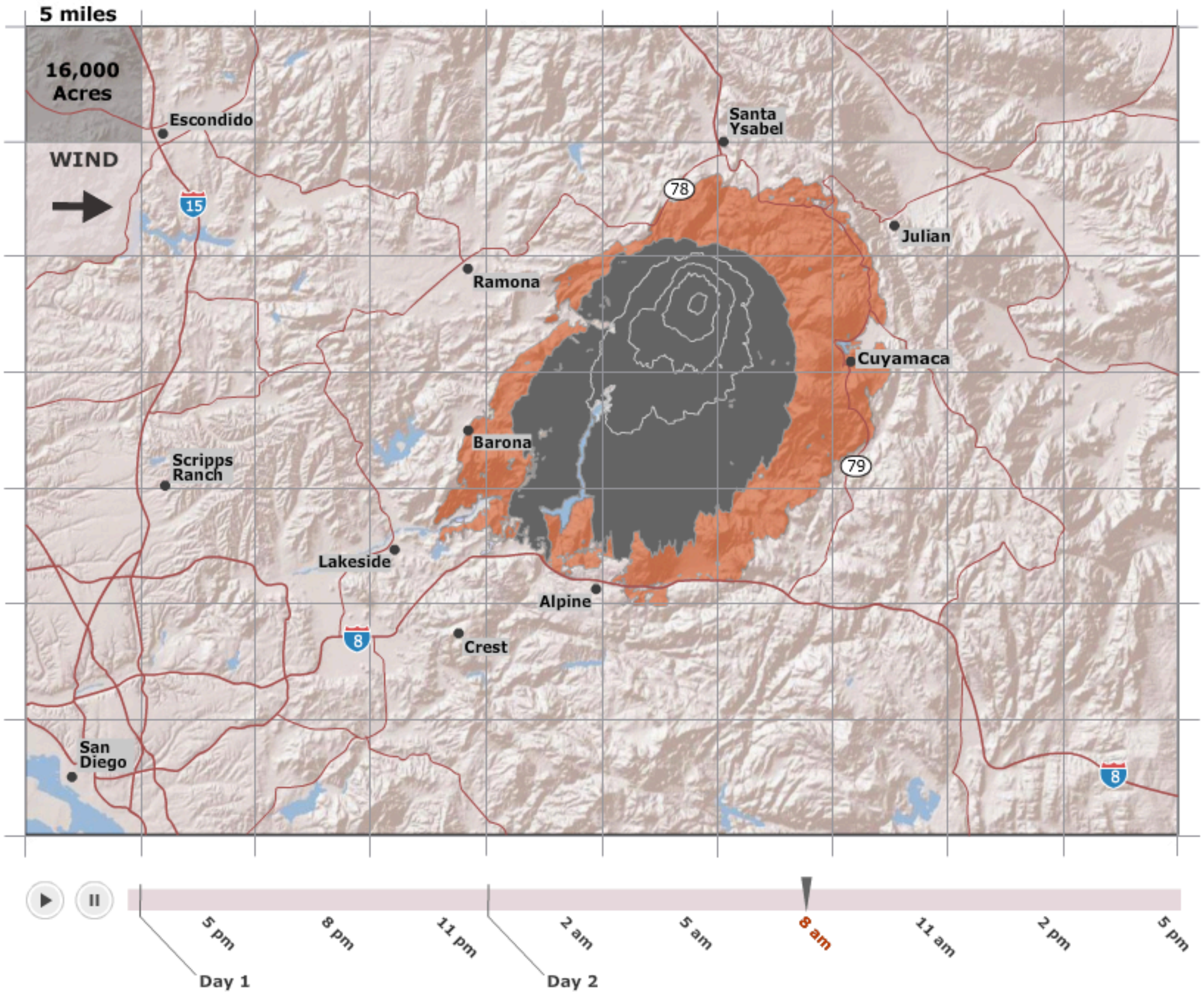


Figure 3. A screenshot of the coarse resolution animation used in the experiment

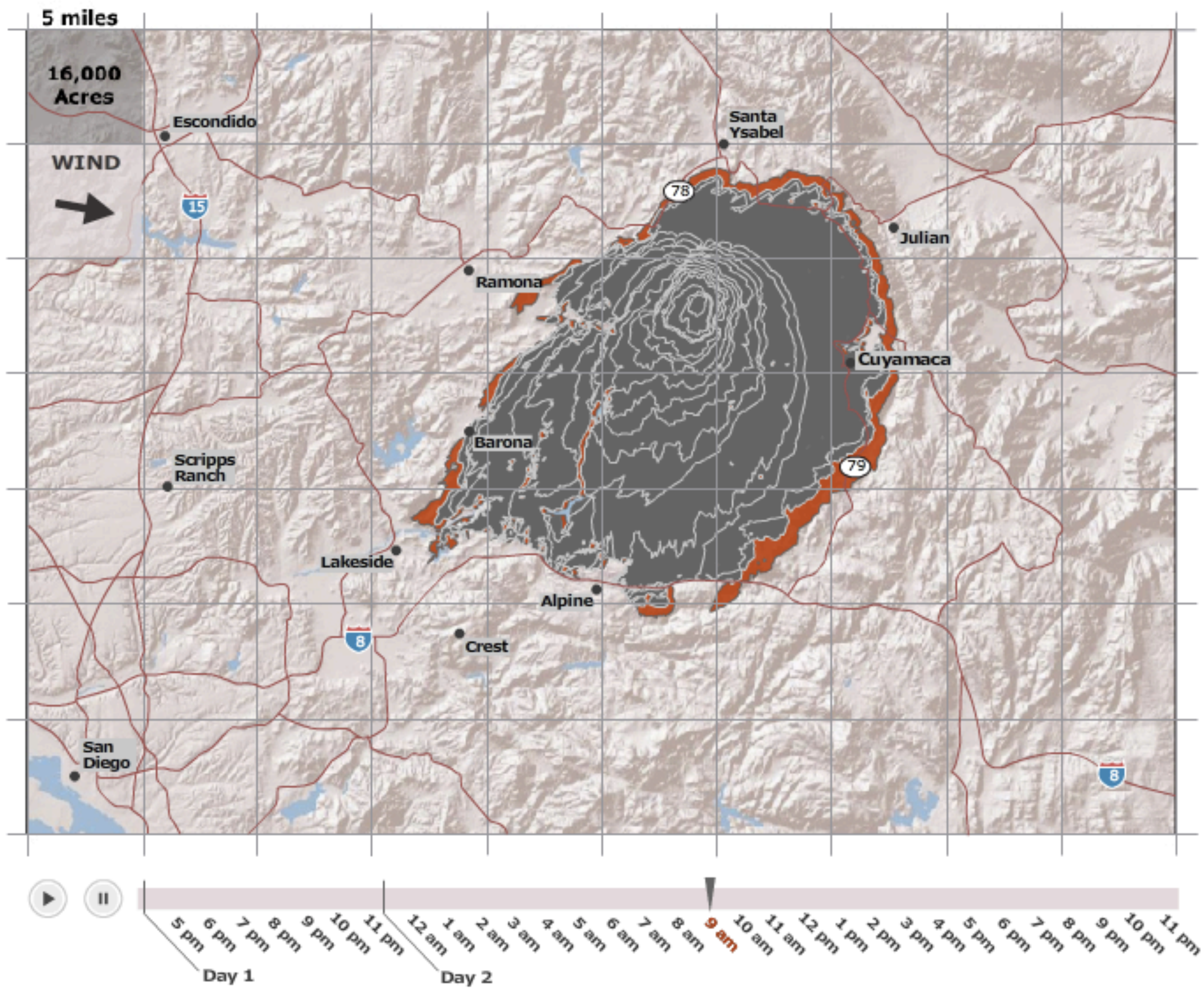


Figure 4. A screenshot of the fine resolution animation used in the experiment.

3.6 Testing Sequence

Testing four different map conditions required a varied testing sequence to eliminate the possibility of a training effect. A random number generator was used to produce two different versions of the test. Half of the participants viewed one map sequence, while the other half viewed the maps in a different order. Refer to Tables 15 and 16 in *Appendix A.* to view the testing sequences used.

3.7 Materials

3.7.1 Hardware

The experiment was conducted on Dell Dimension Desktop computers configured with 19" monitors and a screen resolution of 1280 x 1024 pixels. Each computer screen was placed 58 centimeters from the edge of the desk with the monitor set in the lowest position. Participants were allowed to adjust the screen placement to the most comfortable position for them to view the display. Each display was set to a brightness level of 100% and contrast level to 50%. Participants used both the keyboard and mouse to answer the questions.

3.7.2 Software

The test was designed and developed in Adobe Flash CS4 and Adobe Illustrator CS4. The experiment was administered via Adobe Flash on the Internet using *Mozilla Firefox version 3.6.13* (Mozilla Corporation, 2010). "Full screen" mode provided maximum size to show the graphic displays.

3.8 Experimental Design

The experiment was divided into three parts: A pre-test, map test, and a post-test. The pre-test gathered basic demographic information about the participants and provided background information about the test and maps. The majority of the experiment was the map test designed to measure participants' accuracy, response time, and confidence. The post-test collected information about participants' preferences and map-reading strategies. Refer to *Appendix B* for the experimental test.

3.8.1 Pre-test

The pre-test provided an overview of the experiment and collected background information about the participants. Explanations and examples of animated maps and small-multiple maps were provided as well as a short narrative about wildfire. Participants were informed about and the types of questions that would be presented, as well as instructions describing the animation interface controls and the map layout.

During the pre-test, each subject answered at total of eleven background questions. Participants were asked to indicate their gender, age, if they were a student, their class and major, previous use of various types of maps, and video game usage. Participants were also asked about their familiarity and use of small-multiple maps and animated maps. The goal of the pre-test was to gather general background information about the subjects participating in the experiment as well as introduce them to the test format.

3.8.2 Map Test

The map-test consisted of content questions and confidence questions. Each subject viewed each of the four map types 14 times and completed 14 map-task questions for each map, for a total of 56 content questions. After each question, subjects were asked to indicate how confident they were that their was correct.

3.8.3 Post-test

The post-test consisted of 10 questions: two yes/no, four multiple choice, and four open-ended. This part of the test was designed to collect information on the participants' preferences for each map type, their map-reading strategies, and their thoughts and comments about the test design.

3.9 Test Questions

Subjects were asked content questions about each map and confidence questions about each of their responses. Content questions required the participant to complete basic map tasks and examine the spatial relationships between the fire progression and features on the map for specific timestamps. Confidence questions asked participants how confident they were in their answer by selecting "confident" or "not confident."

Test questions were in either a yes/no or true/false format and were designed to challenge participants to read the maps at various scales by asking questions about polygon, point and line features, scale, and comparisons between scenes. Since each subject viewed each of the four maps 14 times, there were four versions of each content question to avoid the possibility of participants remembering the answers. The alternate versions of the questions were identical, except that they referred to a different location or time on the map. The goal was to mimic the kinds of questions and map tasks that readers would ask of a wildfire map.

3.10 Recruitment and Characteristics of Participants

Advertisements were posted at various locations around Michigan State University requesting map study participants and indicating they would be paid $10 (Refer to *Appendix C* for Advertisement). Fifty people voluntarily participated in the experiment. Twenty-five females and twenty-five males, ranging from 18 to 37 years old (mode: 21) participated. They represented 33 different majors and only four indicated they were Geography majors. All the participants indicated whether they were a freshman (8), sophomore (12), junior (6), senior (13), graduate student (8), or not in school (3).

3.11 Testing Procedure

Subjects completed the test in the Windows computer lab in the Geography Building at Michigan State University. They spent between 12 and 51 minutes (mean: 22 minutes) to complete the map test portion. Between 1 and 13 subjects participated at a time.

When participants arrived at the testing room, they were greeted and thanked for participating and were then assigned a computer. Participants were given a consent form, according to the Michigan State University Institutional Review Board (IRB) protocol, to read, date, and sign (see *Appendix D* for the consent form). After signing and returning the consent form to the researcher, they were told to begin the test and to follow the on-screen instructions. Participants were also asked to work quietly and independently and raise their hand if they had a question. All 50 participants completed the entire test and none asked questions.

Subjects first saw a screen that thanked them for agreeing to participate and instructed them to continue to the next screen. The second screen informed subjects that they would be viewing maps about a wildfire progression and that they were about to begin a pre-test.

After completing the pre-test, subjects were informed they were about to begin the test portion. Participants viewed a single map and question at the same time. One of the four maps displayed on the screen and a content question appeared below the map. Participants were asked to complete the map task and answer the question by clicking on one of the two answer choices. When the map and question appeared on the screen the timer immediately began recording the response time and stopped at the precise moment the participant clicked an answer button. Immediately after answering a question, they were instructed to indicate their confidence of their response. IRB protocol requires that participants be able to skip questions. Therefore a skip button was placed in the lower right corner of the display. Participants were able to skip both content and confidence questions; however, only one person skipped one question.

Immediately following the test, subjects were informed they had finished the test and would next complete a post-test section. The post-test consisted of preference and open-ended questions asking participants about their overall preference for each map type and temporal resolution. They were given multiple-choice questions about preferences and open-ended questions for subjects to describe their map-reading strategies and comments.

At the end of the post-test, subjects were instructed to go to the researcher to receive their $10 compensation. At this point, the participant was given a ten-dollar bill and asked to sign and date the second line on their consent form stating that they had received their payment. Lastly, the participant was thanked and left the testing room.

Chapter 4.
RESULTS AND ANALYSIS

This chapter summarizes the results of the experiment described in Chapter 3. Fifty participants each completed 56 content and confidence questions for the entire test. Map-readers' abilities and preferences were recorded and evaluated across all four design conditions. Task accuracy, response time and confidence were measured for each map type and temporal resolution. Table 1 summarizes the number of questions participants completed for each design condition. Participant demographics and preferences were recorded and included in analyses regarding gender differences and preference toward specific map designs.

Number of Questions by Condition			
	Fine Resolution	Coarse Resolution	Total Questions
Animation	14	14	28
Small-Multiples	14	14	28
Total Questions	28	28	56

Table 1. Total number of questions for each condition.

This chapter begins by summarizing participants' total, overall performance for each response variable: task accuracy, response time, and confidence. The second section examines participants' performance with each map type. The third section reports on the influence of temporal resolution. The fourth section reports on performance across each map type and temporal resolution. The fifth section summarizes map-readers preferences followed by a sixth section on the performance between genders.

4.1 Overall Performance

Table 2 summarizes participant's mean overall performance for task accuracy, response time and confidence for each of the four design conditions tested. Fine resolution small-multiples had the highest accuracy rate (90.9%) followed by the fine resolution animation. Response time was fastest for the coarse resolution small-multiples (average: 21.1 seconds). Fine resolution small multiples resulted in the highest percentage of confident responses (92.7%) while fine resolution animation followed close behind (92.6%).

	Fine Resolution Animation	Coarse Resolution Animation	Fine Resolution Small-multiples	Coarse Resolution Small-multiples
Accuracy (%)	86.1	74.7	90.9	79.9
Response Time (s)	26.6	25.6	22.6	21.1
Confidence (%)	92.6	75.7	92.7	79.9

Table 2. Participants' accuracy, response time, and confidence for each design condition.

4.1.1 Task Accuracy

Table 3 shows various measures of the overall task accuracy for the entire test. Out of the total 56 content questions, participants had a median score of 83.9% (47 out of 56 correct) which was also close to the mean score of 82.7% (46.3). The lowest score was 66.1% (37 out of 56) and the highest was 91.9% (51 out 56). Figure 5 shows the frequency of accurate responses.

Overall Task Accuracy		
Total Number of Questions	56	100%
Maximum	51	91.1
Minimum	37	66.1
Mean	46.3	82.7
Median	47	83.9
75th Percentile	49	87.5
25th Percentile	45	80.3
Standard Deviation	3.53	6.3

Table 3. Descriptive statistics of overall task accuracy.

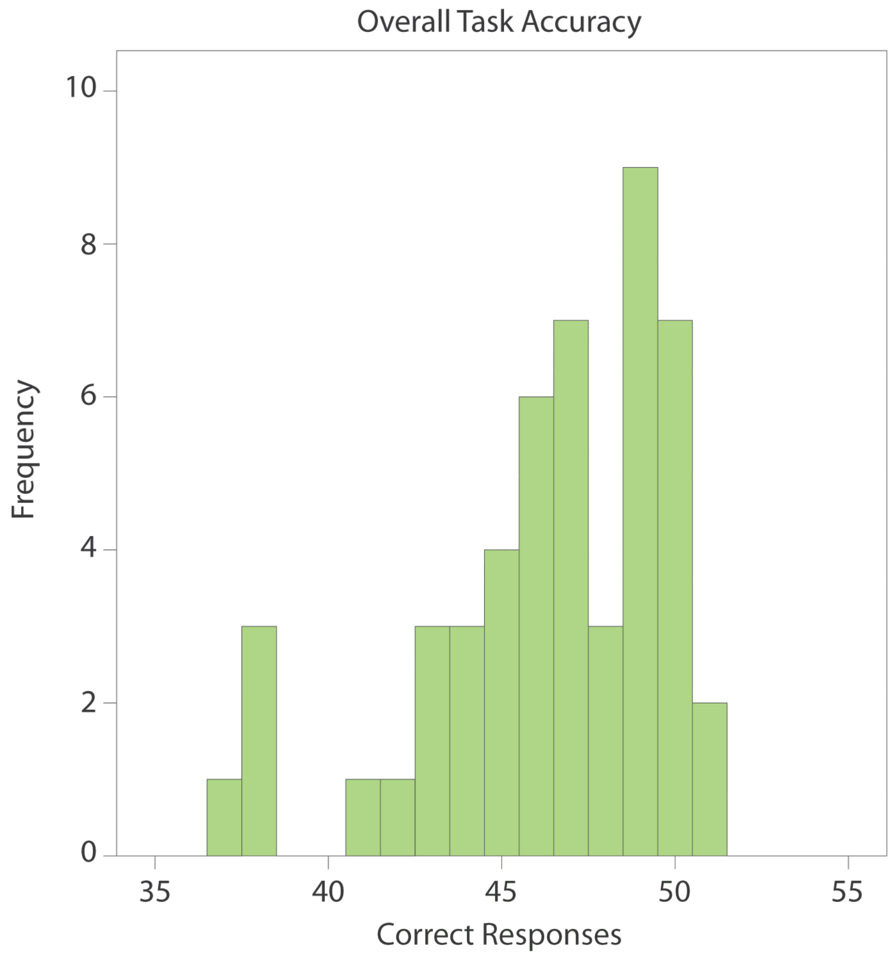


Figure 5. Histogram of overall task accuracy for the content questions.

4.1.2 Response Time

Participants' response time was recorded for each of the 56 content questions. Table 4 summarizes participants average response times for the map test and Figure 6 shows a frequency distribution of responses times. The median response time was 21.6 seconds, which was close to the mean response time of 22.9 seconds. The slowest time was 55.5 seconds (an outlier) and the fastest time was 12.7 seconds. Excluding two outliers at 43.1 and 55.5 seconds, the slowest mean response time was 39.1 seconds.

Overall Response Time (Seconds)	
Slowest	55.5
Fastest	12.7
Mean	22.9
Median	21.6
75th Percentile	27.3
25th Percentile	18.2
Standard Deviation	6.17

Table 4. Descriptive statistics of response times for content questions.

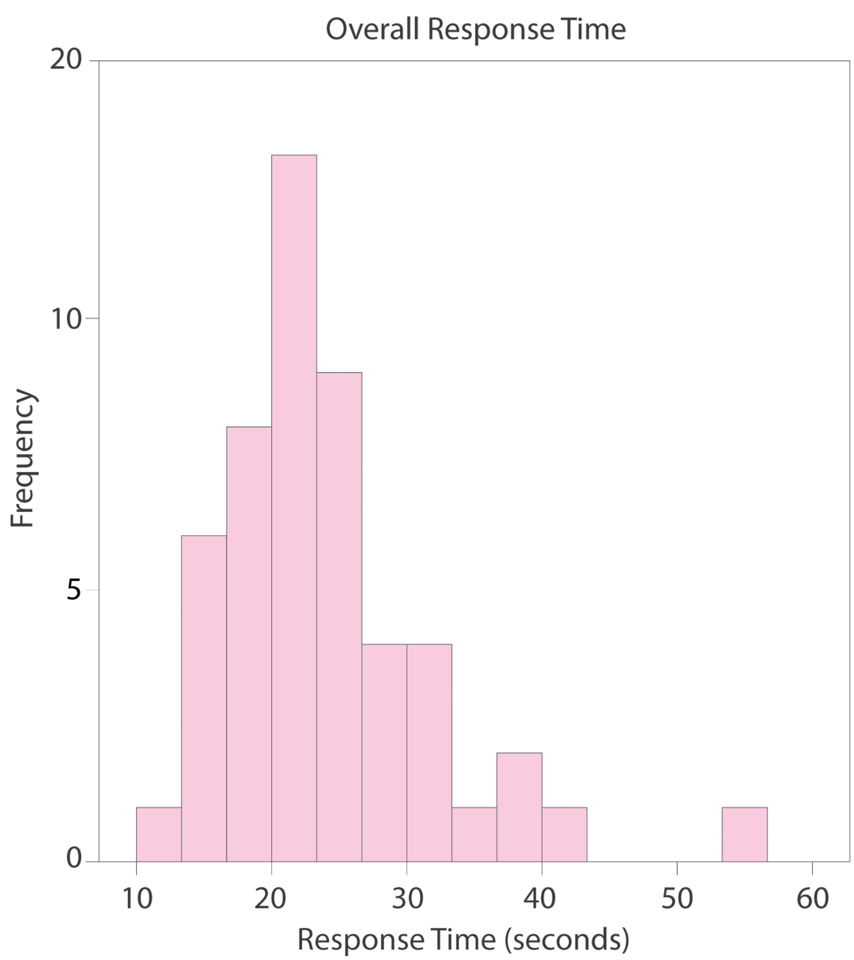


Figure 6. Histogram of response times for content questions.

4.1.3 Confidence

Table 5 summarizes the number of times participants indicated they were confident in their answer out of a total of 56 confidence questions. The median number of times participants chose the "confident" choice was 48 times (or 85.7% of the time) which was very close to the mean of 48.6 (86.8%). The minimum number of confident responses was 41 out of 56 possible (73.2%) excluding an outlier at zero (one person chose "not confident" every time). The maximum was 56 out of 56 possible responses; three participants chose the "confident" choice for every question). Figure 7 illustrates the frequency of confident responses.

Overall Confidence		
Total Number of Questions	56	100%
Maximum	56	100
Minimum	41	73.2
Mean	48.6	86.8
Median	48	85.7
75^{th} Percentile	51.8	92.5
25^{th} Percentile	46	82.1
Standard Deviation	3.90	6.9

Table 5. Descriptive statistics of confident responses.

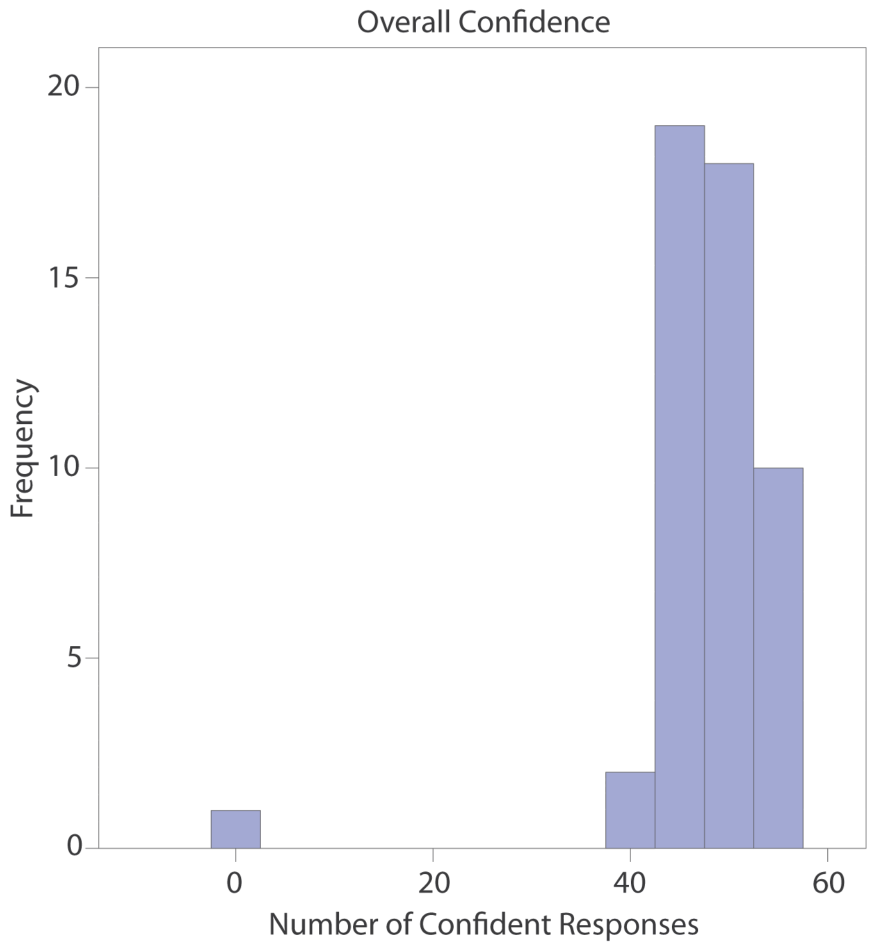


Figure 7. Histogram of participant's average number of confident responses.

4.2 Map Type

Table 6 summarizes participants' accuracy, response time and confidence for the two map types: small multiples and animation.

	Animated Condition	Small-Multiple Condition
Accuracy (%)	80.4	85.4
Response Time (s)	26.1	21.8
Confidence (%)	84.1	86.1

Table 6. Overall accuracy, response time, and confidence for each map type condition.

4.2.1 Accuracy

Overall, participants had a greater number of accurate responses for the small-multiple maps compared to the animated maps. Table 7 summarizes participants accuracy rate between the two map types. Participants correctly answered 1,126 questions out of a total of 1,400 questions about the animated maps (80.4% accuracy). Participants correctly answered 1,189 questions out of a total of 1,399 answered questions about the small-multiple maps (85.4% accuracy). While participants were asked an equal number of questions for each map type, the difference in the total number of questions is due to a participant who skipped one question in the small-multiple condition. The animated condition had an outlier at 60.7%, while the small-multiple condition had outliers of 70, 64.2 and 53.5%. Figure 8 summarizes percentage of correct responses for each map type.

A one-tailed paired *t*-test was conducted to compare participants' accuracy of their responses between the small-multiple map condition and animated map condition at the .05 significance level. There was a significant difference between the accuracy of the animated condition (M =0.854) and small-multiple condition (M =0.804); $t(49)$= 3.867, p<0.001, with a mean difference of 0.050.

	Animated Condition	Small-Multiple Condition
Number of responses	1,400	1,399
Number correct responses	1,126	1,193
Number of incorrect responses	274	206
Accuracy (%)	80.4	85.4

Table 7. Overall total accuracy for each map type tested.

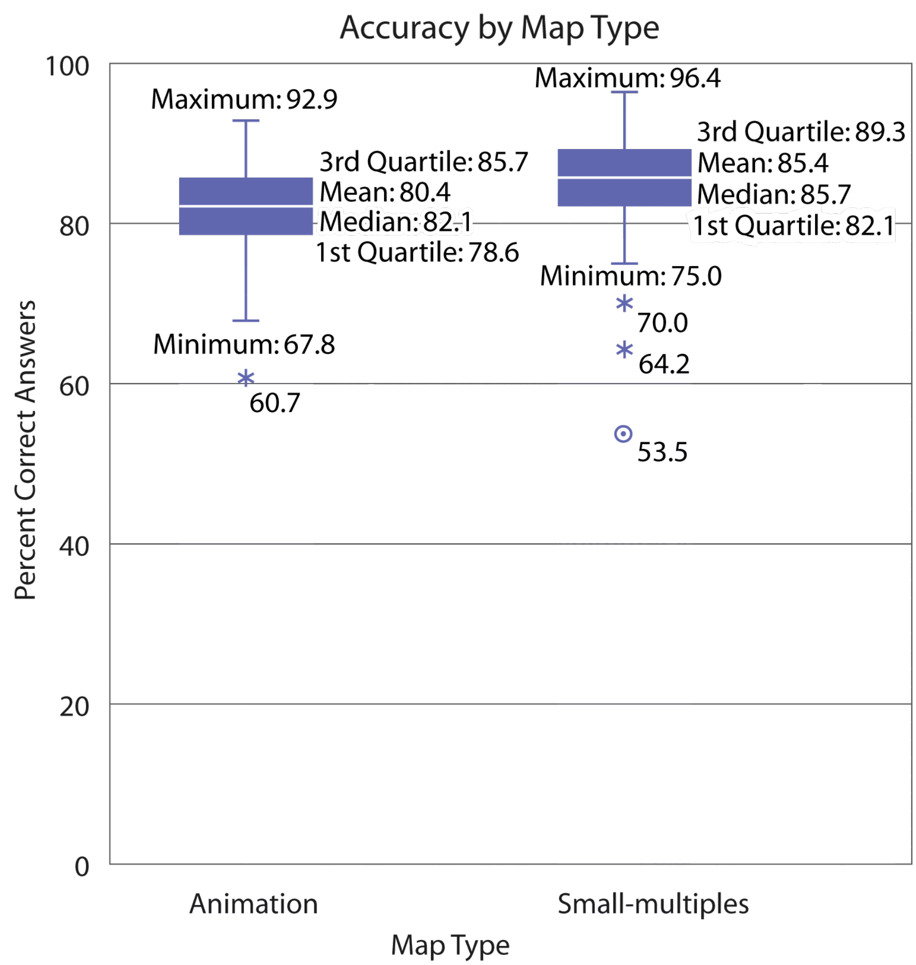


Figure 8. Box plots of accuracy rates for each map type.

4.2.2 Response Time

Participants registered faster response times with the small-multiple maps. On average, participants took 21.8 seconds to answer a question about a small-multiple map, whereas they took an average of 26.1 seconds to answer a question about an animated map. The animated condition had an outlier of 64.4 seconds, the slowest average time recorded. The small-multiple condition had outliers at 46, 42.2, and 35.3 seconds. Figure 9 illustrates the differences in response time between the two map types.

A one-tailed paired *t*-test was conducted to compare average response times between the small-multiple map condition and animated map condition at the .05 significance level. There was a significant difference between their average response times for the animated condition (*M* =26.1 seconds) and the small-multiple condition (*M* =21.8 seconds); $t(49) = -6.112$, $p<0.001$, with a mean difference of 4.3 seconds.

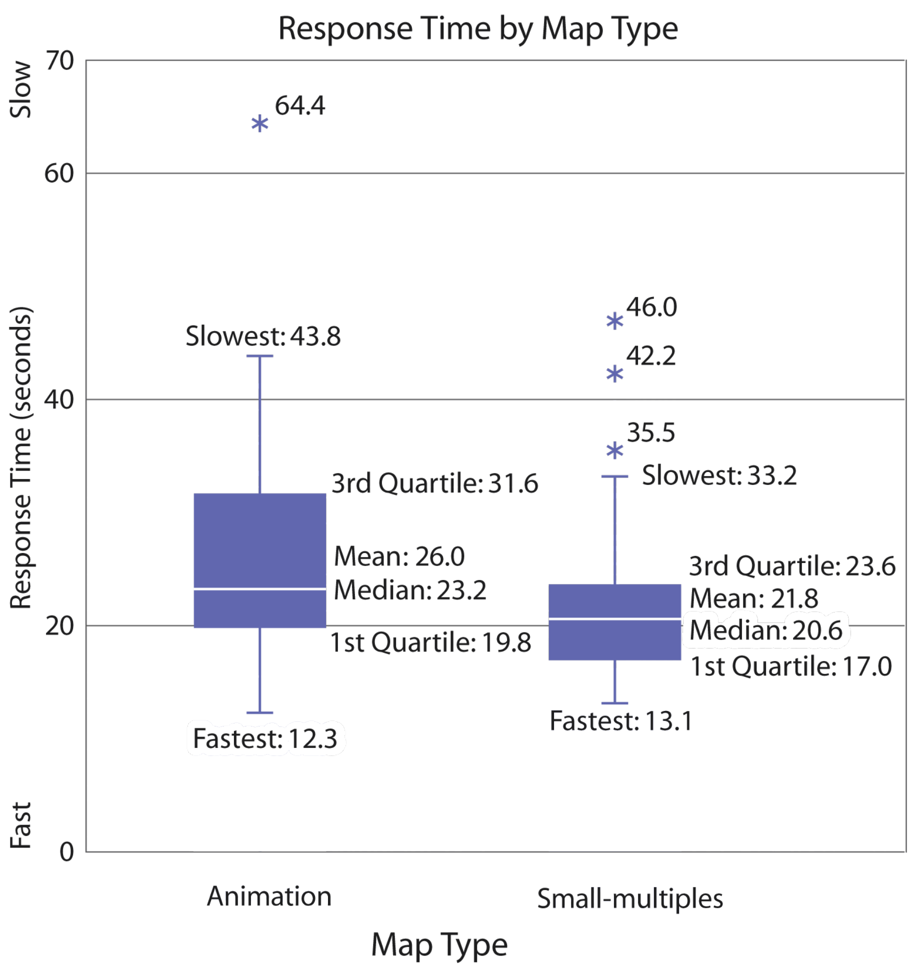


Figure 9. Box plots of response time for each map type.

4.2.3 Confidence

Participants indicated they were confident in their answers about the small-multiple maps more often than the animated maps. When participants correctly answered a question, they indicated they were confident in their answer over three-quarters of the time. Of the 1,189 correct answers for the small-multiple maps, participants indicated they were confident 1,068 times (89.8% of responses). Of the 1,126 questions participants answered correctly for the animated maps, they indicated they were confident 988 times (87.7% of responses). Table 8 summarizes participant's confidence ratings and the accuracy of their response.

Confidence and Accuracy	Animated Condition		Small-Multiple Condition	
Confident and correct	988	70.6%	1068	76.3%
Confident and incorrect	190	13.6%	135	9.6%
Not Confident and correct	138	9.8%	123	8.8%
Not Confident and incorrect	84	6.0%	71	5.1%

Table 8. Confidence rating and accuracy for each map type condition.

A one-tailed paired *t*-test was used to compare participant's confidence in their answers between the small-multiple map condition and animated map condition at the .05 significance level. There was not a significant difference between confidence ratings for the animated condition (M =0.841) and the small-multiple condition (M =0.861); $t(49)= 1.605$, $p=0.057$, with a mean difference of 0.020. Figure 10 illustrates the slight differences in participant's confidence ratings for each map type. Refer to Table 17 in *Appendix E.* for all *t*-test results comparing map types.

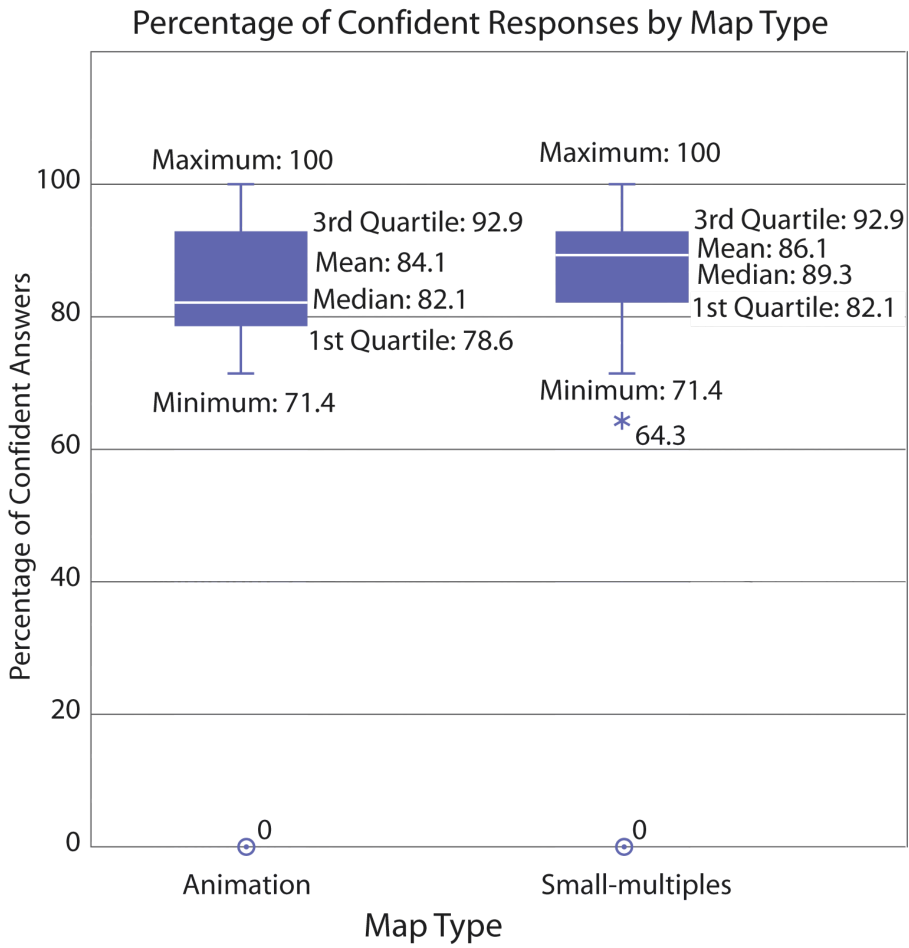


Figure 10. Box plots of the percentage of confident responses for each map type.

4.3 Temporal Resolution

Map reader abilities were evaluated for the two levels of temporal resolution used in the experiment: coarse and fine resolution. In this section, the temporal resolution is evaluated irrespective of map-type. Table 9 summarizes participant's accuracy, response time, and confidence for both levels of resolution.

	Fine Resolution	Coarse Resolution
Accuracy (%)	88.5	77.3
Response Time (s)	24.6	23.3
Confidence (%)	92.6	77.6

Table 9. Overall accuracy, response time, and confidence for each resolution condition.

4.3.1 Accuracy

Temporal resolution has a significant influence on task accuracy. Participants tended to achieve high task accuracy rates with the fine resolution maps. They correctly answered 1,239 questions out of a total of 1,400 answered questions for the fine resolution maps (88.5%). Participants correctly answered 1,080 questions out of a total of 1,399 answered questions for the coarse resolution maps (77.2%). Figure 11 illustrates the differences in participant's accuracy rates for each resolution condition.

A one-tailed paired *t*-test was used to compare participant's accuracy between the fine resolution condition and the coarse resolution condition at the .05 significance level. There was a significant difference between the fine resolution condition ($M = 0.885$) and the accuracy of the coarse resolution condition ($M = 0.773$); $t(49) = 8.765$, $p < 0.001$, with a mean difference of 0.112.

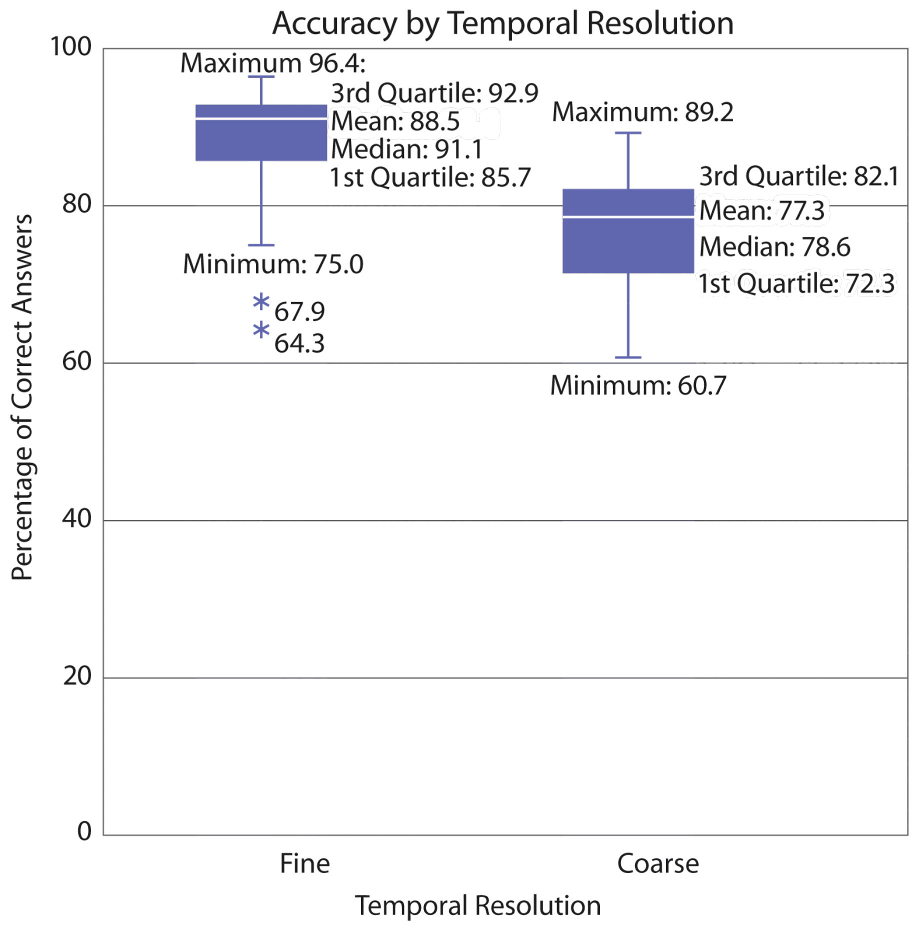


Figure 11. Box plots of accuracy rates for each temporal resolution.

4.3.2 Response Time

The resolution of the map displays did not significantly influence response time. Response times were only slightly faster with the coarse resolution maps. Figure 12 illustrates differences between average response times for each resolution condition. The median response times were similar with the fine resolution maps having a median time of 21.6 seconds and 21.4 seconds for the coarse resolution maps. Participants were able to complete a map task in less than 38.2 seconds (slowest) with the fine resolution maps, except that it took one person an average of 63.9 seconds to answer the questions (outlier). Participants were able to answer questions about the coarse resolution maps in less than 38.3 seconds (slowest) except for two people (outliers) with an average of 47.9 and 41.5 seconds.

A one-tailed paired *t*-test was used to compare participant's mean response times between the fine resolution condition and the coarse resolution condition at the .05 significance level. Response times were not significantly different between the fine resolution condition (M=24.6 seconds) and the coarse resolution condition (M=23.3 seconds); $t(49)$= 1.822, p=0.963, with a mean difference of 1.3 seconds.

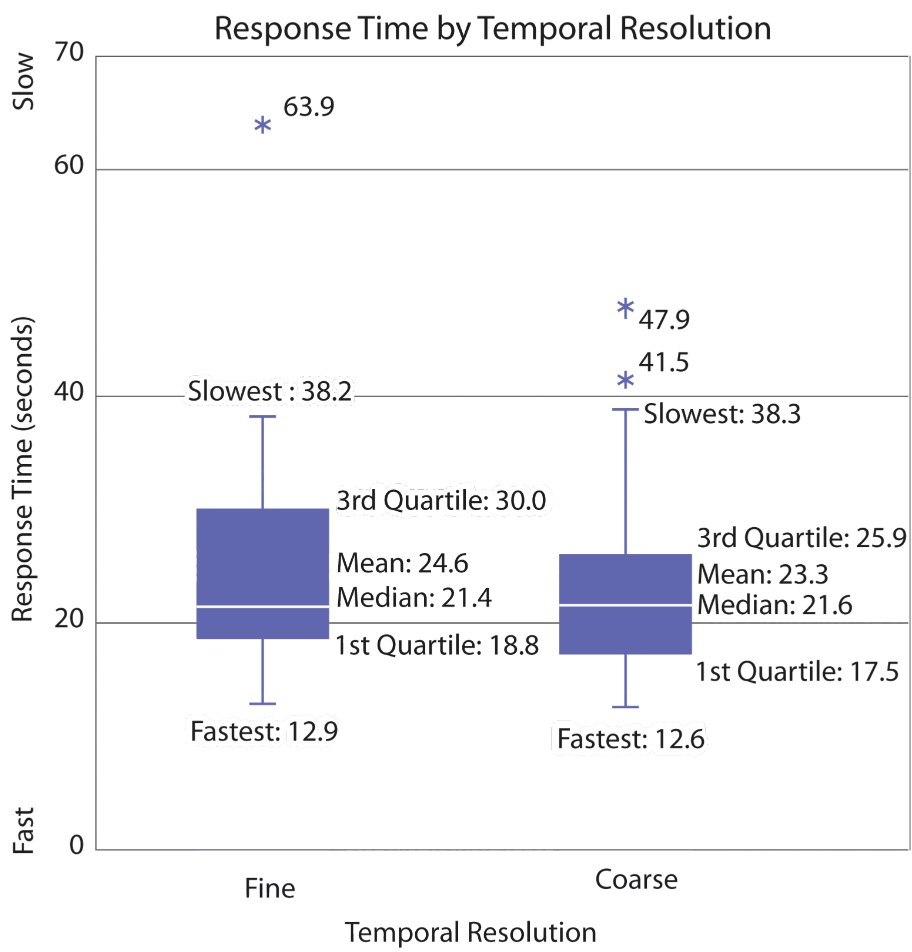


Figure 12. Box plots of response time for each temporal resolution.

4.3.3 Confidence

Participants were significantly more confident with their responses to the questions on fine resolution maps. Table 10 summarizes confidence ratings in relation to the accuracy of their responses out of total of 1,400 possible confident responses for each resolution condition. Out of the total 1,239 questions correctly answered about the fine resolution maps, they chose the correct answer *and* indicated they were confident in their answer 1,171 times (94.5%). Out of the total 1,080 questions participants answered correctly about the coarse resolution maps, they chose the correct answer *and* indicated they were confident in their answer 885 times (82.0%).

Confidence and Accuracy	Fine Resolution		Coarse Resolution	
Confident and correct	117	83.6%	885	63.2%
Confident and incorrect	126	9.0%	199	14.2%
Not Confident and correct	68	4.8%	193	13.8%
Not Confident and incorrect	35	2.5%	120	8.6%

Table 10. Confidence and accuracy rates out of a total 1,400 possible responses for each resolution condition.

A one-tailed paired *t*-test was used to evaluate participant's confidence ratings between the fine resolution and the coarse resolution conditions at the .05 significance level. Participants confidence ratings were significantly different between the fine resolution condition (M=0.926) and the coarse resolution condition (M=0.776); $t(49)$= 8.662, p<0.001, with a mean difference of 0.150. Figure 13 illustrates the difference in participant's confidence between the two resolution conditions. Refer to Table 18 in *Appendix E.* for all *t*-test results comparing the fine and coarse resolution maps.

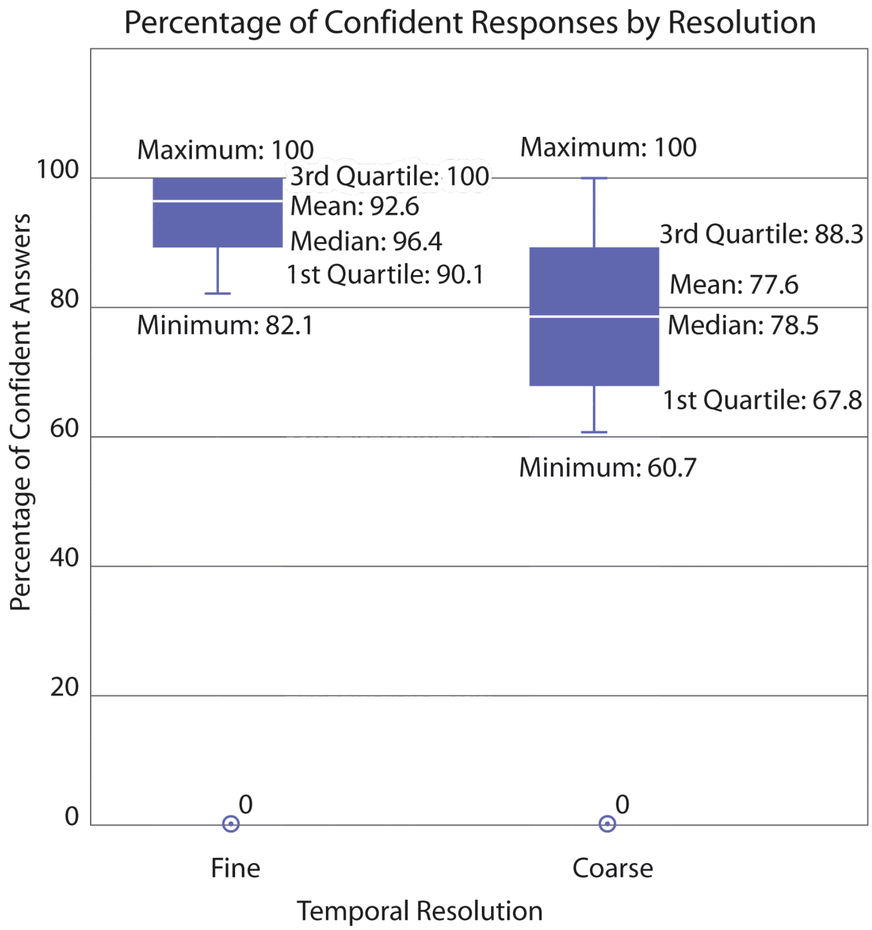


Figure 13. Box plots of confidence ratings for each temporal resolution.

4.4 Performance Across Map Types and Resolutions

4.4.1 Task Accuracy

Table 11 summarizes participants' performance for each design condition. The fine resolution small-multiple map yielded the highest accuracy rate with a mean of 90.7%, followed closely by the fine resolution animation with 86.4%.

	Animation				Small-Multiples			
	Fine Resolution		Coarse Resolution		Fine Resolution		Coarse Resolution	
Number of Questions	14	100%	14	100%	14	100%	14	100%
Maximum	14	100	12	85.7	14	100	13	92.8
Minimum	9	64.3	7	50	7	50	7	50
Mean	12.1	86.4	10.4	74.3	12.7	90.7	11.1	79.3
Median	12	85.7	11	78.5	13	92.8	11	78.5
75^{th} Percentile	13	92.8	11	78.5	14	100	12	85.7
25^{th} Percentile	11	78.5	10	71.4	12	85.7	10	71.4
Standard Deviation	1.07	7.6	1.11	7.9	1.55	11.1	1.48	10.5

Table 11. Descriptive statistics of participants' overall performance for each design condition.

The influence of both map type and temporal resolution significantly affect task accuracy. A one-way repeated measures ANOVA was used to compare the effect of map type on task accuracy across all four design conditions at the .05 significance level. The main effect of map type on accuracy was significant between conditions, $F(3, 147)=33.771$, $p<0.001$. A comparison of the main effect using the Bonferroni correction indicated significant differences between all four conditions. The significant results from the ANOVA are illustrated in Table 12 and Figure 14.

Task Accuracy Across Design Conditions

Design Condition (I)	Design Condition (J)	Mean Difference (I-J)	Standard Error	*p*-Value[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Fine Resolution Animation (FRA)	CRA	.115*	0.013	0.000	0.078	0.151
	CRSM	.062*	0.019	0.009	0.011	0.113
	FRSM	-.047*	0.015	0.020	-0.089	-0.005
Coarse Resolution Animation (CRA)	FRA	-.115*	0.013	0.000	-0.151	-0.078
	CRSM	-.053*	0.018	0.034	-0.103	-0.003
	FRSM	-.162*	0.018	0.000	-0.211	-0.113
Fine Resolution Small-Multiple (FRSM)	FRA	.047*	0.015	0.020	0.005	0.089
	CRA	.162*	0.018	0.000	0.113	0.211
	CRSM	.109*	0.020	0.000	0.055	0.163
Coarse Resolution Small-Multiple (CRSM)	FRA	-.062*	0.019	0.009	-0.113	-0.011
	CRA	.053*	0.018	0.034	0.003	0.103
	FRSM	-.109*	0.020	0.000	-0.163	-0.055

*. The mean difference is significant at the .05 level

a. Bonferroni adjustment

Table 12. Pairwise comparisons of accuracy across all design conditions.

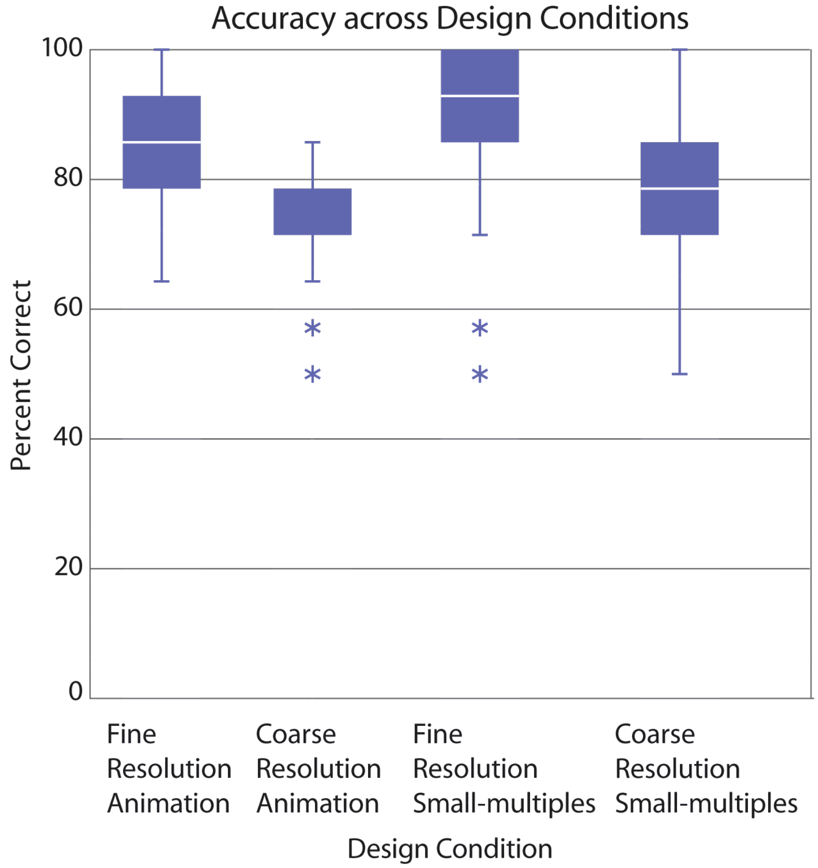


Figure 14. Box plots of accuracy across all four design conditions.

4.4.2 Response Time

Mean response time varied slightly across the four design conditions. The coarse resolution small-multiples had the fastest response time with an average 21.1 seconds per question. Figure 15 illustrates response times across all four conditions.

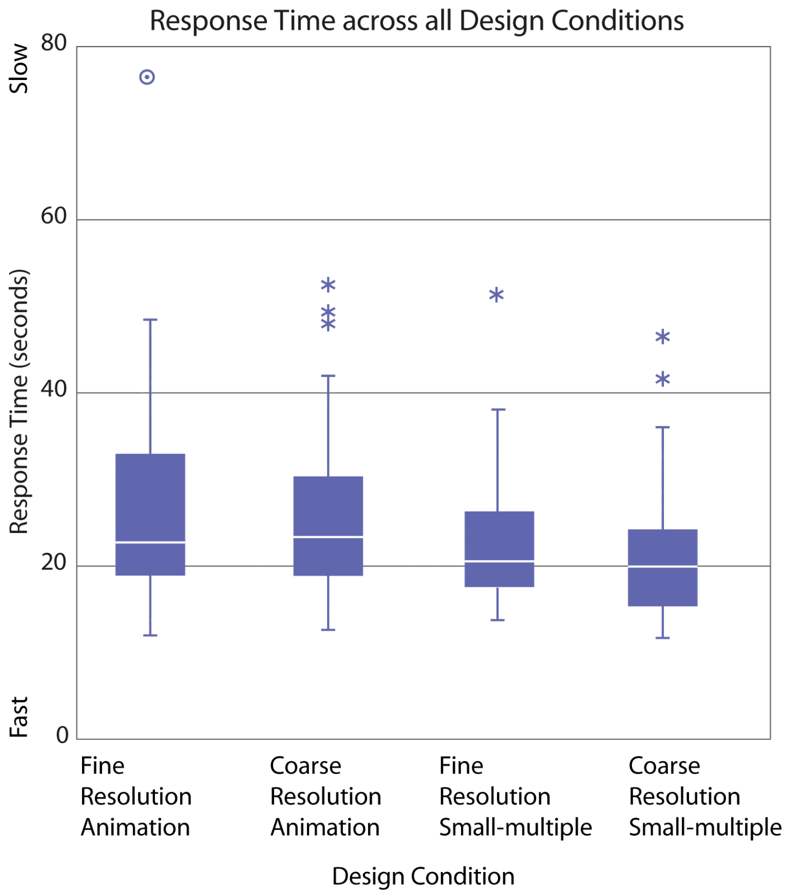


Figure 15. Box plots of response time across all four design conditions.

Map type significantly affects response time, while variations in temporal resolution do not significantly affect response time. A one-way repeated measures ANOVA was used to compare the effect of map type on response time across all four design conditions at the .05 significance level. The main effect of map type was significant across all four conditions, $F(3, 147)=15.414$, $p<0.001$. For comparisons of the main effect, a Bonferroni correction indicated significant differences between the map type conditions ($p<0.001$), but did not indicate significant differences between the resolution conditions ($p=1.000$). The response times between the fine resolution animation and the coarse resolution animation were not significantly different ($p=1.000$). The response times between the fine resolution small multiple and coarse resolution small multiple were not significantly different either (p=0.062). Table 13 summarizes the pairwise comparisons from the ANOVA.

Response Time Across Design Conditions

Design Condition (I)	Design Condition (J)	Mean Difference (I-J)	Standard Error	p-Value[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Fine Resolution Animation (FRA)	CRA	1.009	1.133	1.000	-2.106	4.124
	CRSM	5.520*	1.236	0.000	2.121	8.920
	FRSM	4.022*	1.126	0.005	0.927	7.118
Coarse Resolution Animation (CRA)	FRA	-1.009	1.133	1.000	-4.124	2.106
	CRSM	4.511*	0.600	0.000	2.862	6.161
	FRSM	3.013*	0.627	0.000	1.289	4.737
Fine Resolution Small-Multiple (FRSM)	FRA	-4.022*	1.126	0.005	-7.118	-0.927
	CRA	-3.013*	0.627	0.000	-4.737	-1.289
	CRSM	1.498	0.561	0.062	-0.045	3.042
Coarse Resolution Small-Multiple (CRSM)	FRA	-5.520*	1.236	0.000	-8.920	-2.121
	CRA	-4.511*	0.600	0.000	-6.161	-2.862
	FRSM	-1.498	0.561	0.062	-3.042	0.045

*. The mean difference is significant at the .05 level
a. Bonferroni adjustment

Table 13. Pairwise comparisons of response time across all design conditions.

4.4.3 Confidence

Participants indicated they were confident in their responses more often with fine resolution maps, compared to the coarse resolution maps. Figure 16 illustrates the percentage of confident answers across all four design conditions.

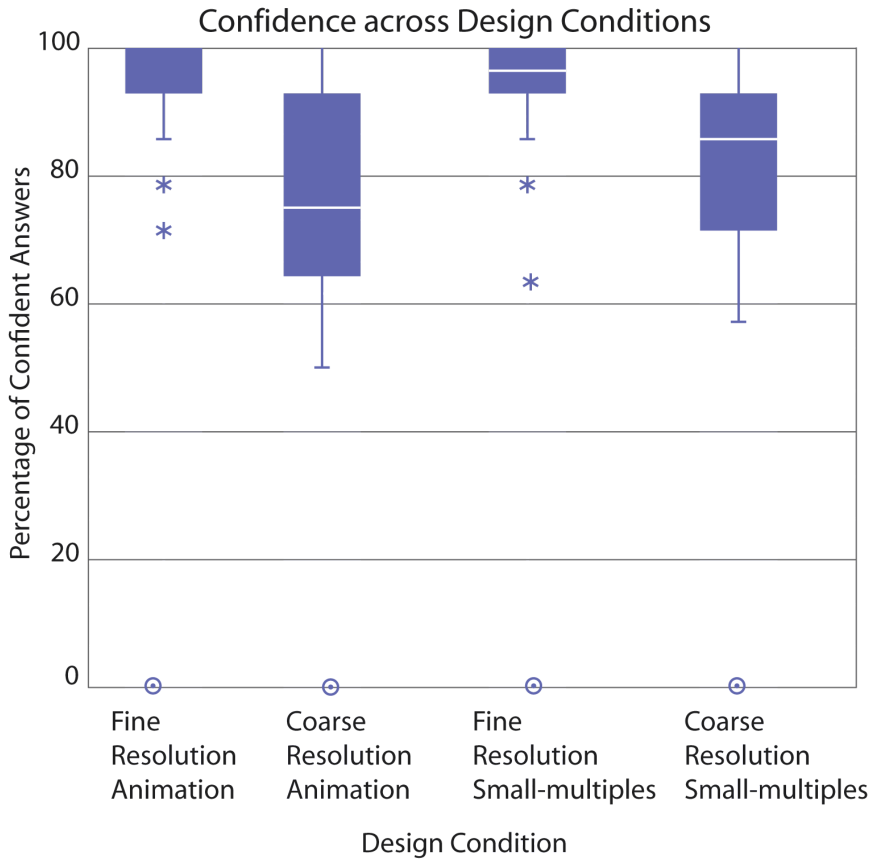


Figure 16. Box plots of the percentage of confident responses across all design conditions.

Variations in temporal resolution significantly affect confidence, while map type does not. A one-way repeated measures ANOVA was used to compare the effect of map type on confidence across all four design conditions at the .05 significance level. The main effect of map type was significant across all four conditions, $F(3, 147)=43.001$, $p<0.001$. For multiple comparisons of the main effect, a Bonferroni correction indicated significant differences between the animated and small-multiple conditions ($p<0.001$), but did not indicate significant differences between the fine resolution animation and fine resolution small-multiple conditions ($p=1.000$) or the coarse resolution animation and coarse resolution small-multiple conditions ($p=0.174$).

Confidence Across Design Conditions

Design Condition (I)	Design Condition (J)	Mean Difference (I-J)	Standard Error	*p*-Value[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Fine Resolution Animation (FRA)	CRA	.169*	0.020	0.000	0.113	0.224
	CRSM	.130*	0.021	0.000	0.071	0.189
	FRSM	-0.001	0.014	1.000	-0.039	0.036
Coarse Resolution Animation (CRA)	FRA	-.169*	0.020	0.000	-0.224	-0.113
	CRSM	-0.038	0.017	0.174	-0.086	0.009
	FRSM	-.170*	0.021	0.000	-0.228	-0.112
Coarse Resolution Small-Multiple (CRSM)	FRA	-.130*	0.021	0.000	-0.189	-0.071
	CRA	0.038	0.017	0.174	-0.009	0.086
	FRSM	-.132*	0.019	0.000	-0.184	-0.079
Fine Resolution Small-Multiple (FRSM)	FRA	0.001	0.014	1.000	-0.036	0.039
	CRA	.170*	0.021	0.000	0.112	0.228
	CRSM	.132*	0.019	0.000	0.079	0.184

*. The mean difference is significant at the .05 level

a. Bonferroni adjustment

Table 14. Pairwise comparisons of confidence across all design conditions

4.5 User Preference

At the end of the post-test participants were asked to indicate which maps they preferred. They were asked about their preferences between the small-multiple maps and animated maps and which of the four maps they preferred overall. Participants generally preferred animated maps to small multiples and preferred the fine resolution to the coarse resolution maps.

4.5.1 Animation

Participants were asked to indicate their preference between the two types of animated maps. Figure 17 illustrates the participant's preferences for the two animated maps tested. Over half of the participants (70%) preferred the fine resolution animated map. Fifteen (30%) participants preferred the coarse resolution animated map.

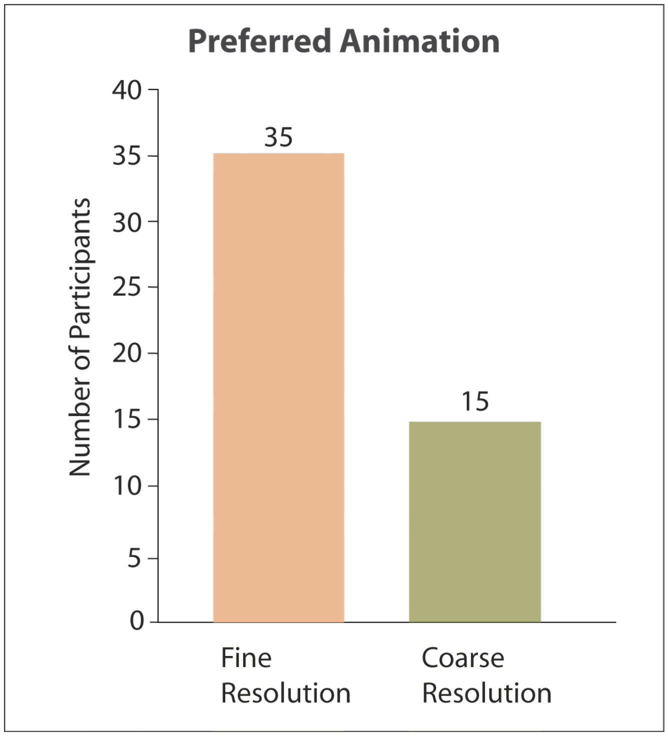


Figure 17. Bar chart of preference for the animated maps.

4.5.2 Small-multiples

Participants were asked to indicate their preference between the two types of small-multiple maps. Just over half of the participants (52%) preferred the fine resolution to the coarse resolution small-multiple map. Twenty-four participants (48%) preferred the coarse resolution small-multiple map.

4.5.3 Overall Map Preference

Participants were also asked to indicate their overall map preference among the four types presented in the test. Figure 18 illustrates participants overall preferences for the four maps tested. Over half of the participants (52%) preferred the fine resolution animated map to the other three maps. Out of the 50 subjects that participated, ten (20%) preferred the coarse resolution animation, while eight (16%) preferred the fine resolution small multiple, and six (12%) favored the coarse resolution small multiple.

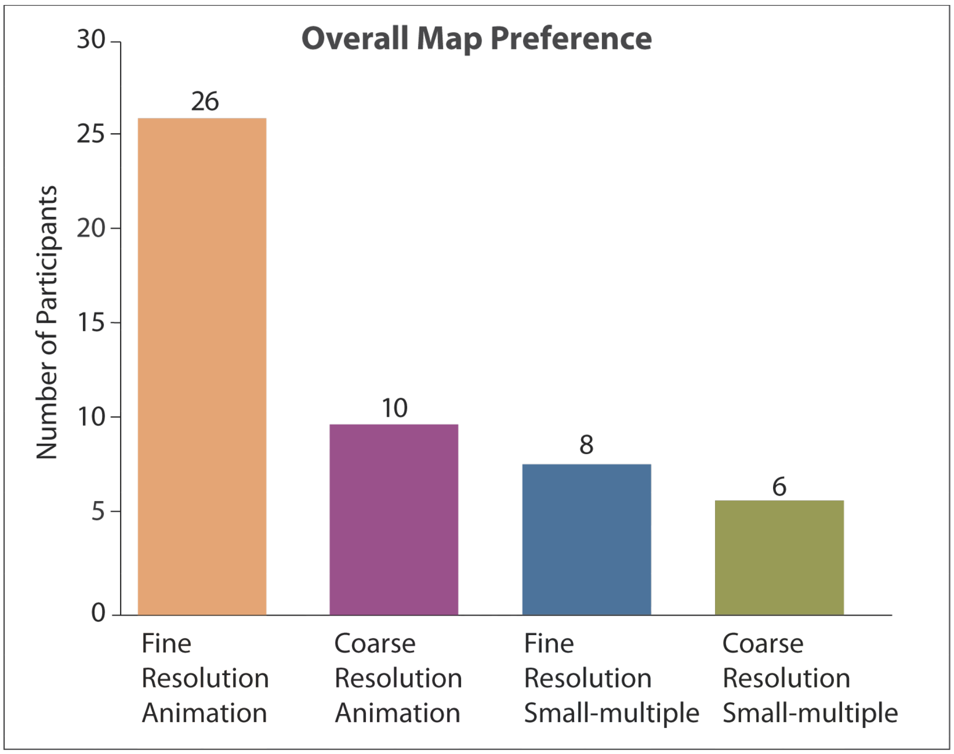


Figure 18. Bar chart of overall map preference.

4.6 Gender Differences

Overall accuracy, response time, and confidence were evaluated between genders. A two-sample *t*-test was used to evaluate differences between the performances of each gender at the .05 significance level.

4.6 1 Accuracy

Males had a higher accuracy rate compared to the females, however there was not a significant difference between their overall accuracy scores; $t(48)= 1.280$, $p=0.207$, with a mean difference of 0.022. The males had a mean accuracy of 84.0%, while the females had a mean accuracy of 81.8%.

4.6.2 Response Time

Females had a longer response time compared to the males, however there was not a significant difference between their overall response times; $t(48)= 1.540$, $p=0.130$, with a mean difference of 3.5 seconds. The males had a mean response time of 22.2 seconds per question while the females had a mean response time was 25.7 seconds per question.

4.6.3 Confidence

Males indicated they were confident in their answers more times overall compared to the females, however there was not a significant difference between their overall confidence ratings; $t(48)= 1.301$, $p=0.200$, with a mean difference of 0.037. On average, males indicated they were confident on 87.4% of their answers, while the females felt confident on 83.8% of their answers.

Chapter 5.
DISCUSSION

Overall, the results reveal that cartographic design decisions influence map-readers' abilities to apprehend information from displays illustrating the progression of a wildfire event. The main finding of this thesis is that both map type and temporal resolution are important factors affecting map reader performance. The results indicate that small-multiples elicit quicker response times than animations, and temporal resolution influences accuracy and confidence. This chapter discusses the implications of map type and temporal resolution in terms of task accuracy, response time, and confidence as well as explores participants' map preferences, the performance between genders, and experiment limitations.

5.1 Influence of Map Type

5.1.1 Task Accuracy

The results of the experiment indicate that map-readers are able to complete basic wildfire-related map tasks more accurately with small-multiple maps, which supports the first hypothesis. Participants may have been able to correctly answer more questions associated with the small-multiple maps because small multiples enable users to control the pace and duration in a way that conventional animations do not. Multiple participants noted the animated maps were distracting and moved too fast or too slow to answer the questions. Participants who felt the animation moved too fast might have became frustrated to the point that it affected their accuracy. One participant noted, "the animation required me to pause and rewind at certain times when I did not manage to catch the movement of the wildfire at that particular time as the timeline was moving too fast."

5.1.2 Response time

The response time results support hypothesis 2 in which small-multiples elicit faster response times. Participants completed wildfire-related map tasks significantly faster with small-multiple displays. There are multiple factors that may explain the significant differences in response time between the two map types. Response times may be longer and have a greater range of times with the animated maps because some participants indicated they played the entire animation through the first time and then skipped to the timestamps they needed to answer the question. The small-multiple map interface did not require users to learn any buttons or navigation features which might account for the shorter response times. Even conventional animation interfaces are not as intuitive as the "invisible" small-multiple interface. In the post-test, one participant stated, "the static nature made it easier to compare between times."

Split attention is one of the main limitations of animation and happens when multiple display events occur at the same time (Harrower, 2007). Some participants indicated they preferred the small-multiple maps because they could see all the changes at the same time. The longer response times for the animation could have been attributable to the split attention effect. Although in a study by Suchow and Alvarez (2011) examining the effects of moving objects that simultaneously change in hue, size, and shape, suggest that if viewers are directed to attend to a specific set of objects, it will discourage any shifts in attention. For a majority of the questions in the experiment, participants were asked about a specific location on the map for a certain timestamp. According to the motion-silencing concept from Suchow and Alvarez (2011), if participants were directed to focus on a specific time or location in question, they have the ability to silence the other moving objects. The concept of "silencing" could improve the effectiveness of animated map displays if the users are cued. In the absence of such cues such as with the map used in this study, the influence of split attention and change blindness could have resulted in the longer response times for the animations. However, for this study it would seem plausible for map-readers to have a slower response time with the animation because they needed to watch the progression at a predetermined speed, whereas on the small-multiple maps, they did not have to wait for the fire perimeters to appear on the screen.

5.1.3 Confidence

There was not a significant difference between participants' confidence levels between the animation and small-multiple condition. This finding does not support hypothesis three, and instead supports the null hypothesis because there is no difference between participants' confidence ratings between map types. In the post-test some participants noted that the small-multiples were easier to follow and they could double-check their answers with less effort. One person noted that, "With the small multiples I was better able to gauge the progress with a concrete grasp of time." While small-multiples had a higher accuracy rate, it seems they would also elicit significantly higher confidence ratings. However, the results indicate that map type does not influence confidence.

5.2 Influence of Temporal Resolution

5.2.1 Task Accuracy

There were significant differences between the fine resolution and the coarse resolution conditions; participants scored significantly higher with the finer temporal resolution maps. Since the fine resolution maps displayed more timestamps, more information was present on the map, which may be why participants scored higher. When participants were not provided with all the information they had to interpolate between the missing timestamps, which may have affected their accuracy. One participant noted that, “it was easier to answer the questions when all the information was presented on the map, compared to the coarse resolution where important scenes were missing.” With the fine resolution maps having over three times the amount of geographic information, it demonstrates that the more information available to help answer the question increases accuracy.

5.2.2 Response time

Participants’ average response times were slightly shorter with the coarse resolution maps compared to the fine resolution maps, however there was not a significant difference. Since some of the questions associated with the coarse resolution maps required participants to interpolate between known scenes, it could have influenced their response time. One participant noted that, “it was difficult to accurately determine the answer when the time needed to answer the question was not on the map, so I just guessed or did not spend as much time trying to figure out the right answer.” On the other hand, others liked the coarse resolution maps because they were not overwhelmed with as much information.

Participants may have taken longer to answer questions about the fine resolution maps because of the level of detailed information available. For example the legend on the fine resolution animation consisted of 31 timestamps listed in a row, which might make it more difficult in terms of time, to find and select a desired timestamp, compared to the coarse resolution animation where there were only nine timestamps to search through. Results suggest that the level of temporal resolution displayed on a map, has little cost in terms of response time.

5.2.3 Confidence

Resolution also significantly affects readers' confidence levels. This finding implies that, in terms of confidence and temporal resolution, the more participants had to mentally interpolate between scenes the less confident they were. One participant noted that, "with the nine scene maps I often felt I was missing the data required to answer the questions properly, leading me to a lack of confidence in my answers about those questions." Another stated that, "If I had to extrapolate information between missing scenes, I felt less confident in my answer." Generally, if participants felt confident in their answer, they were also correct.

5.3 Overall User Preferences

Overall, despite decreased accuracy and slower response times, participants expressed significant preferences for animation. The results of user preferences support hypotheses 4 and 8, in which readers preferred animated maps and fine temporal resolution maps. While the findings about performance support the fact that participants comprehend information more accurately from small-multiple maps, interestingly it conflicts with their overall map preference. They answered more questions correctly and confidently with the small-multiple maps, yet curiously they still favored the animations overall. While the fine resolution animation was the most popular, it is interesting to note that the coarse resolution animation was still preferred over both of the small-multiple maps. If preference is not tied to accuracy or confidence, why do people prefer animation to small-multiples?

At the end of the experiment, participants were asked to indicate their preference for each map and why they preferred one type to the other. Participants who preferred the animations wrote, "*seeing* the changes was more intuitive and easier to process" and "the animated maps provided a more fluid motion of the progression." Many indicated the animation was easier to understand because the progression of the fire was explicitly symbolized. Another wrote, "the movement and direction of the fire was more obvious with the animation." It appears that participants preferred the animation partly because it congruently visualized the dynamic phenomenon.

Not all preferred the animations; some favored small multiples. The subset of preferences between the two small-multiple maps was split down the middle, between those who favored the fine and coarse resolution small-multiples. The slight difference may be attributable to the design constraints of displaying 31 small maps on the screen. To accommodate the constraints of the visual display, the 31-scene small-multiple map displayed nine maps at a time and required participants to scroll through the map series in order to view all of the maps. Some participants indicated that having to scroll through the maps was "annoying" while others felt the coarse resolution small-multiple maps were "easier to keep up with", "easier to process with less information" and that they could take their time looking at everything at once. One participant felt that the fine resolution small-multiples had "too much information overall, especially when the amount of change was very small." It appears that participants prefer to view all the information at one time and that it is easier to make comparisons when more scenes are displayed. This finding implies that small multiples may only be useful or popular until a certain point and beyond that they are overwhelming or provide unnecessary detail. In contrast, animation can support fine resolution data or a large number of scenes. Map-readers have less difficulty sifting through the information in a fine resolution animation when they have the ability to view only the necessary scenes, unlike small multiples where too much information becomes "annoying."

Campbell and Egbert (1990) discussed the novelty and usefulness of animation and concluded that animated maps are something new and different and can evoke a certain amount of enthusiasm. Viewing dynamic events in an interactive and animated environment may contain a certain amount of newness and therefore make them more preferable over static representations. Goodchild (1988) stated, "The primary motivation in new technology is often novelty" (p. 317). In this digital era with interactive mapping applications, such as Google Maps or Google Earth, users are accustomed to navigating displays and clicking buttons to find more information. Thrower (1959) believed that audiences accustomed to animations from movies and television would find static representations of the same phenomena less than satisfactory. Although, 53-years old, Thrower's belief may still help explain the difference in overall preference; one participant noted, "although the small multiples were easier to read, there were too many and it was boring."

5.4 Gender Differences

A significant difference between genders and their map-reading abilities was not an expected finding or a goal of this study, however it was briefly investigated. While males were slightly more accurate, confident, and had faster response times, there were no significant differences between gender performances.

The most notable, yet not statistically significant difference, between genders was response time. Males were generally able to respond quicker than the females. Woodard and Gridina (2000) found that twice as many males play video games than females, while Green and Bavelier (2007) concluded that people who regularly play video games have improved visual abilities and attention. In the experiment, 17 out of 20 gamers were male which can partly explain the difference in response time between males and females in this study.

5.5 Limitations

The maps used in this study were designed to be computationally and informationally equivalent in terms of their information content and interactivity, however there were limitations to each design.

5.5.1 Map Design

The map design included two significant limitations that could be easily overcome in future studies: color scheme and map orientation. An intuitive color scheme was chosen to depict actively burning fire perimeters from previously burnt areas using orange and gray, respectively. Some participants' indicated that they were confused between the different colors used for the fire perimeters and that it took them multiple questions until they realized what the colors represented. The solution to this limitation could be to provide a preview of a similar fire map in the pre-test or an explanation or legend describing what each color represented.

The second potential limitation to the design of both map types was use of the wind arrow and questions asking about direction. Two participants indicated they were "unsure whether north was up" on each map. The perpendicular scale bars/grid on the maps was not a sufficient cue to indicate north. Future experiments should include a north arrow, or explain the map orientation at the beginning of the test.

5.5.2 Interactivity

One of the disadvantages of small-multiples uncovered from this research was that their usability declines as the number of temporal snapshots increase. While the coarse resolution small-multiple map fit on the display, the fine resolution map required a scroll bar. This design element frustrated many participants due to the scrolling design. More research is needed to identify limitations in small-multiple map design with large datasets.

To provide a more interactive experience for readers of fine resolution small-multiple maps, other designs should be considered. For example, a majority of participants indicated that they skipped to specific timestamps to answer certain questions. The fine resolution map could be designed with a search box that allows readers to type in the timestamp needed and the display would jump to the correct instance, similar to the way large PDF documents are accessed. Another technique could include a single large map as the main display element and a sidebar showing small maps. Even though participant responses were more accurate and faster with the small-multiple maps, it is worth investigating other design representation strategies for fine resolution data to determine if a different and simpler design influences map preference.

The interface used for the animated maps was designed to be simple and afford readers similar interactive opportunities as the small-multiple maps, however limitations in the interface design may have affected participants accuracy and response times. Some participants indicated the addition of a forward and backward button would have been helpful. The temporal legend bar only permitted participants to select a timestamp button as opposed to dragging a slider bar to brush across the legend. The discrete buttons were chosen over the continuous slide bar to congruently match the data since data was available only for specific timestamps. Had the perimeter data been interpolated to generate the progression between the main scenes, a slider bar might have been more appropriate. Because most applications with temporal legends allow users to scroll across the legend, participants may be accustomed to that design and expect the same opportunity on the animated maps. Multiple participants noted the animation speed was too quick. A sliding temporal legend bar would give participants more control over the animation pace because the speed would be dependent on how fast or slow the user moved the legend bar. Another option to accommodate different animation speeds would be to provide an option to choose a speed, such as 'fast' or 'slow'.

5.5.3 Novice/Expert Paradigm

The accuracy of the results could have been influenced by the supplemental knowledge of the people who participated in the experiment. Participants may have had a more difficult time reading the maps overall due to their lack of familiarity with the subject. Due to their limited exposure to wildfire events and maps in the mid-Michigan area, they are unversed in wildfire warnings and precautions (only four people indicated that they had lived in an area where wildfires occur). To alleviate this potential limitation, other natural, dynamic processes that occur within the research study area could be used, such as in Michigan, tornadoes or a thunderstorm movement could be depicted. Alternatively, recruiting wildfire experts may influence the results, specifically in terms of accuracy. Furthermore, providing a training session for the novices that included examples of fire maps, and an explanation of fire behavior and common terms could improve accuracy rates and possibly confidence.

5.5.4 Question Limitations

The types of questions asked or the way they were phrased could be improved for future tests. Questions about the speed of fire, such as " Did the fire spread faster at 4am that 2am on day two?" could be clarified in either a training session before the test or stated, "the fire is moving very quickly at 4am compared to 2am." Because the animations played at the same speed, it was important that the readers did not look for differences in the actual speed of the animation, but used the size of the fire polygons to determine and compare between timestamps.

There may be certain questions that favored each type of map. Depending on the question the answer may be more visible on one map more than the other. This study briefly investigated participants' performance with certain types of map tasks by asking questions related to point and line features, direction, and comparisons between scenes. In terms of task accuracy, response time, and confidence, participants had higher accuracy rates, responded quicker, and were more confident overall with the small-multiple maps on answering questions about point and line features and comparing between scenes.

Detailed questions about specific locations may be more difficult to answer with small multiples due to their small size; furthermore, screen resolution, brightness, and map dimensions could have also effected how clearly readers' viewed the maps. Changes in size, such as graduated circles or polygons may be more evident with animation, specifically if the magnitude of change is large. The issues discussed here require future research to fully understand which type of map enhances the visual variables more effectively and accurately.

Chapter 6.
CONCLUSION

This thesis revealed that design and temporal resolution are important elements; they have a huge influence on task accuracy, response time, confidence, and preference. Map type significantly affects accuracy and response time, but not confidence. The level of temporal resolution significantly affects accuracy and confidence, but not at a cost to response time. In terms of user preferences, the findings presented in this thesis raise an important question: Why do users like animated maps more than small-multiple maps, despite significantly worse performance and confidence? Further research is needed to investigate the design variables and cognitive and aesthetic aspects of animated maps to understand what makes them attractive to readers.

Temporal resolution is an important factor, not only in terms of accuracy and confidence, but preference as well. Providing map-readers with the opportunity to adjust the level of temporal resolution may appeal to more users and may even decrease response time by allowing readers to view as much information as they feel necessary to complete a map task. Additional research is needed to evaluate the effectiveness of small multiples in terms of the maximum number and size of maps to display and how to incorporate an interface to make effective use of small multiples with large datasets.

The results of this study provided valuable quantitative information about user performance and qualitative insight about user preferences, however it also raises additional questions with respect to animated maps and fire maps overall.

Can animated maps be improved so that people who like them will be more accurate and confident while using them?

The results of this study reveal that a single type of animation is not beneficial or appealing to all. Map-readers expect and want animations to provide as much user control as the invisible interface of static graphics. We need to understand why people performed worse with the animated maps and how we can improve the design or interface to make them more effective. A standard format or interface would allow people to become used to the design and familiar with the controls, which in turn may increase accuracy and confidence and decrease response time. A standard format might make it easier for people to use animated maps overall.

Can a standard fire map exist?

Depending on the audience and use of the fire map, there might have to be different types of standardized maps. The maps firefighters use are different from the maps used to convey wildfire information to novices and the general public because each audience has different needs. The audience of this study was novices and people unversed in fire maps. Fire is a natural disaster that requires residents living in danger of wildfires to have a basic understanding of fire behavior and be able to accurately comprehend the information presented on maps. Current maps presented in the media illustrate wildfires as point symbols, shaded polygons or as lines and circles, and sometimes do not provide adequate information to make inferences. Novices should be able to see how the fire moved across the landscape in the context of landmarks and familiar features to help orient them on the map.

Alternatively, firefighters may require a different standardized map with detailed topography, vegetation, hydrologic features, and access routes. Animated maps would not be a feasible option to use in the field and small multiples may be too small to illustrate the necessary information. Both of these map types could be more beneficial to firefighters during after-action reviews or training. Fire maps require further research on the designs suitable for different audiences; their current state contains many different formats, which could cause confusion and maybe create more questions than answers.

Can animations provide implicit learning?

The experiment did not include questions that could imply implicit learning occurred. The map-tasks were explicitly stated without demonstrating any relationship between the tasks. To accurately determine whether readers comprehended information from the maps would require more implicit questions about overall trends or patterns on the displays. Rather than asking about a specific location or time, a question about the overall fire behavior could provide insight about implicit learning. Because wildfires tend to progress more slowly during the nighttime and when winds calm, a question about the speed or magnitude of change occurring during the evening hours would help identify whether map readers were comprehending implicit information.

Both animated and small-multiple maps provide the opportunity for implicit learning, and each may be better for completing different kinds of map-tasks that would imply learning. Animation affords readers the ability to congruently view a fire progressing, which may make the changes in size (or speed of the fire) more evident and therefore easier to understand the factors affecting those changes, such as wind. In contrast, small-multiples provide a clear view of all the changes at the same time, which makes it easier to compare between scenes and follow the changing wind direction at the same time. Incorporating additional map tasks in the experiment about the overall behavior of the fire and its movement around landmarks, such as roads would provide insight as to which map enhances implicit learning. They would also help set a foundation for the types of questions to ask during experiments to understand how design variables influence different types of map tasks.

What is the future of animated maps?

Animated maps are still in their infancy and there is a lot to learn about their design, how people interact with them, their applications, and abilities to help answer explicit and implicit questions. For animated maps to be effective, they need to provide an intuitive or standard interface that will not impede the opportunity for learning or knowledge construction. We need to figure out how to ask more informative questions about animated maps; maybe we are not testing animations with the right methods or asking the right kind of questions to fully understand their effectiveness.

To this point it has been difficult to actually quantify and determine the effectiveness of animated maps, due to the types of questions asked in experiments. We need to be able to ask questions that require implicit answers rather than the common location-specific questions. Static maps allow us to look at the map as whole and take in the information to get a sense of the overall trend or patterns hidden in the map whereas animation makes it difficult to get a holistic view. The response variables measured in this study were chosen because they could easily be quantified and used as a proxy towards understanding the overall effectiveness of different design variables. Recording accuracy of simple map tasks demonstrated significant differences in readers' abilities to complete tasks however, it revels little about the kind of information comprehended from the maps and whether implicit learning occurred. The open-ended questions in the post-test provided valuable information about preferences and strategies, however it is difficult to quantify their responses.

An animation interface should be designed similar to the interactivity afforded by a small-multiple display, which is easy to use and provides the user complete control over the dynamic variables. Fabrikant et al. (2008) conducted an experiment to record readers' eye-movements while they viewed a small-multiple display; the experiment revealed how often we look back and forth at the individual maps in order to complete a map-task. Re-creating the eye movements as mouse clicks in an animation, would demonstrate how a user would constantly need to click buttons to compare scenes. Having to repeatedly click around an animated map interface will not only increase response time, but also frustration by adding the additional navigation tasks.

Both animated maps and small multiples are viable means to present dynamic geographic process, however each have limitations to their design that could be improved upon. It is important to address those limitations and listen to what map-readers like and prefer. We must design these types of maps with the users' needs in mind, paying attention to the level of temporal resolution, the controls of the animation, and the digital display of small-multiple maps. Accommodating these needs may help alleviate frustrations associated with these maps and ultimately increase their effectiveness and applications for portraying dynamic processes.

APPENDICES

APPENDIX A.

TESTING SEQUENCES

Testing Sequence: Version 1

Question Number	Map	Question Number	Map
1	CRSM	29	CRA
2	CRA	30	CRA
3	FRA	31	FRSM
4	CRA	32	FRA
5	FRSM	33	CRA
6	CRSM	34	FRSM
7	CRA	35	CRA
8	FRA	36	FRA
9	FRSM	37	FRSM
10	CRA	38	CRA
11	FRSM	39	CRSM
12	CRSM	40	FRSM
13	CRA	41	FRA
14	FRA	42	CRSM
15	CRSM	43	FRA
16	CRSM	44	FRSM
17	FRSM	45	FRSM
18	CRSM	46	CRSM
19	FRA	47	CRSM
20	CRSM	48	FRSM
21	CRA	49	FRSM
22	FRA	50	CRA
23	FRA	51	FRA
24	CRSM	52	FRSM
25	FRA	53	FRA
26	FRA	54	CRA
27	FRSM	55	CRSM
28	CRA	56	CRSM

FRA = Fine Resolution Animation
CRA = Coarse Resolution Animation
FRSM = Fine Resolution Small-Multiple
CRSM = Coarse Resolution Small-Multiple

Table 15. One of the two testing sequences used in the experiment.

Testing Sequence: Version 2

Question Number	Map	Question Number	Map
1	CRSM	29	CRA
2	CRA	30	CRSM
3	CRA	31	FRA
4	FRA	32	CRA
5	FRSM	33	FRSM
6	FRSM	34	FRSM
7	FRA	35	FRA
8	CRSM	36	FRSM
9	CRA	37	CRSM
10	CRSM	38	CRSM
11	FRSM	39	CRA
12	FRA	40	CRSM
13	FRSM	41	FRSM
14	CRA	42	CRA
15	FRA	43	FRSM
16	CRA	44	FRA
17	FRA	45	FRSM
18	FRA	46	CRSM
19	FRA	47	FRA
20	FRA	48	CRA
21	CRA	49	CRSM
22	CRA	50	CRSM
23	CRA	51	CRSM
24	FRA	52	CRSM
25	CRSM	53	FRA
26	FRSM	54	FRSM
27	CRSM	55	FRSM
28	FRSM	56	CRA

FRA = Fine Resolution Animation
CRA = Coarse Resolution Animation
FRSM = Fine Resolution Small-Multiple
CRSM = Coarse Resolution Small-Multiple

Table 16. The second testing sequence used in the experiment.

APPENDIX B.

EXPERIMENT TEST

Thank you for agreeing to participate in this study

Continue

This test is designed to compare four different kinds of maps about a wildfire progression

Continue

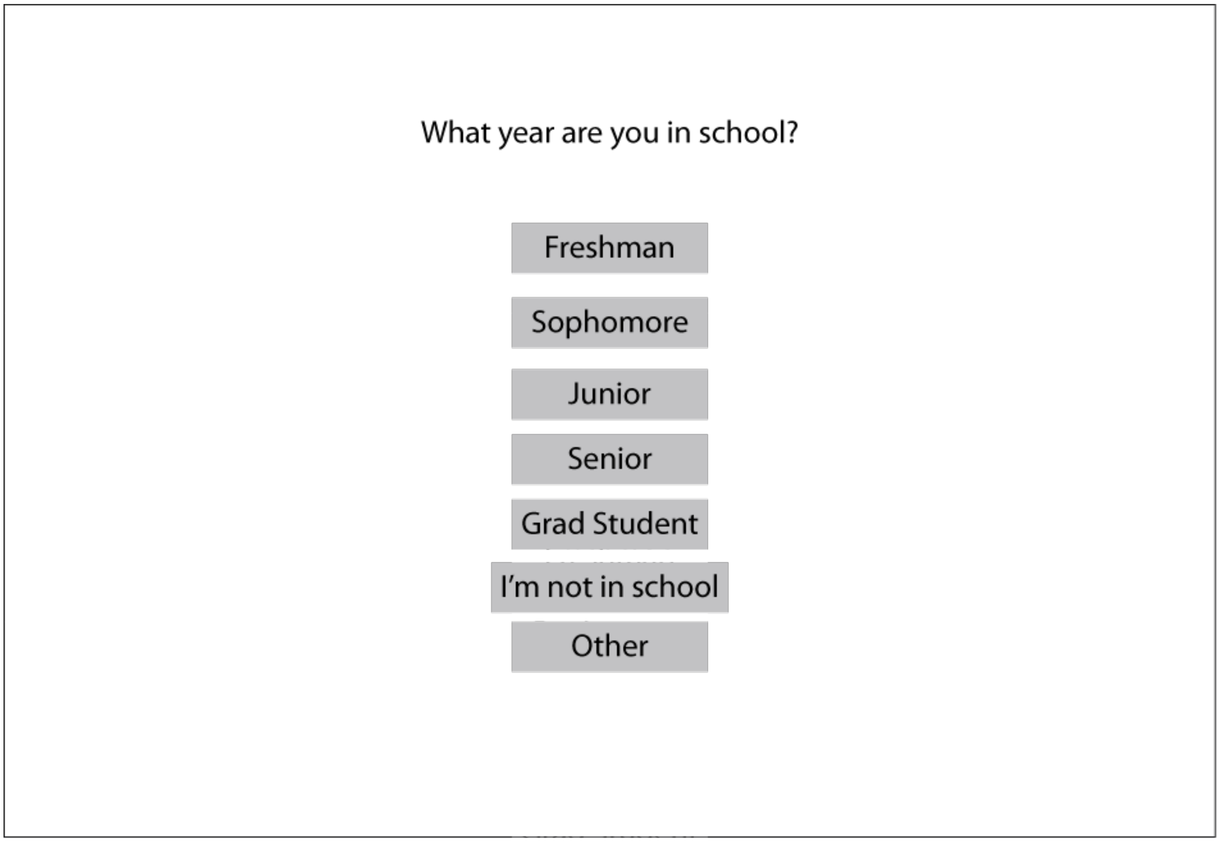
You will now complete a **pre-test** asking general background questions about yourself

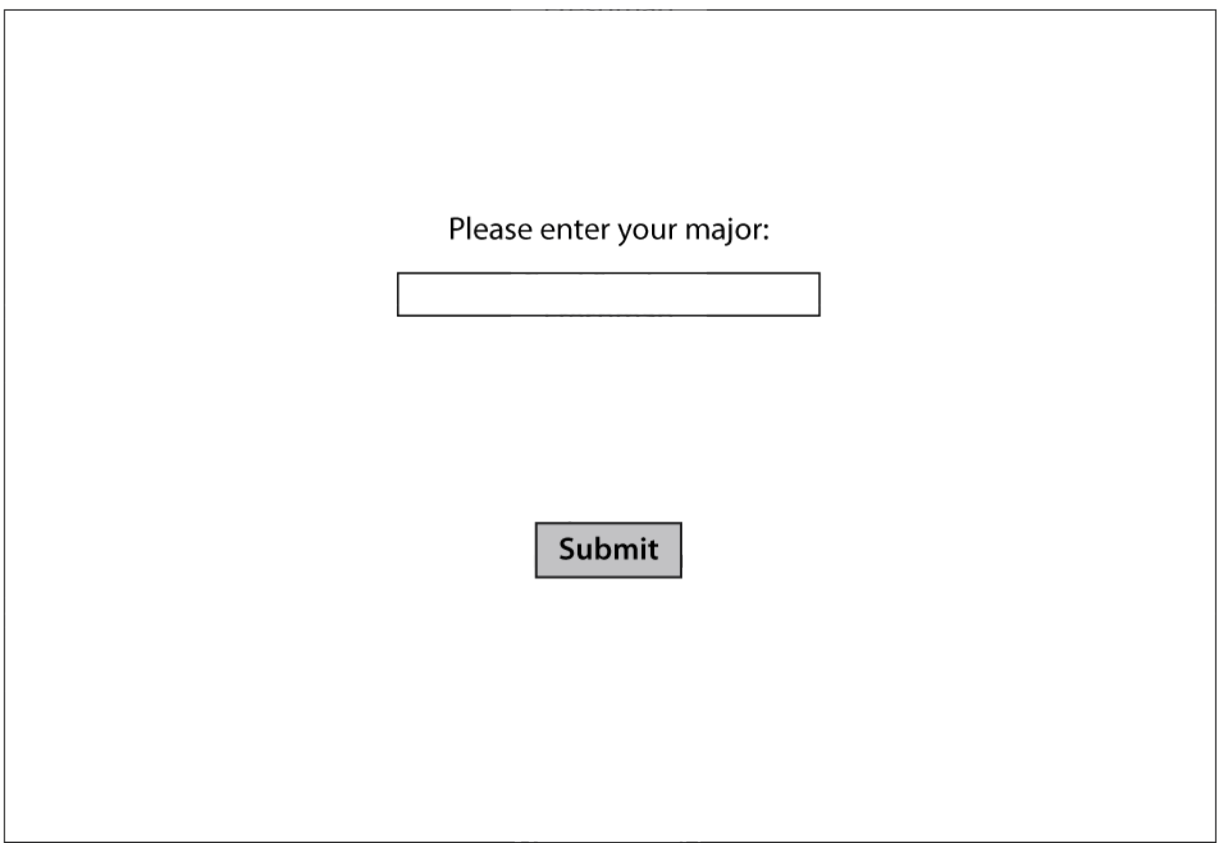
Continue

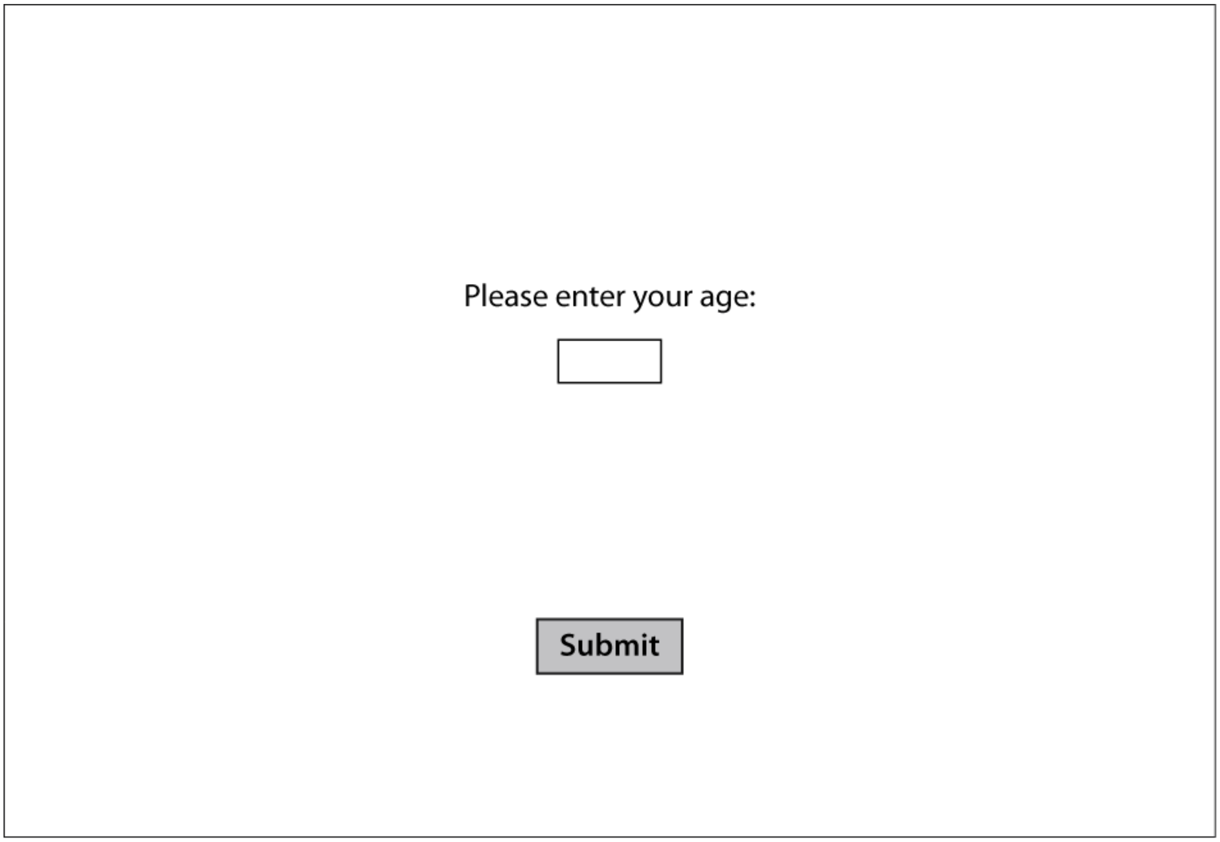
Please indicate your gender:

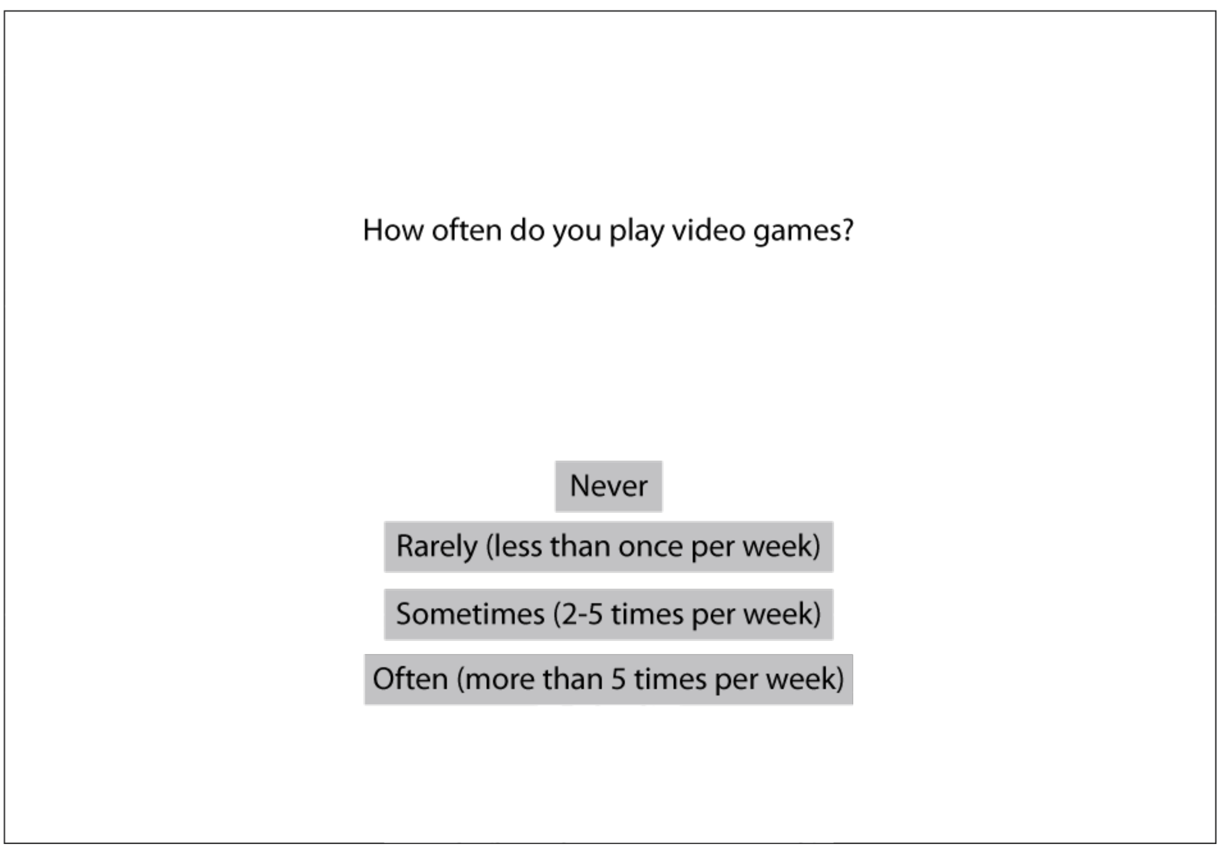
Male

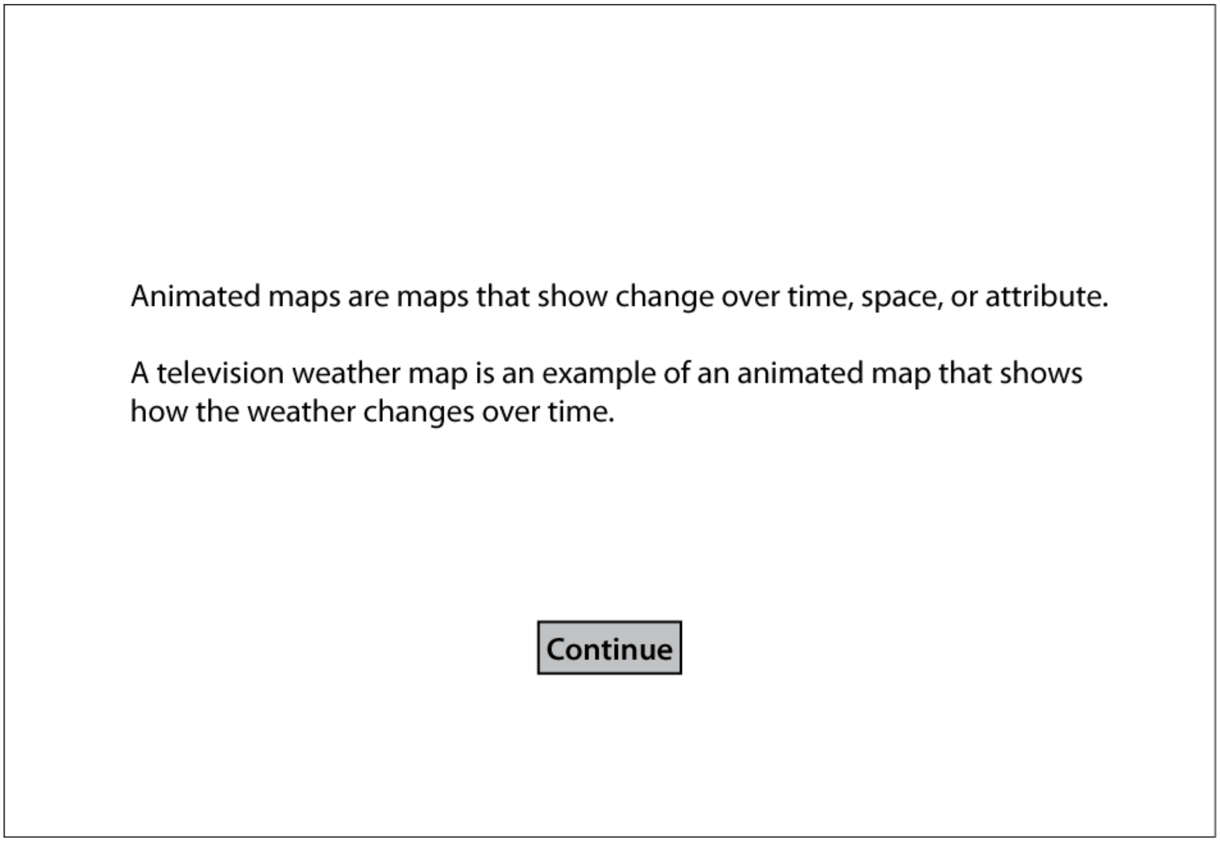
Female


What year are you in school?
Freshman
Sophomore
Junior
Senior
Grad Student
I'm not in school
Other

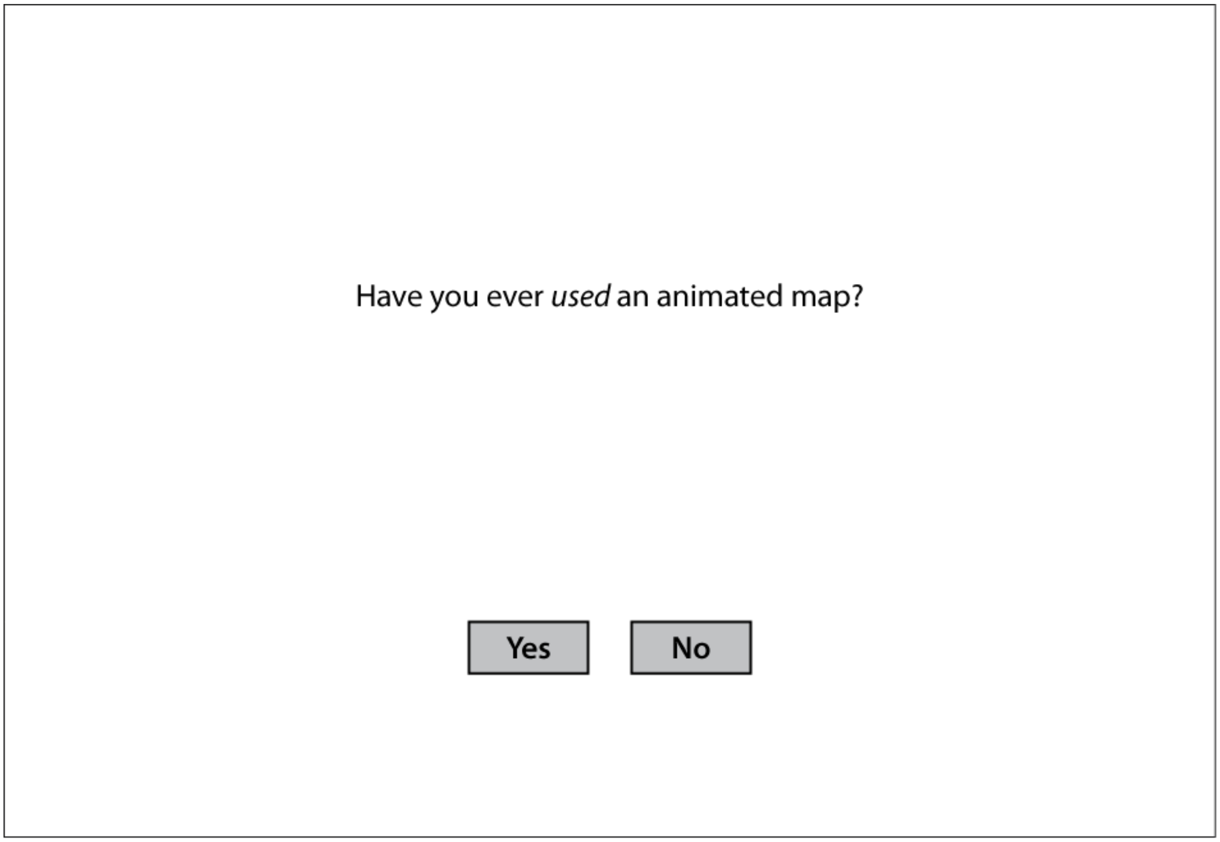

Please enter your major:
Submit

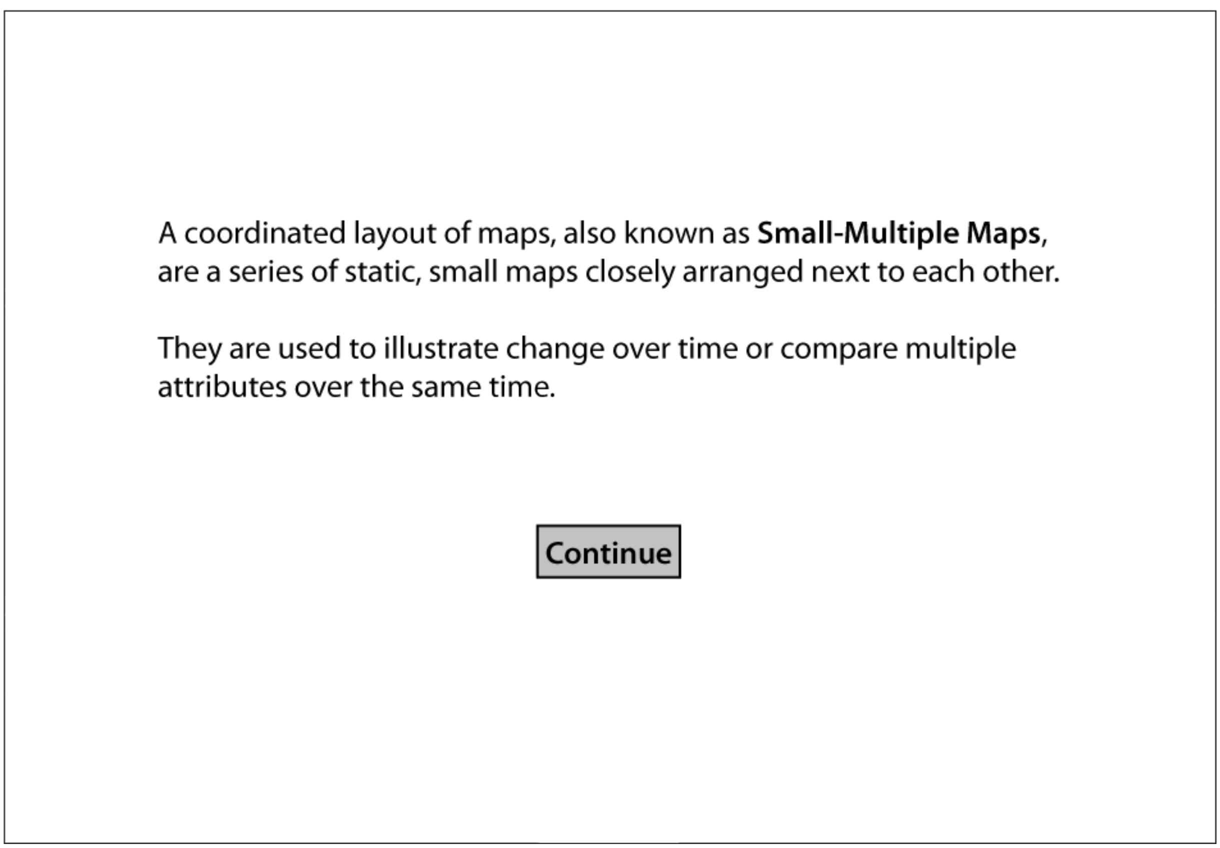

Please enter your age:
Submit


How often do you play video games?
Never
Rarely (less than once per week)
Sometimes (2-5 times per week)
Often (more than 5 times per week)


Animated maps are maps that show change over time, space, or attribute.
A television weather map is an example of an animated map that shows how the weather changes over time.
Continue

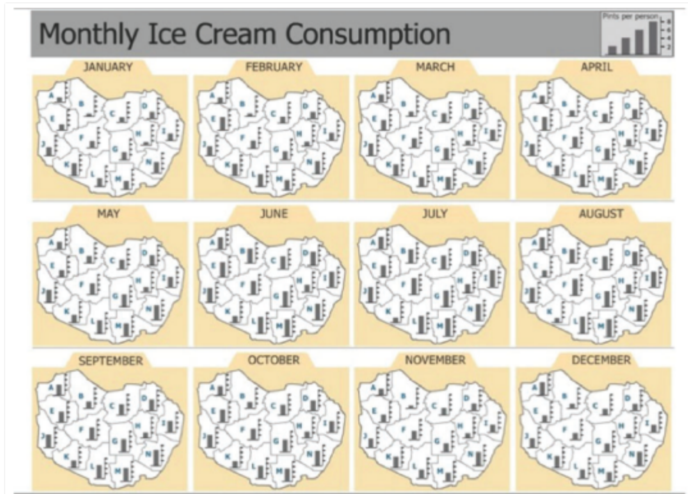

Have you ever *seen* an animated map?
Yes
No


Have you ever *used* an animated map?
Yes
No


A coordinated layout of maps, also known as **Small-Multiple Maps**, are a series of static, small maps closely arranged next to each other.
They are used to illustrate change over time or compare multiple attributes over the same time.
Continue

This is an example of a **small-multiple map** showing monthly ice cream consumption by county over a year.

This small-multiple map contains **12-scenes**- one for each month



Continue

Have you ever *seen* a small-multiple map before this test?

Yes **No**

Note. Map image from, "Novel method to measure inference affordance in static small-multiple map displays representing dynamic processes," on page 205, by Fabrikant, S., Rebich-Hespanha, S., Andrienko, N., Andrienko, G., & Montello, D., 2008, Cartographic Journal, 45(3). Copyright 2008 by The British Cartographic Society. Reprinted with permission.

Have you ever *used* a small-multiple map?

Yes No

Which kinds of maps have you referred to in the past two months?
(Check all that apply)

- ☐ Paper map
- ☐ Interactive maps (i.e. Google Maps or Bing Maps)
- ☐ In-car navigation system maps
- ☐ Animated weather map
- ☐ Static map on the computer
- ☐ 3-D map

Submit

Wildfires are fires that burned uncontrolled through forests, brush, and prairies. They can occur naturally, or are sometimes started by humans.

Maps may help people understand how wildfires behave.

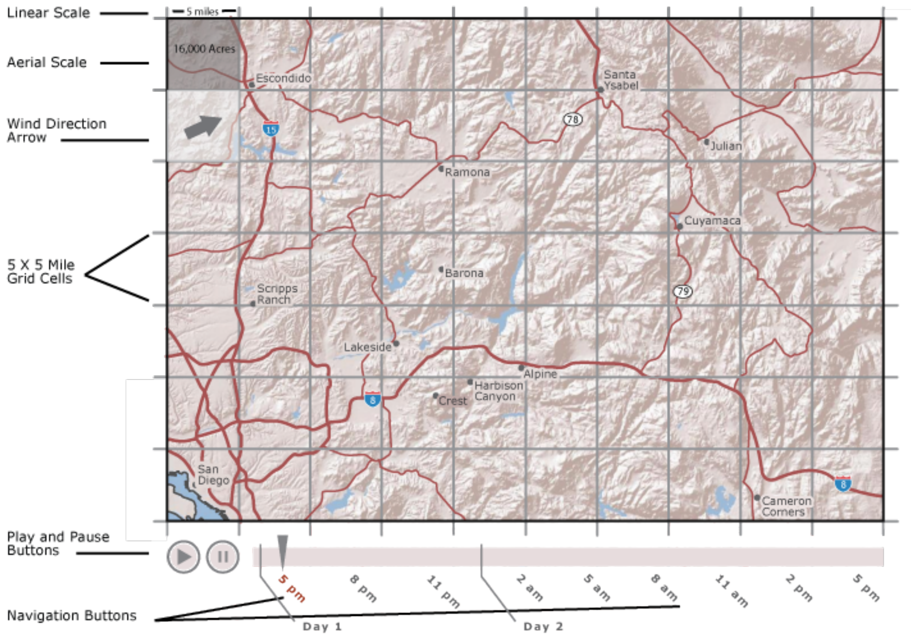
Continue

Have you ever lived in an area with wildfires?

Yes No

In the test you will view two different animated maps. The animation interface and controls look like the image below.

Please take a moment to familiarize yourself with the layout and buttons.



Continue

There are two types of questions you will be asked during the test.
The first type of question will ask you about something on the map.

Continue

The second type of question will ask how confident you are with your answer.

Confident | Not Confident

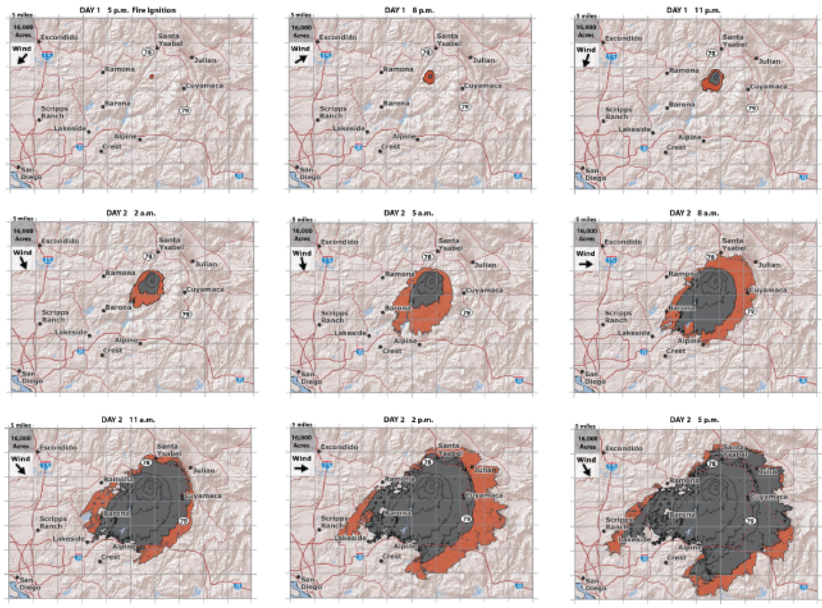
Continue

Please read each question carefully, you will not be able to go back to change your answer.

Make sure to try your best when you answer each question.

Press 'Start' to begin the test.

Start



Did the fire cross over highway 79 by 6am on day 2?

Yes No

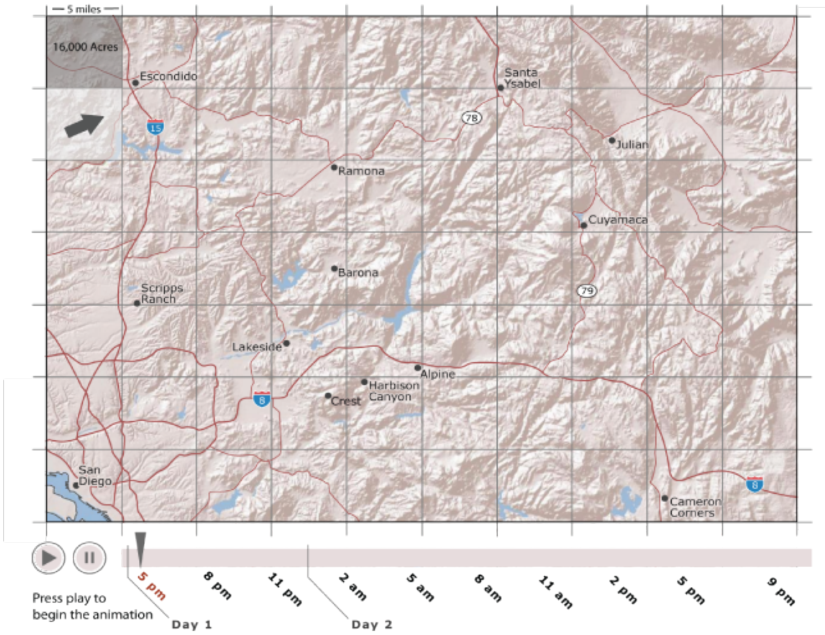
Skip

How confident are you about your answer?

Confident Not Confident

Participant's viewed this screen after each content question.

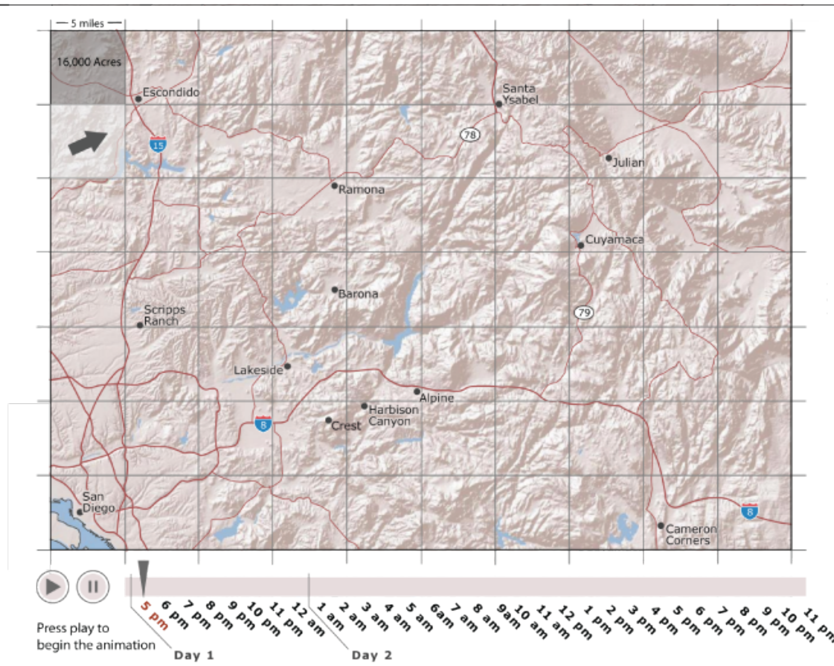
Skip



The fire had crossed over highway 78 by 10am on day 2.

True False

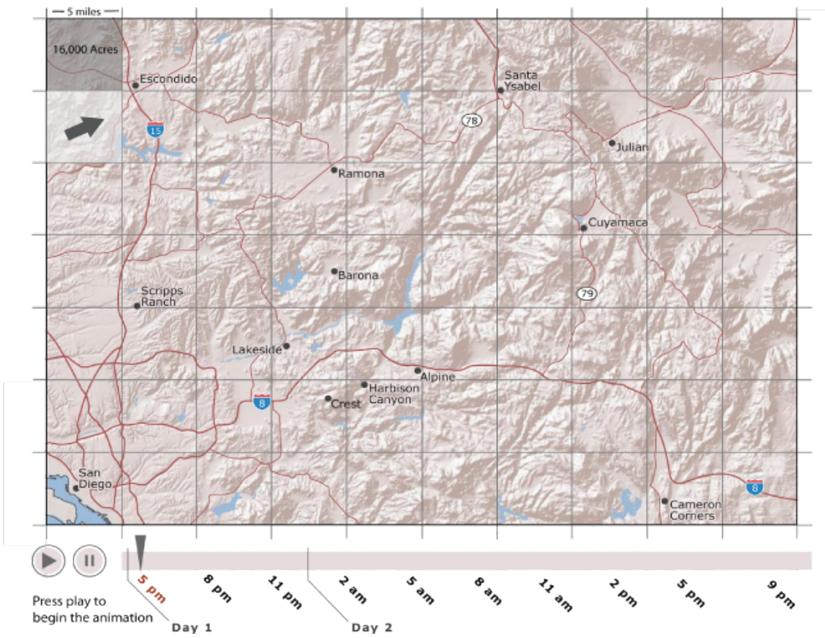
Skip



Did the wind shift direction from 11am to 7pm on day 2?

Yes No

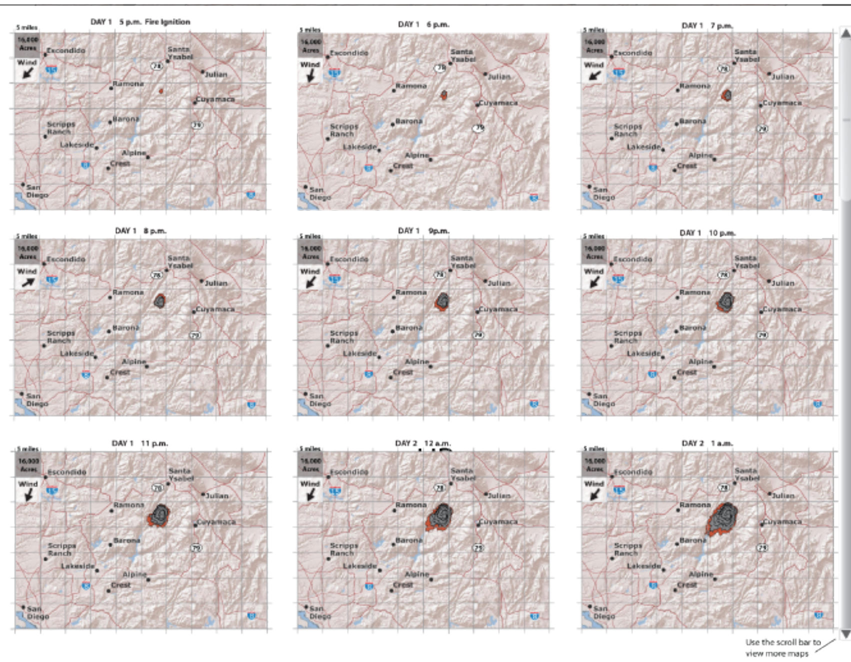
Skip



Was the fire burning north of highway 78 by 11am on day 2?

Yes No

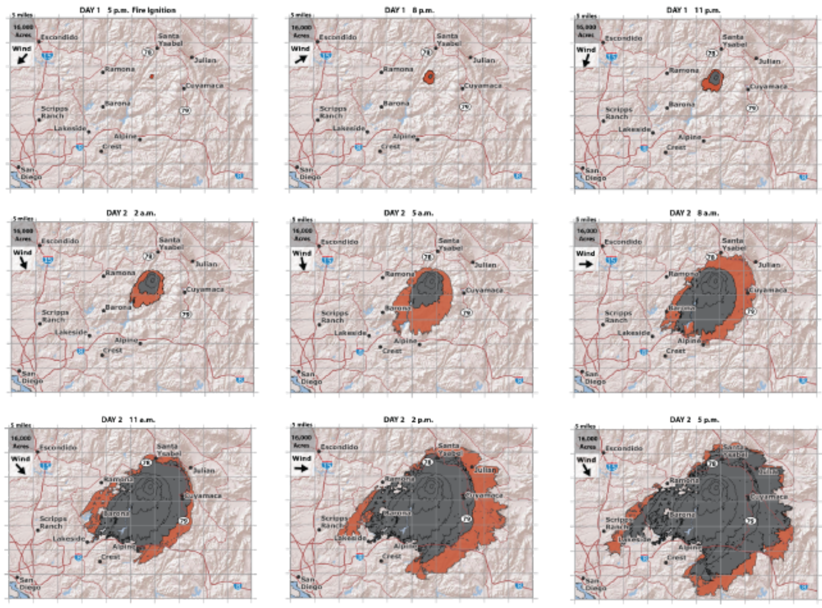
Skip



Was the dominant direction of the fire to the west on day 2 by 9pm?

Yes No

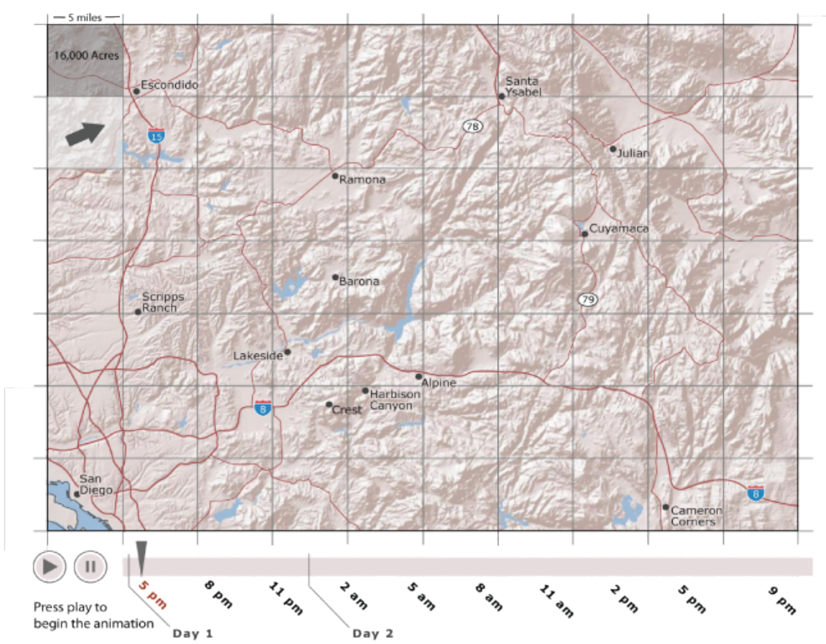
Skip



Did the fire spread faster at 2am than 5pm on day 2?

Yes No

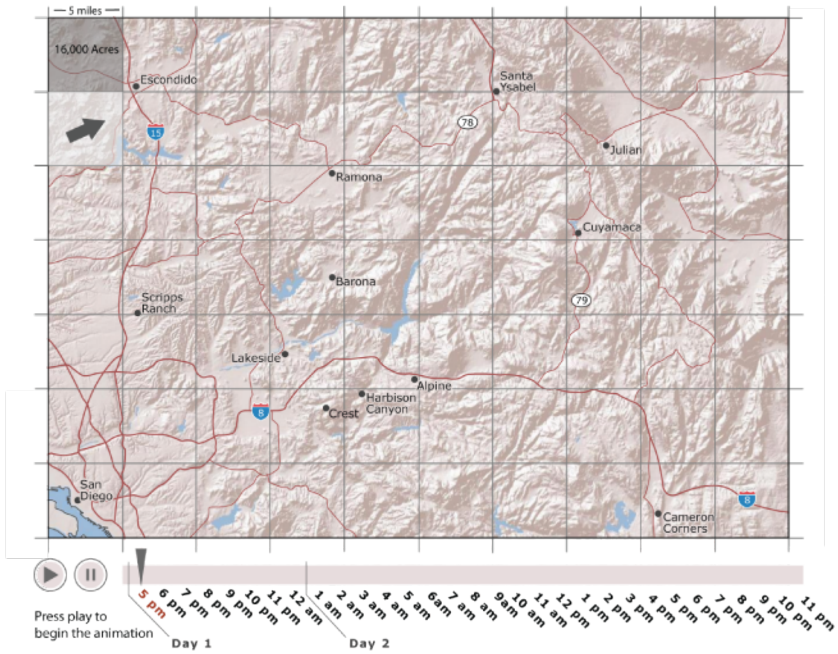
Skip



Was the dominant direction of the fire to the northeast on day 1 by 11pm?

Yes No

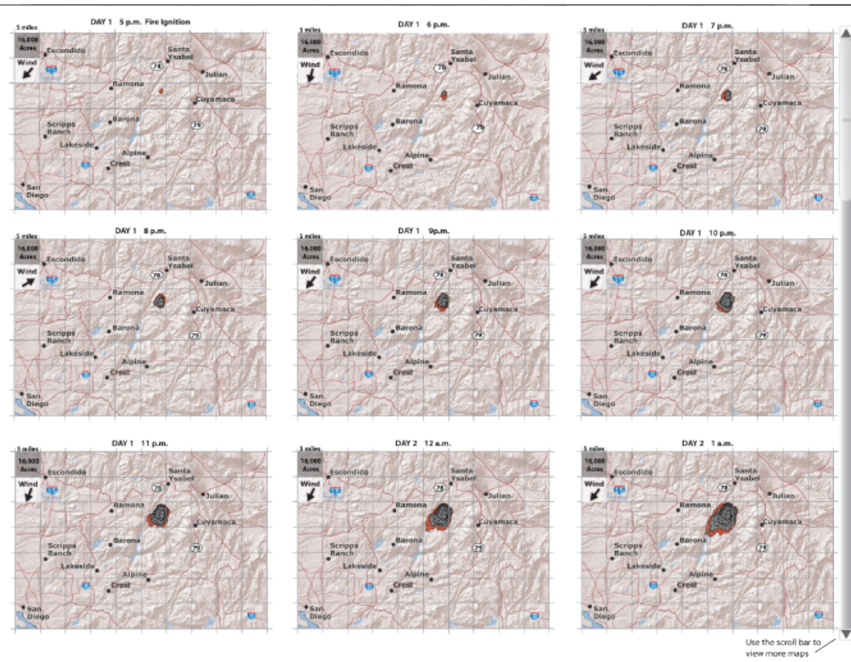
Skip



The fire burned over 32,000 acres total by 6am on day 2.

True False

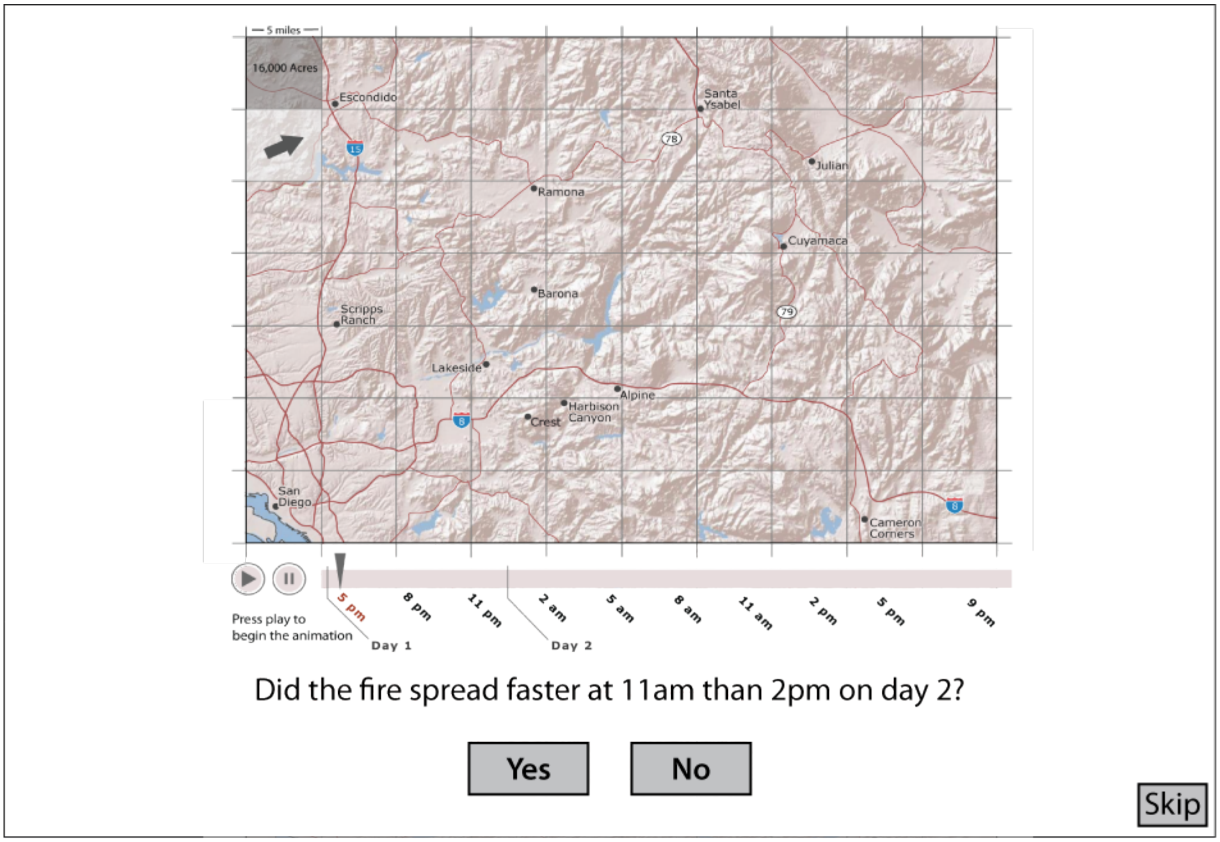
Skip

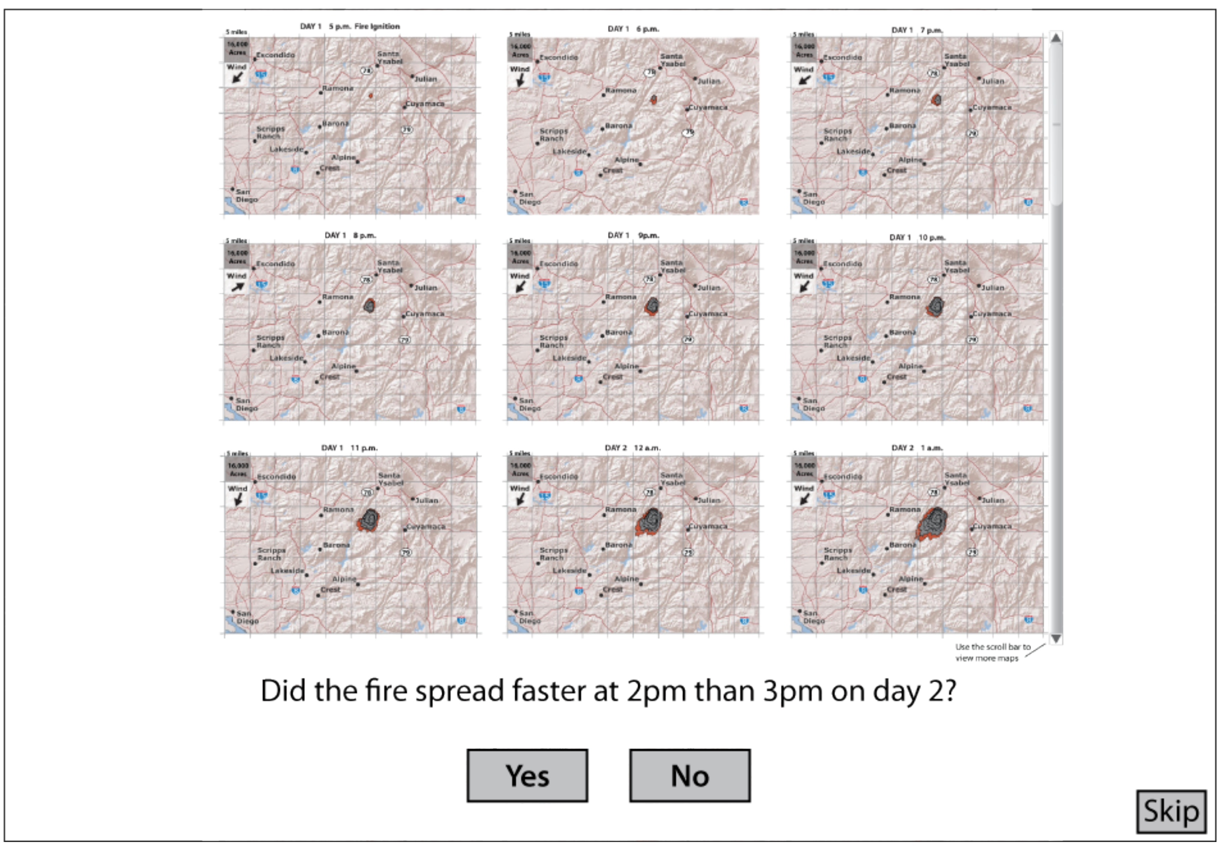


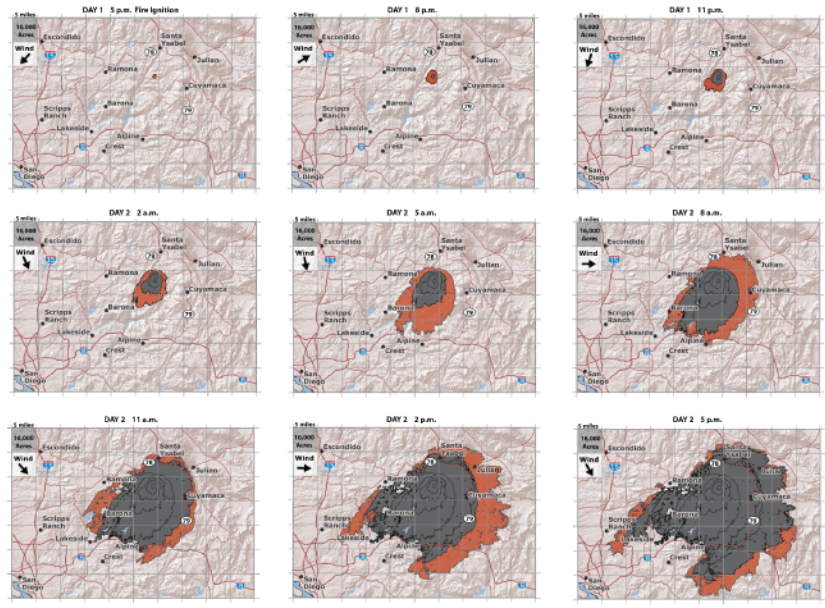
The dominant direction of the fire on day 2 at 2pm was to the southwest.

True False

Skip


5 miles
16,000 Acres
Escondido
Santa Ysabel
78
Julian
15
Ramona
Cuyamaca
79
Barona
Scripps Ranch
Lakeside
Alpine
Harbison Canyon
Crest
8
San Diego
Cameron Corners
Press play to begin the animation
5 pm
8 pm
11 pm
2 am
5 am
8 am
11 am
2 pm
5 pm
9 pm
Day 1
Day 2
Did the fire spread faster at 11am than 2pm on day 2?
Yes
No
Skip

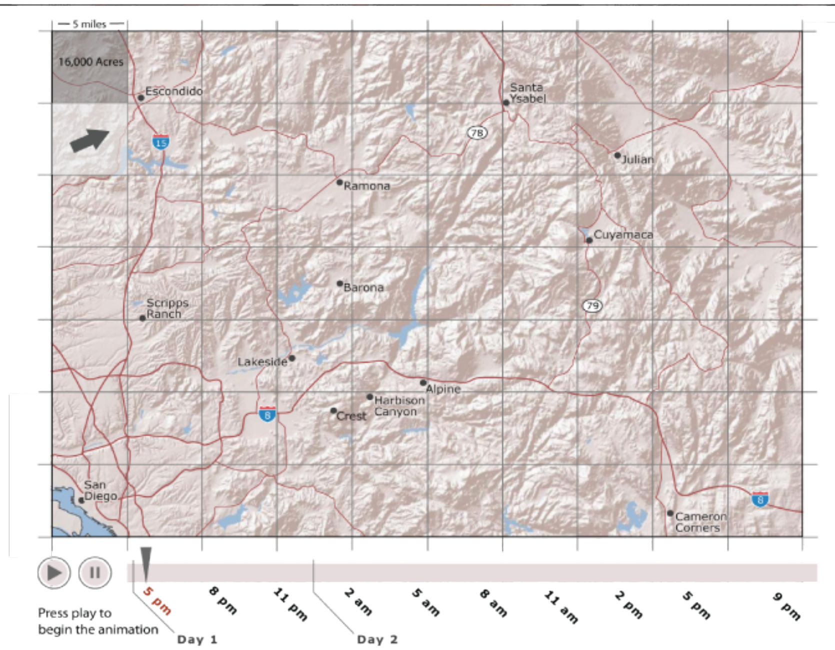

DAY 1 5 p.m. Fire Ignition
DAY 1 6 p.m.
DAY 1 7 p.m.
DAY 1 8 p.m.
DAY 1 9p.m.
DAY 1 10 p.m.
DAY 1 11 p.m.
DAY 2 12 a.m.
DAY 2 1 a.m.
Use the scroll bar to view more maps
Did the fire spread faster at 2pm than 3pm on day 2?
Yes
No
Skip



The wind shifted direction from 1am to 3am on day 2.

True False

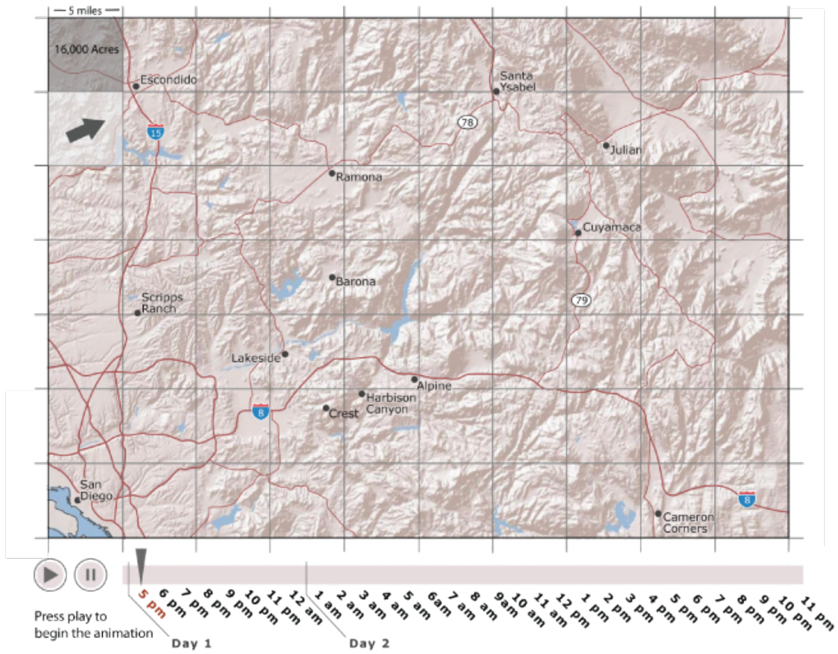
Skip



Did the fire move through the town of Cuyamaca by 7am on day 2?

Yes No

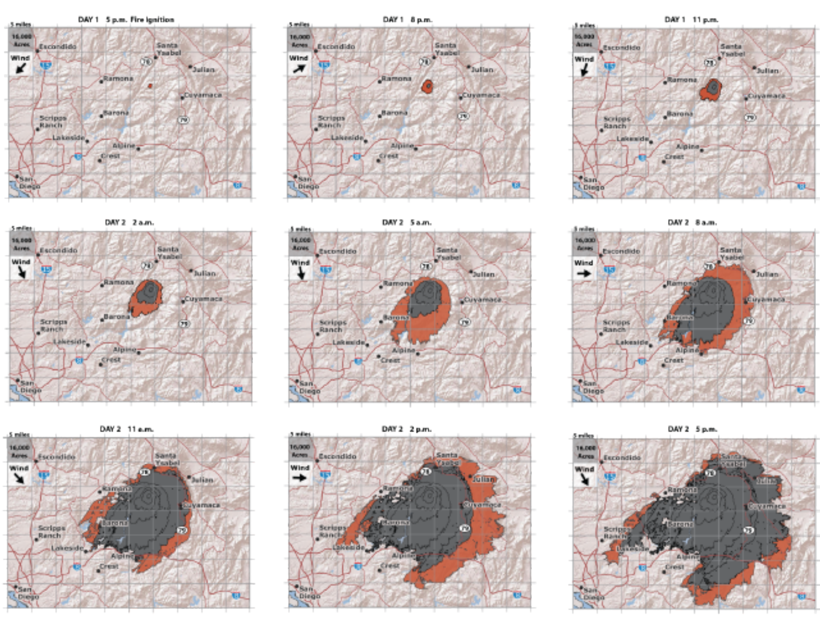
Skip



The fire had crossed over highway 79 by 6am on day 2.

True | False

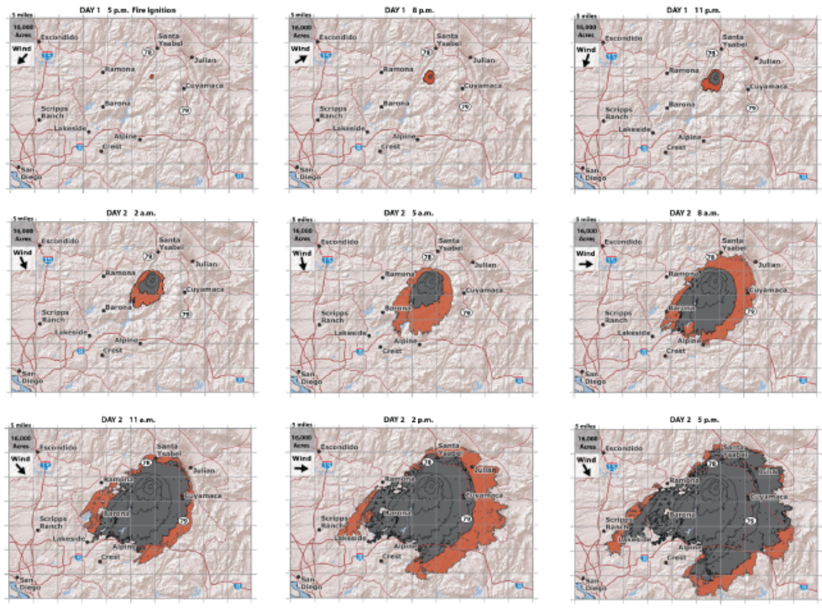
Skip



Did the fire reach the town of Cuyamaca on day 1?

Yes | No

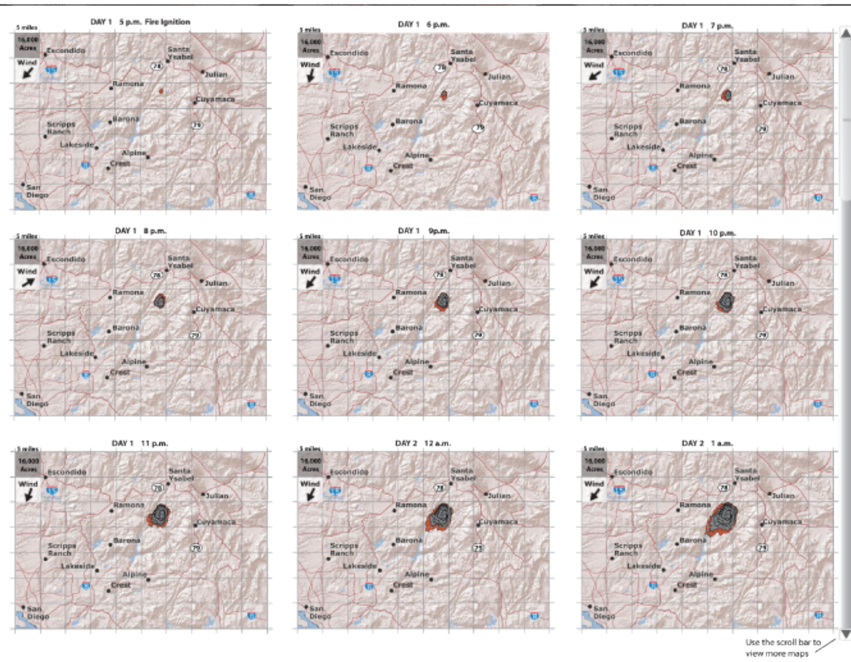
Skip



The whole fire affects an area over 25 miles across from its northern and southern most points.

True False

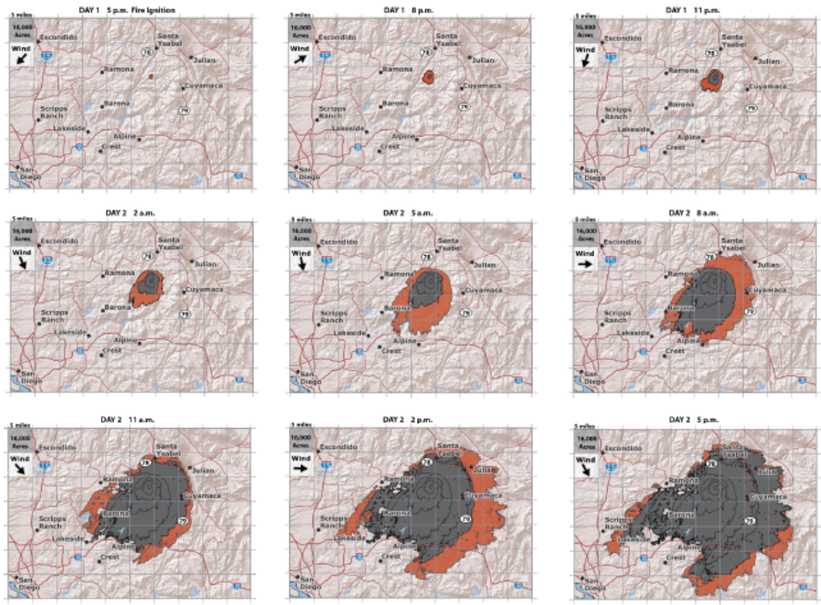
Skip



Did the fire move through the town of Julian by 7am on day 2?

Yes No

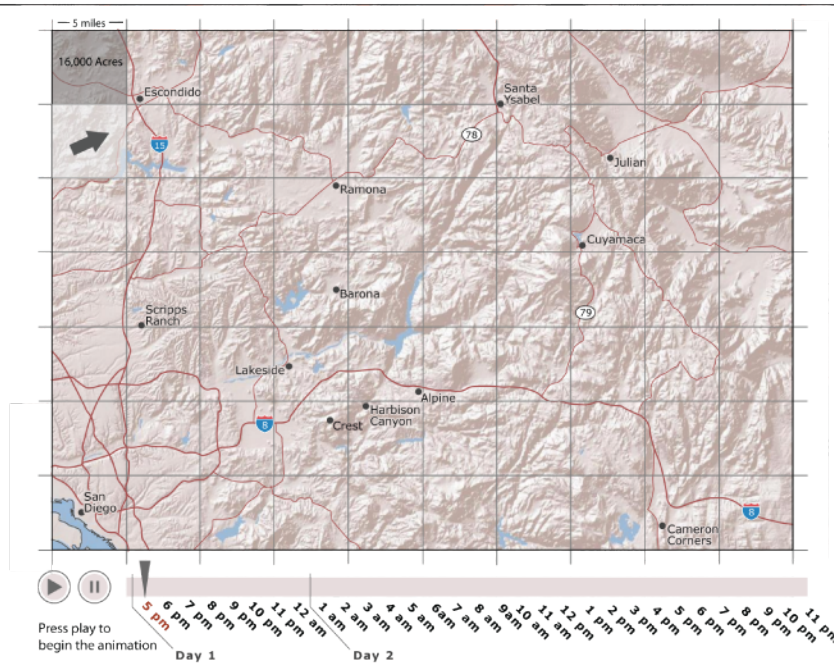
Skip



The dominant direction of the fire on day 2 at 2am progressed towards the southwest.

True False

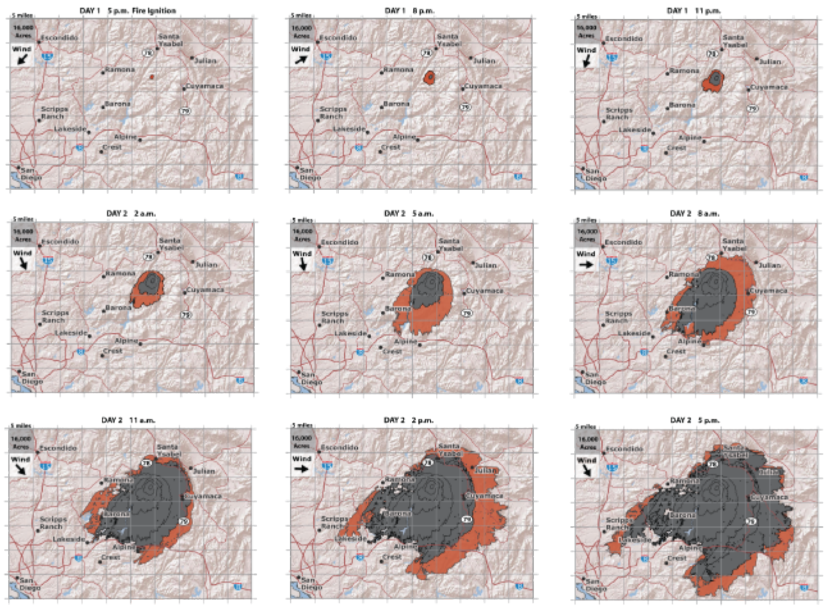
Skip



Did the fire spread faster at 6am compared to 7am on day 2?

Yes No

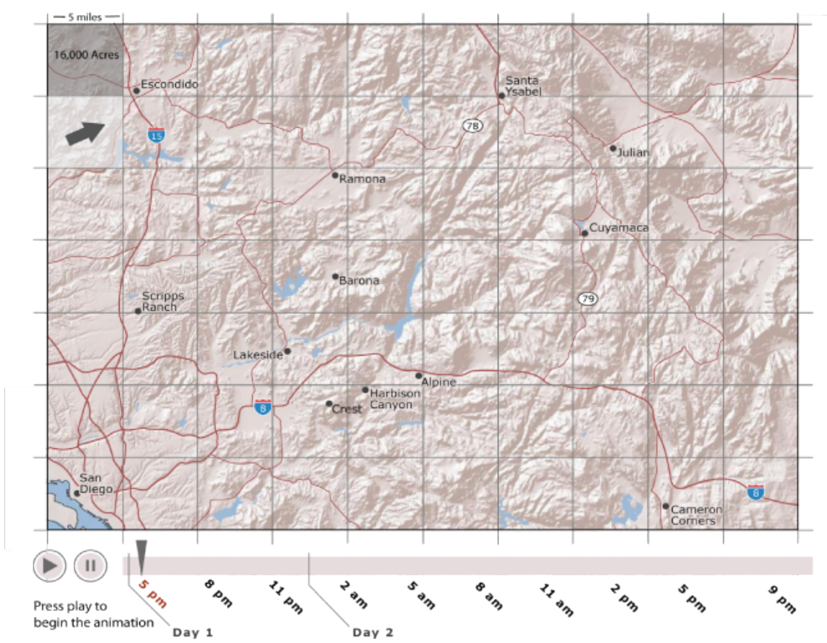
Skip



Was the fire burning east of highway 79 by 11am on day 2?

Yes No

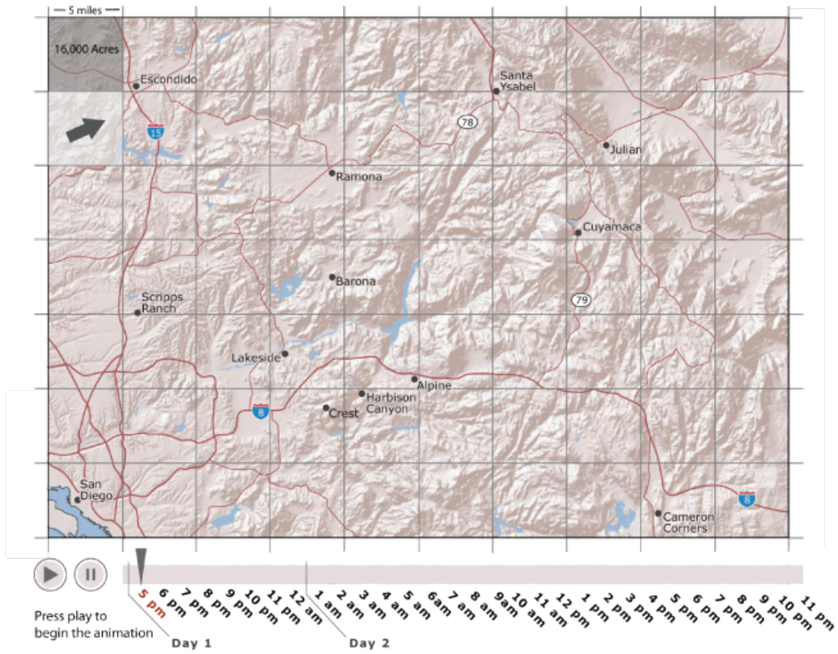
Skip



The dominant direction of the fire progression shifted from 10am to 11am on day 2.

True False

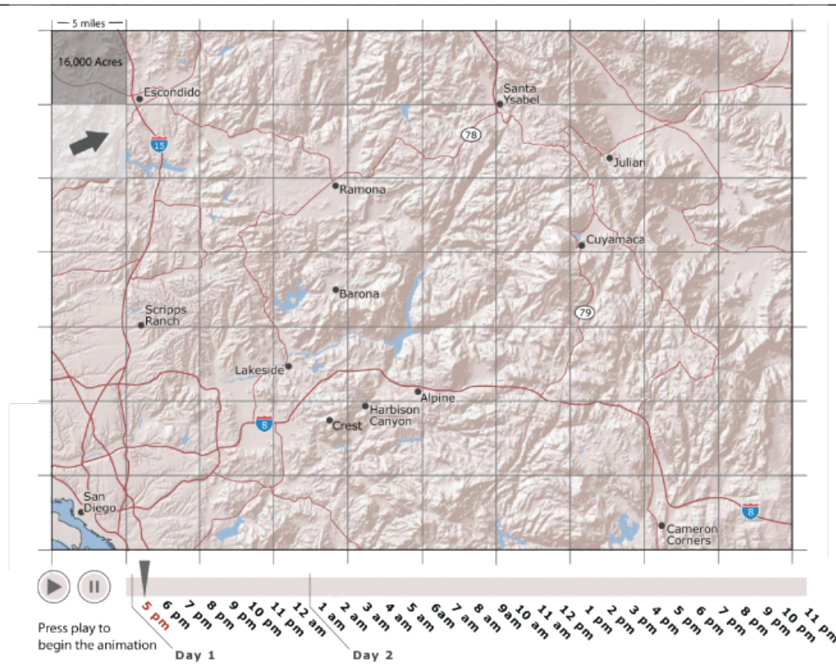
Skip



Does the fire extend over 20 miles across from east to west at 6am on day 2?

Yes No

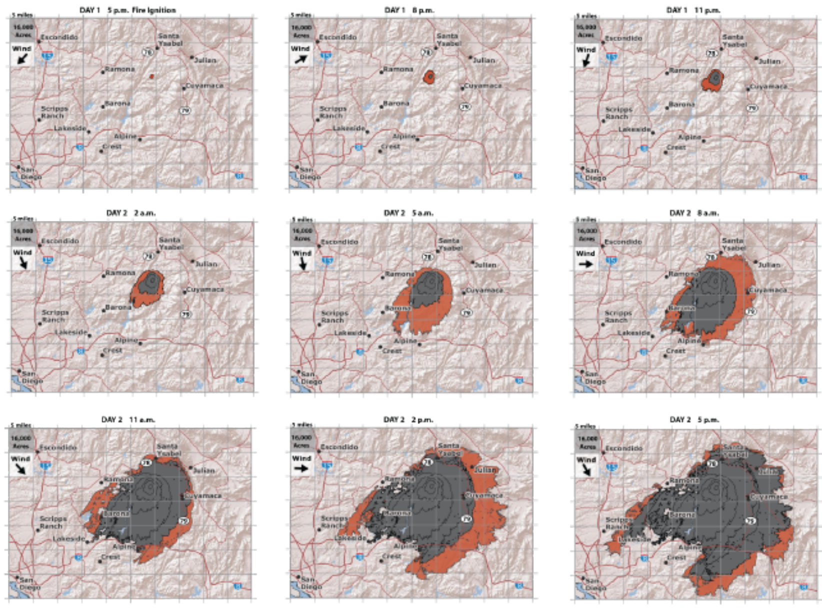
Skip



The dominant direction of the fire progressed towards the southwest on day 2 by 4am.

True False

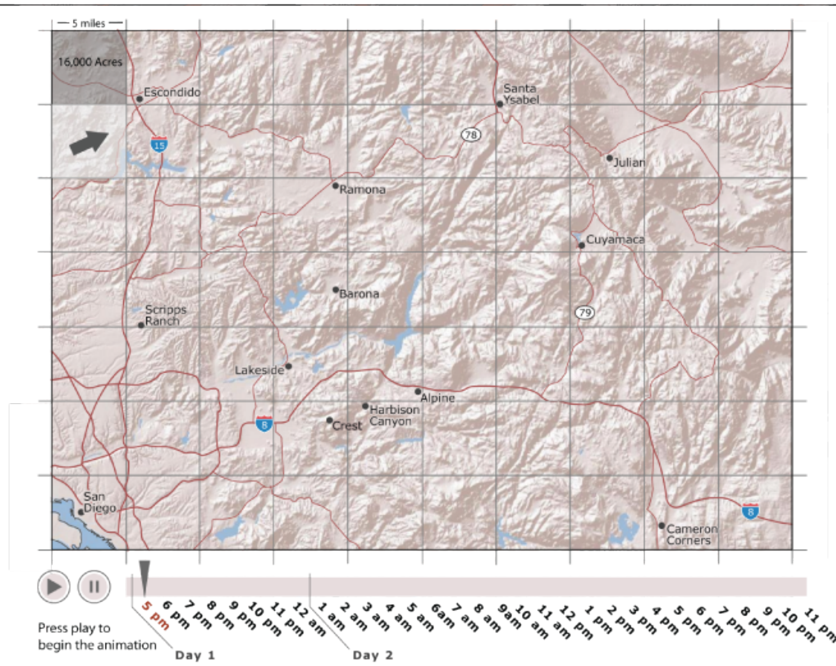
Skip



Does the fire affect an area over 5 miles across from north to south by 2am on day 2?

Yes No

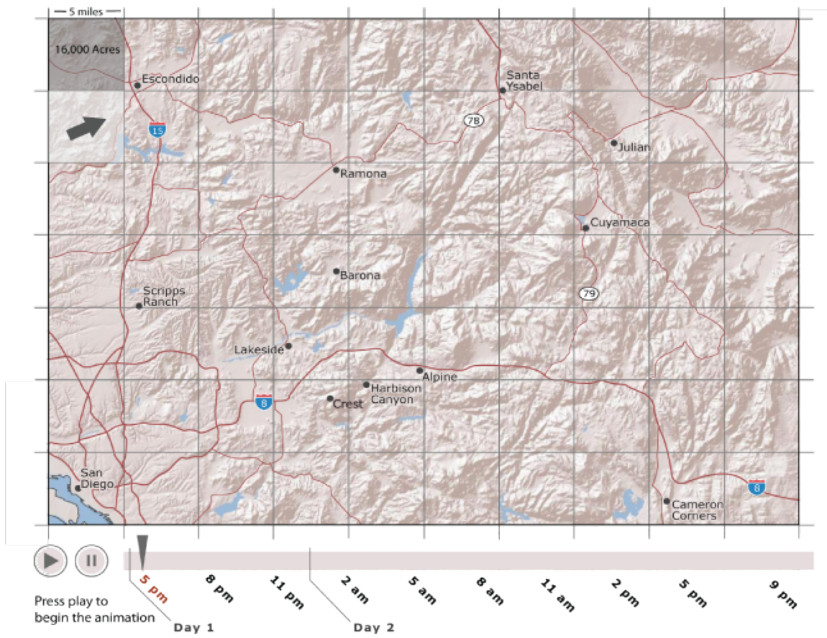
Skip



The fire spread faster at 9am than 1pm on day 2.

True False

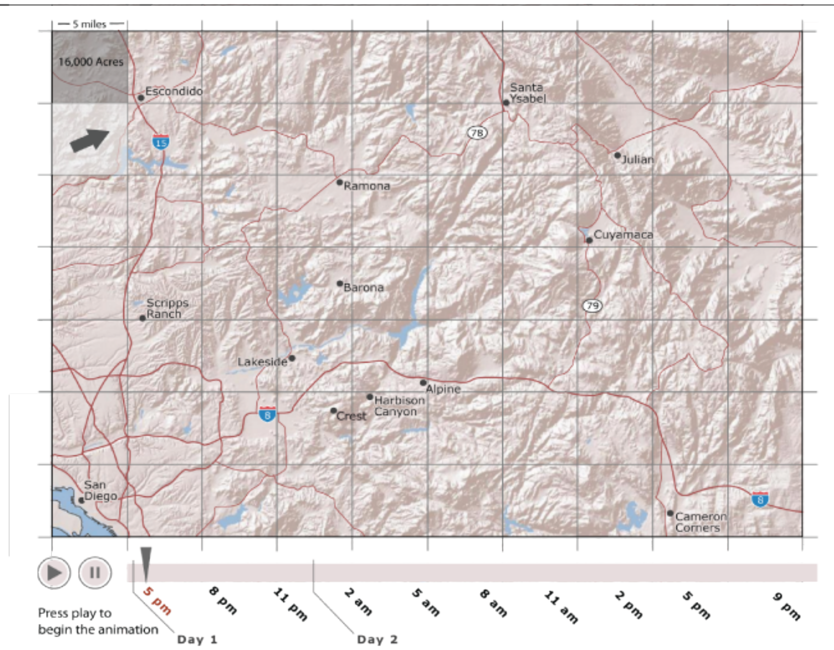
Skip



Did the fire cross over highway 78 by 6am on day 2?

Yes No

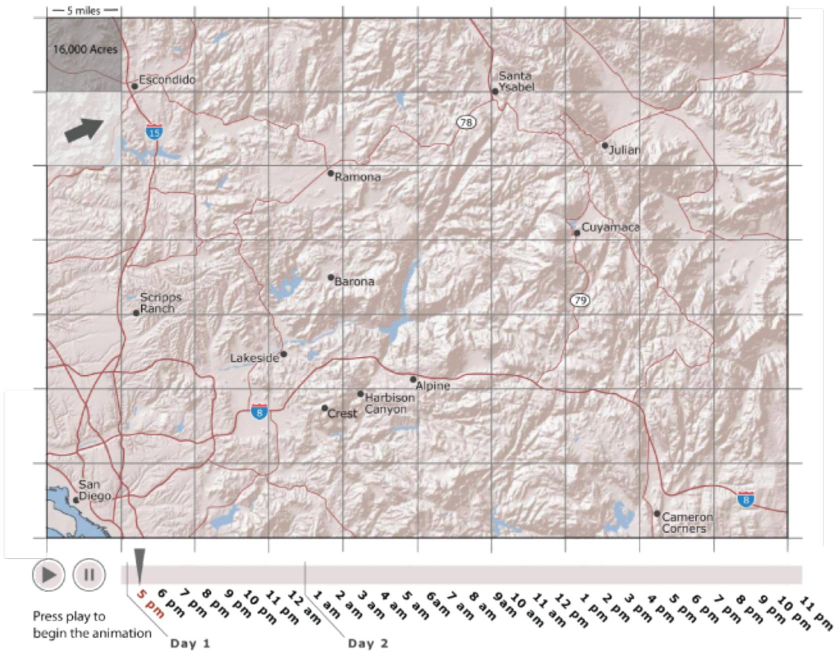
Skip



The dominant direction of the fire on day at 8am was towards the southwest.

True False

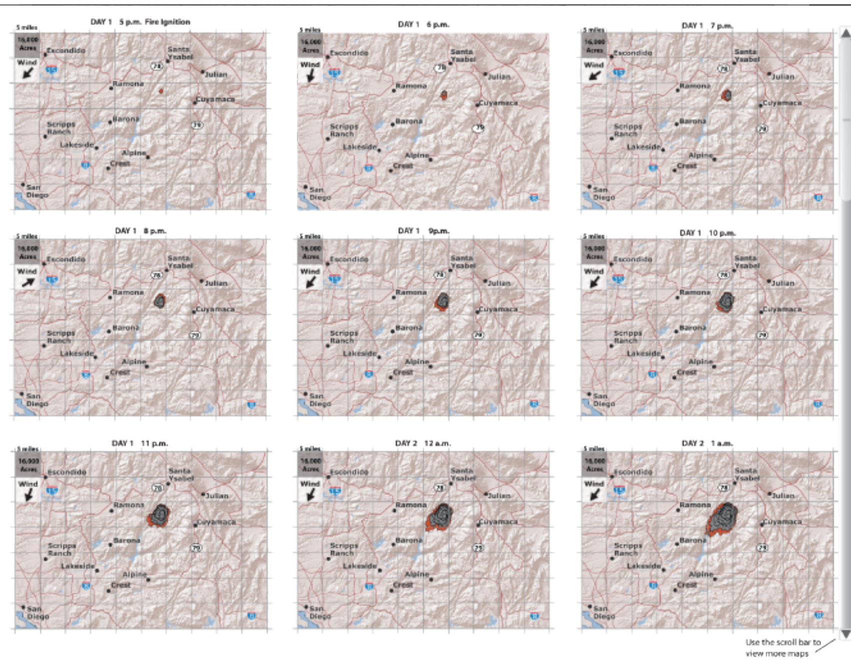
Skip



Was the fire across interstate 8 by 6am on day 2?

Yes No

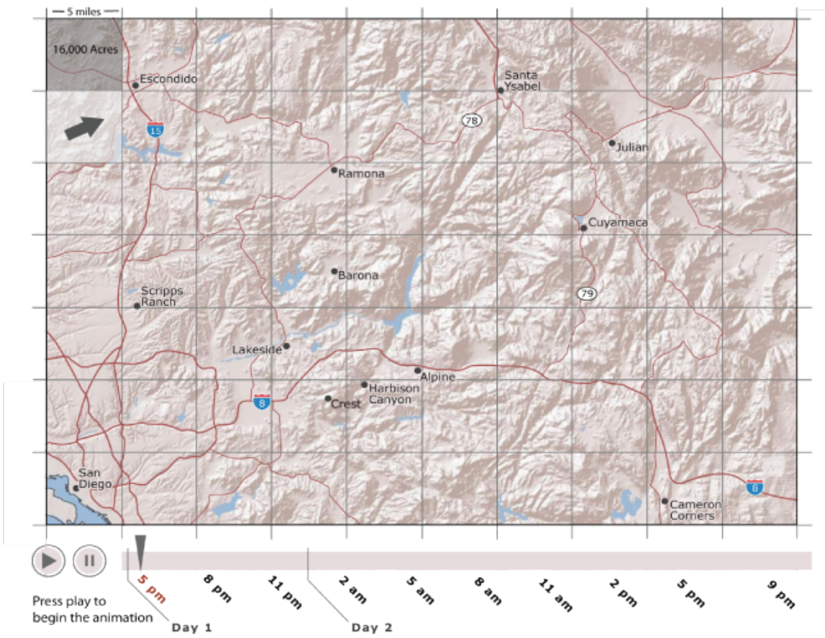
Skip



Was the fire burning west of interstate 15 by 8pm on day 2?

Yes No

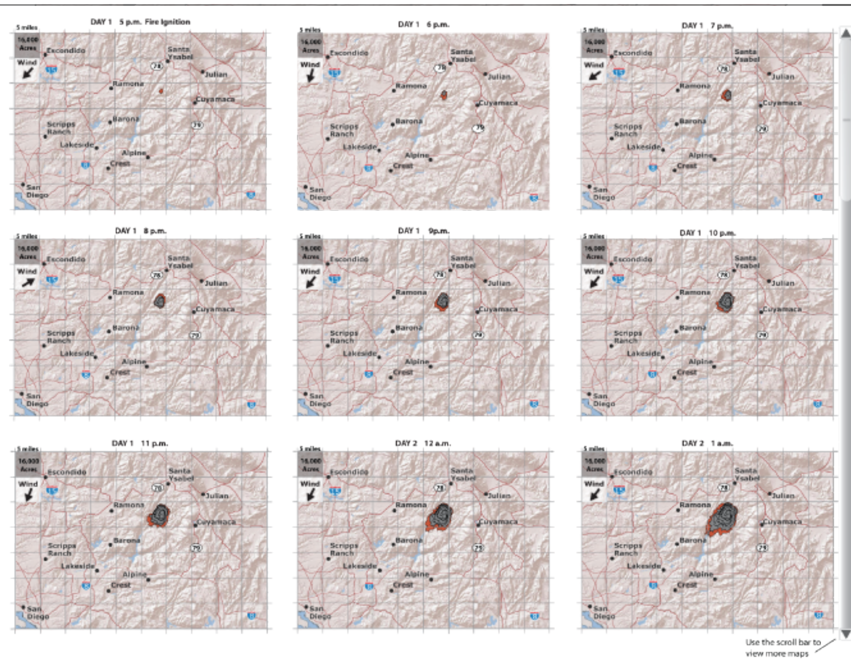
Skip



Did the wind shift direction from 12pm to 1pm on day 2?

Yes No

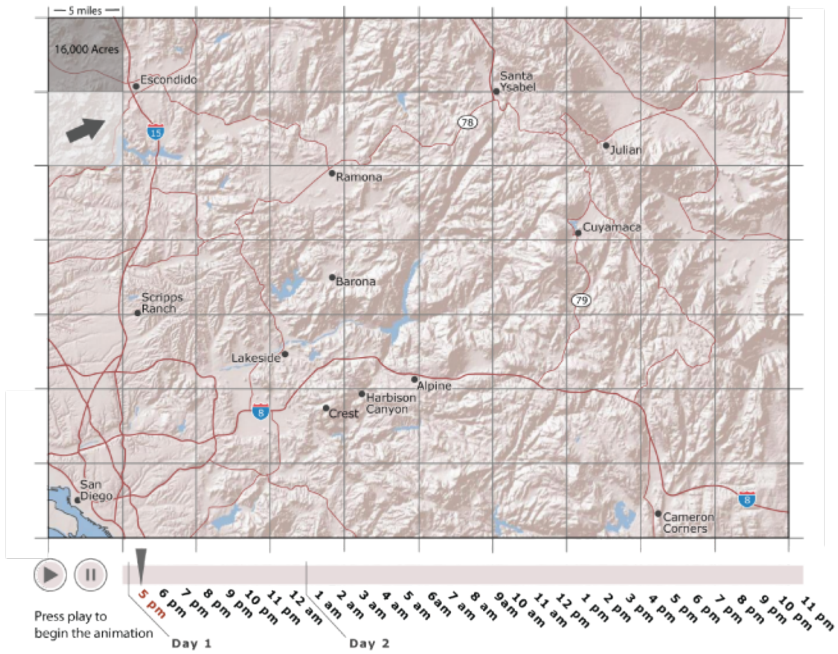
Skip



Does the fire extend over 25 miles across from its northern and southern most ends by 5pm on day 2?

Yes No

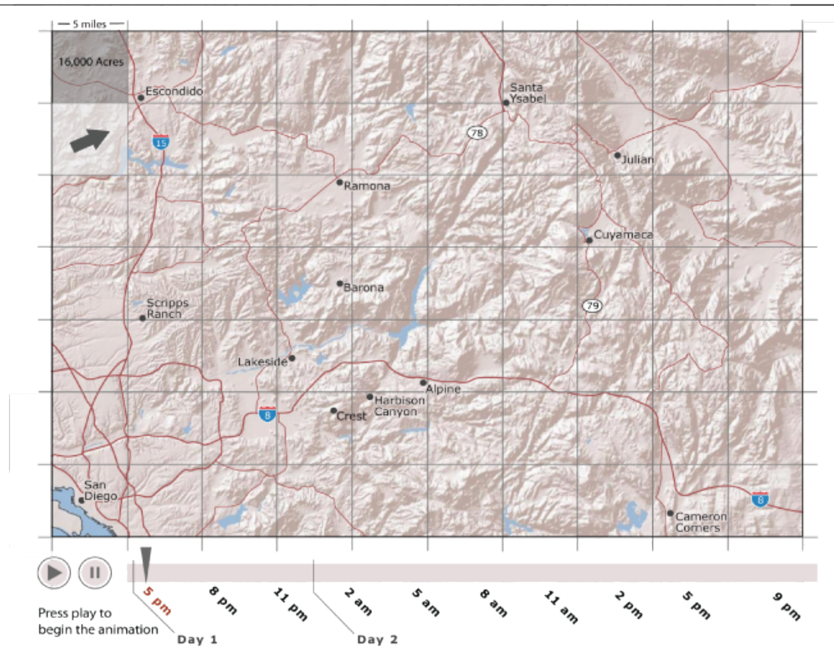
Skip



Did the fire reach the town of Barona on Day 1?

Yes No

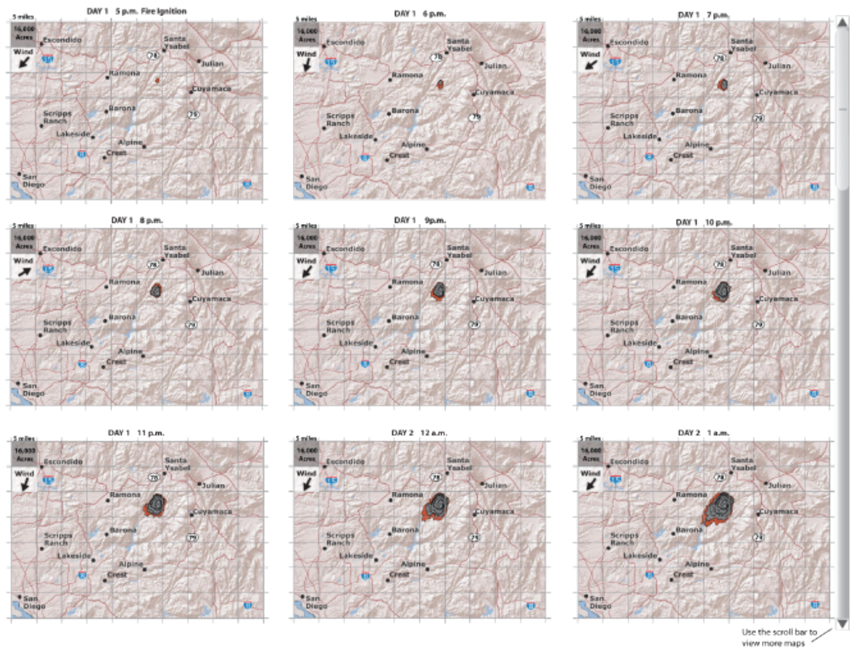
Skip



The whole fire extends over 30 miles across from its northern and southern most points.

True False

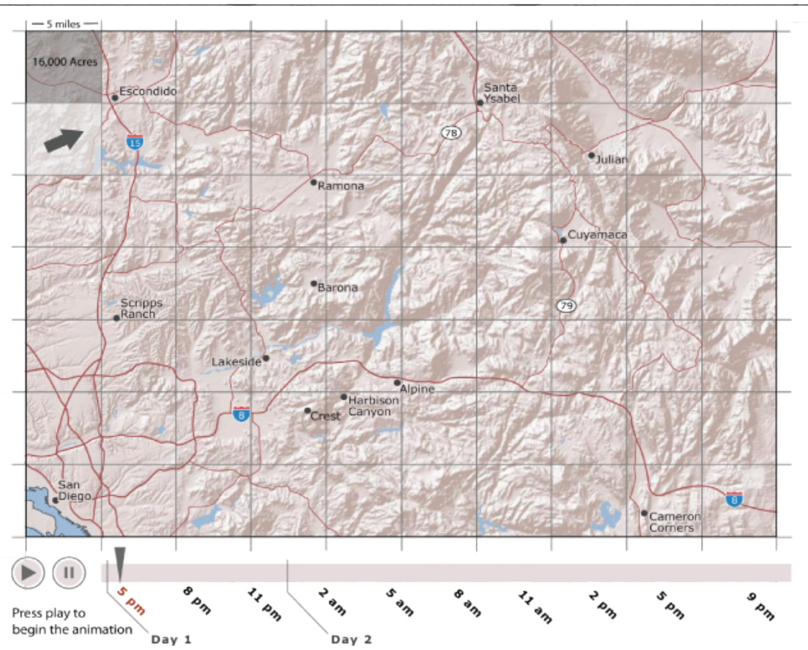
Skip



Did the fire cross Interstate 15 by 6am on day 2?

Yes No

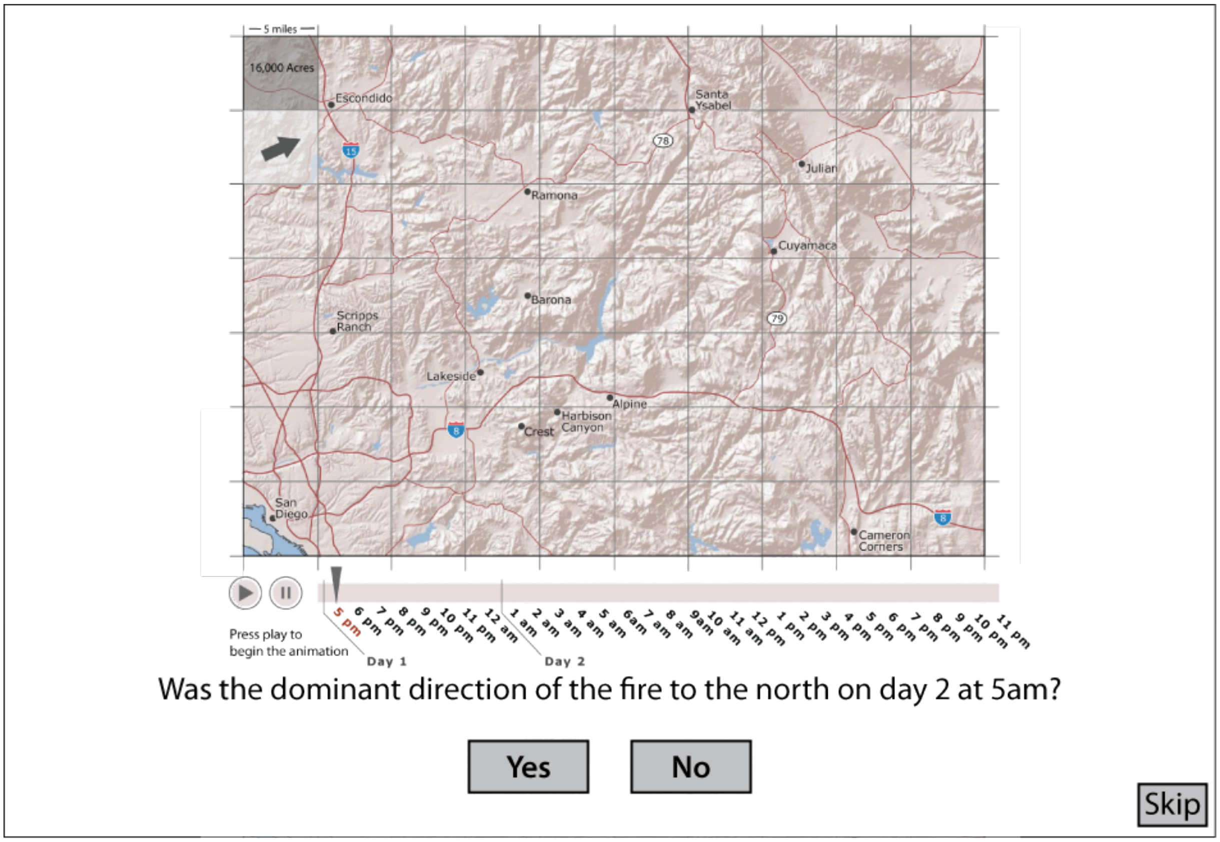
Skip

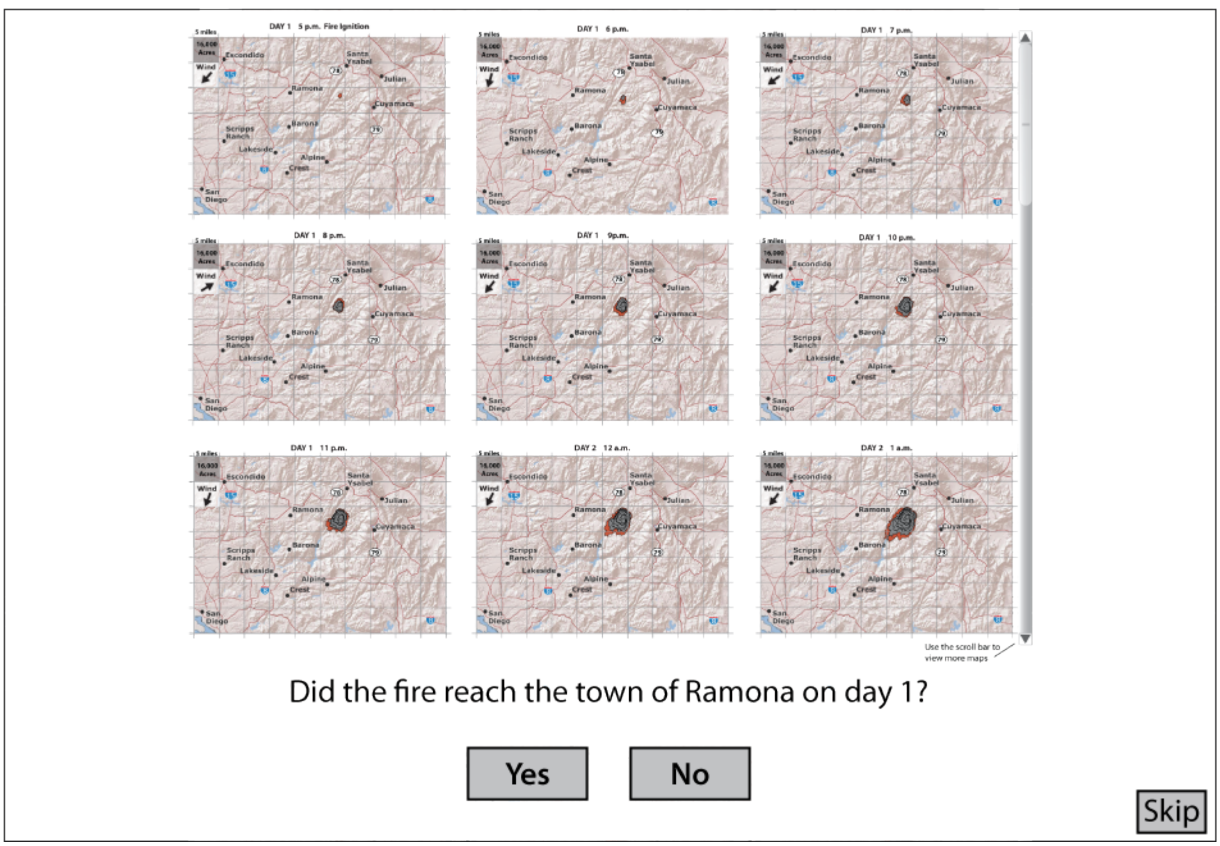


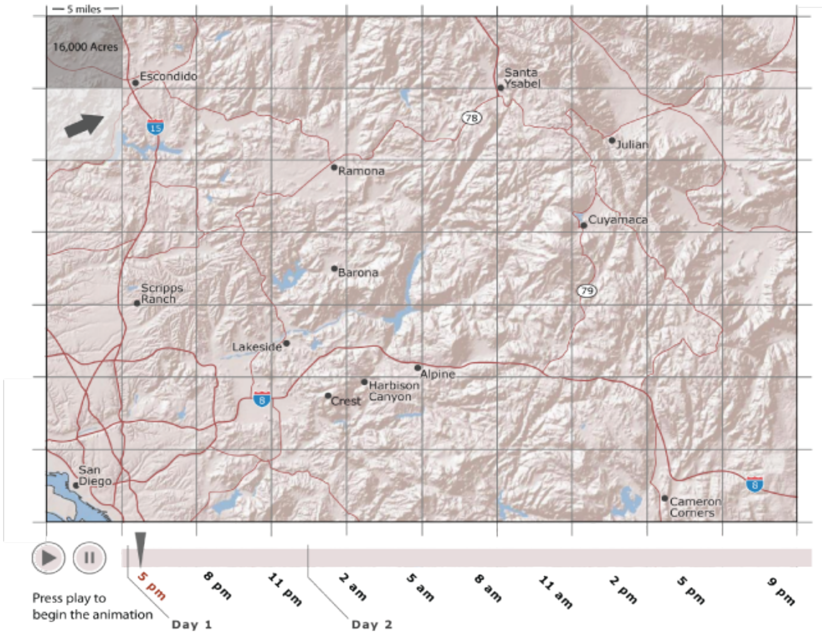
The fire burned over 48,000 acres total by 2am on day 2.

True False

Skip


5 miles
16,000 Acres
Escondido
Santa Ysabel
Julian
Ramona
Cuyamaca
Barona
Scripps Ranch
Lakeside
Alpine
Harbison Canyon
Crest
San Diego
Cameron Corners
Press play to begin the animation
5 pm 6 pm 7 pm 8 pm 9 pm 10 pm 11 pm 12 am 1 am 2 am 3 am 4 am 5 am 6am 7 am 8 am 9am 10 am 11 am 12 pm 1 pm 2 pm 3 pm 4 pm 5 pm 6 pm 7 pm 8 pm 9 pm 10 pm 11 pm
Day 1
Day 2
Was the dominant direction of the fire to the north on day 2 at 5am?
Yes
No
Skip

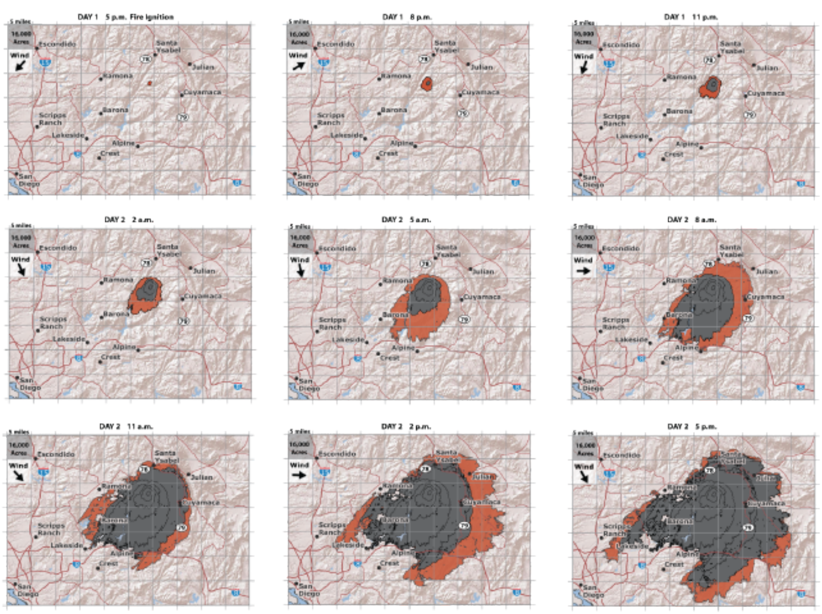

Did the fire reach the town of Ramona on day 1?
Yes
No
Skip



The fire extends over 5 miles across on day 1 by 9pm.

True False

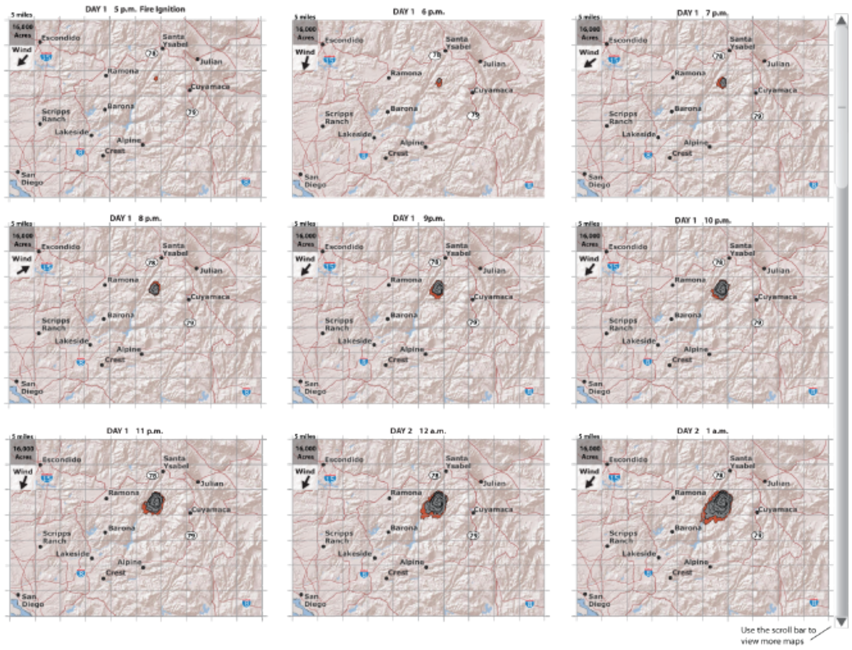
Skip



Did the fire reach the town of Santa Ysabel by 7am on day 2?

Yes No

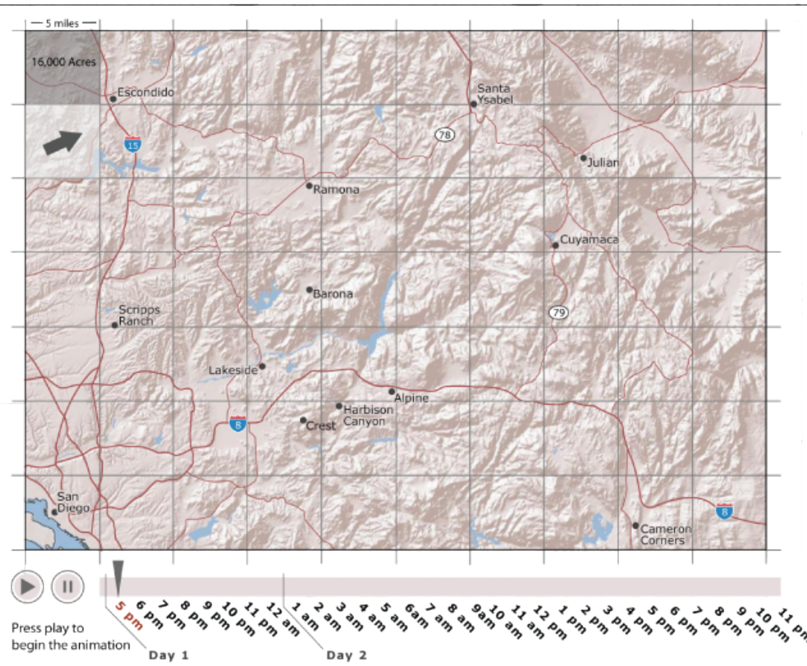
Skip



The whole fire extends over 30 miles across from its eastern and western most points.

True False

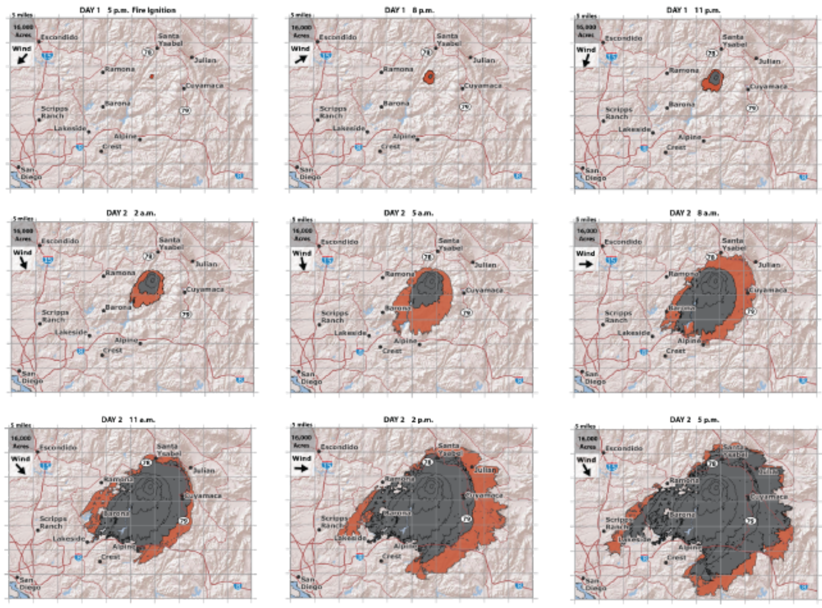
Skip



Did the fire reach the town of Barona by 8am on day 2?

Yes No

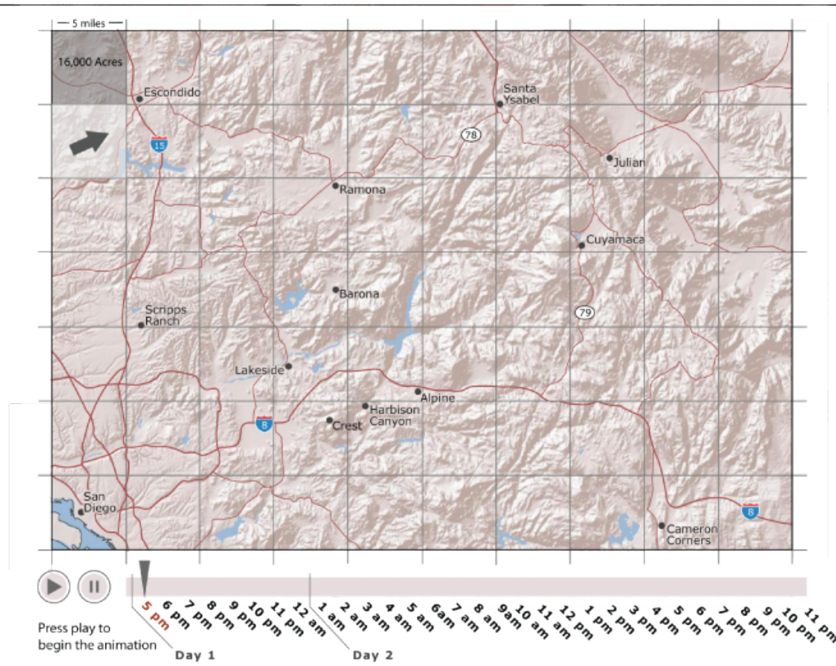
Skip



The fire spread faster at 4am than 2am on day 2.

True False

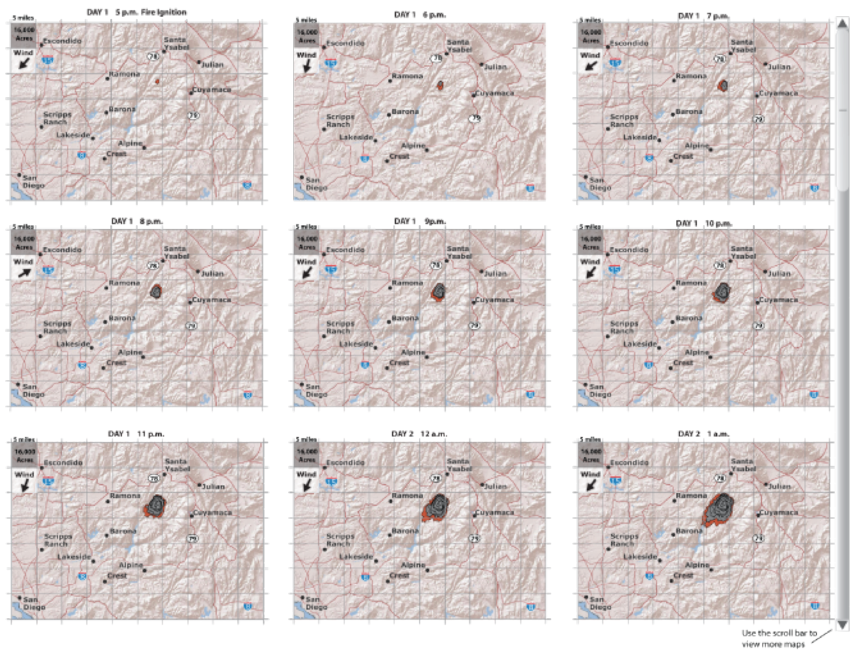
Skip



The fire extends over 40 miles across from its eastern and western most points by 11pm on day 2.

True False

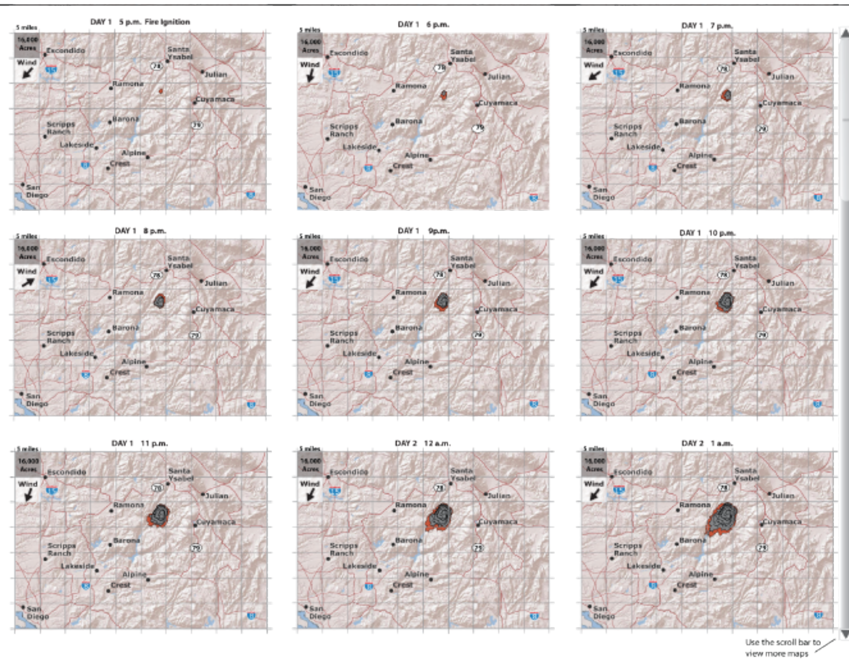
Skip



The dominant direction of the fire progression shifted from 8pm to 9pm on day 1.

True False

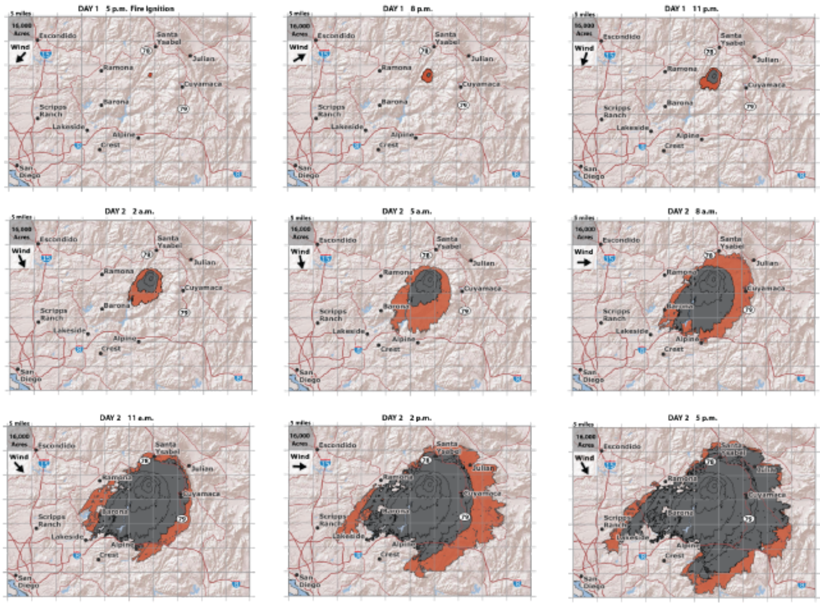
Skip



Did the wind shift direction from 6am to 3pm on day 2?

Yes No

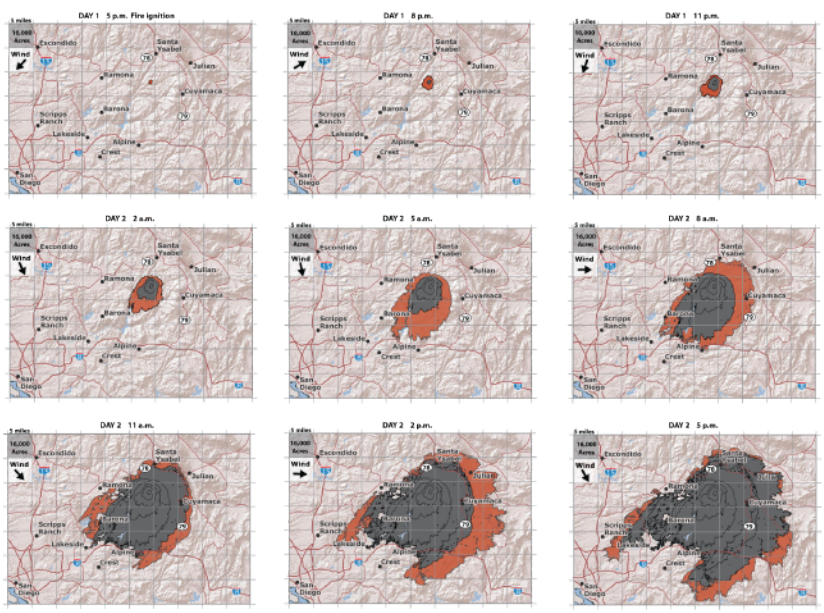
Skip



The dominant direction of the fire progression shifted from 4am to 5am on day 2.

True False

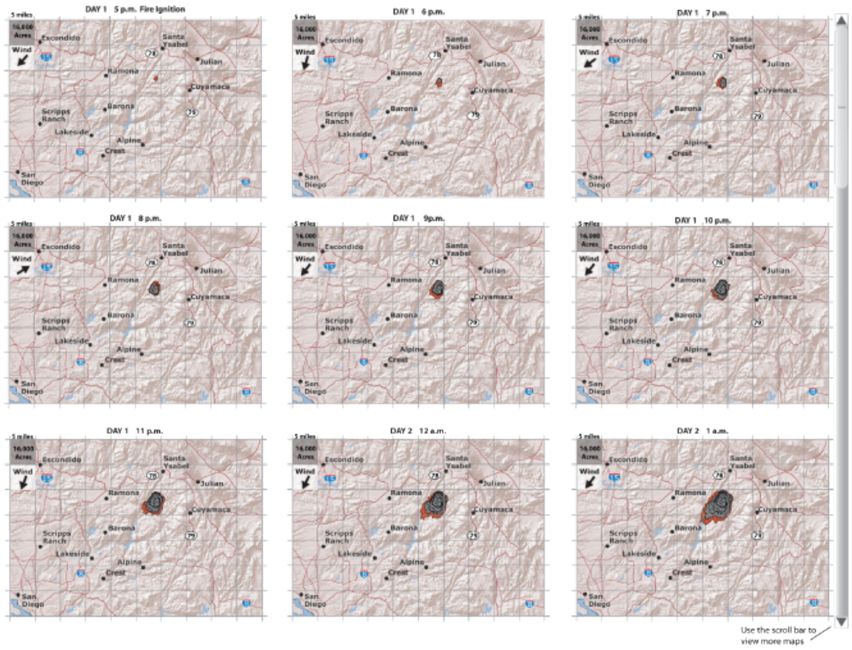
Skip



Was the dominant direction of the fire to the southeast on day 1 at 11pm?

Yes No

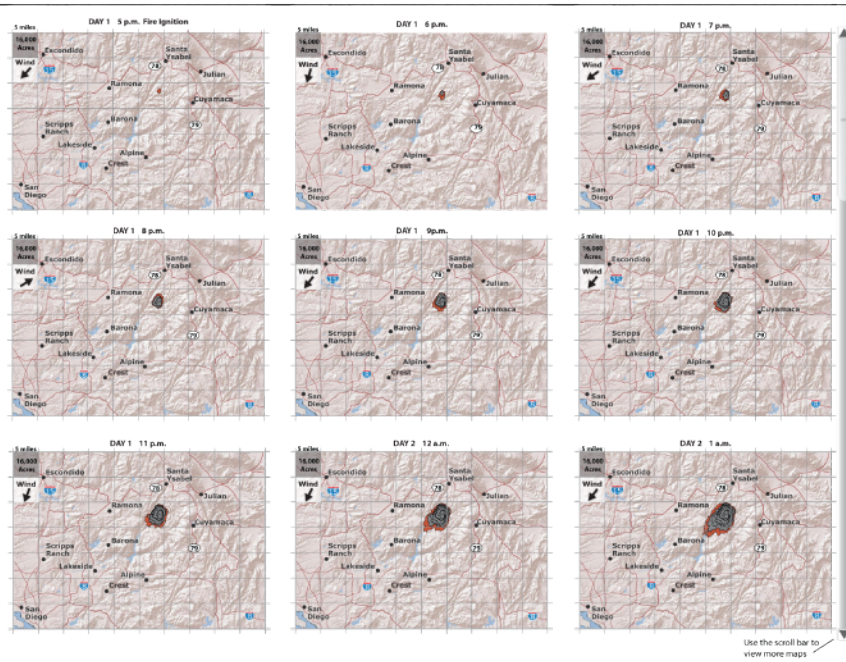
Skip



The fire had crossed over Interstate 8 by 8am on day 2.

True False

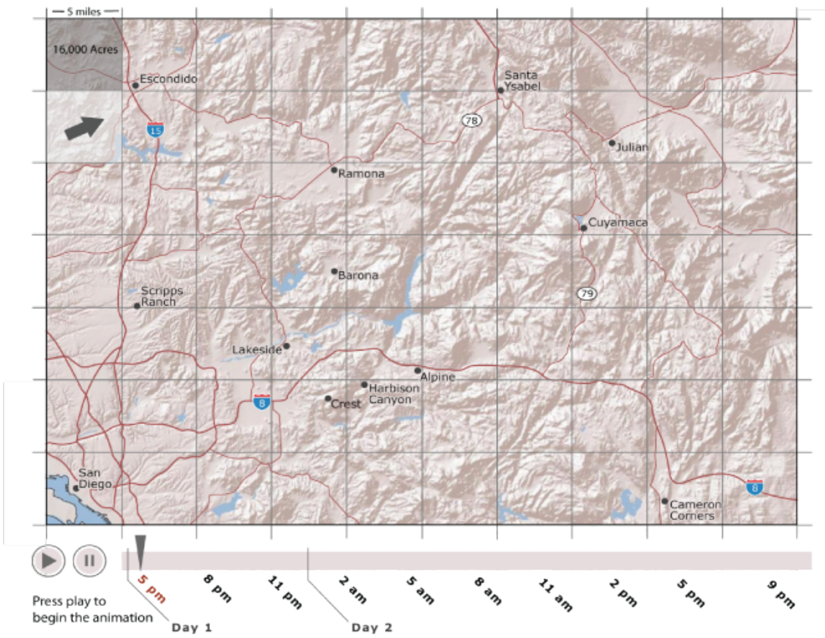
Skip



The fire spread faster at 6pm that 2pm on day 2.

True False

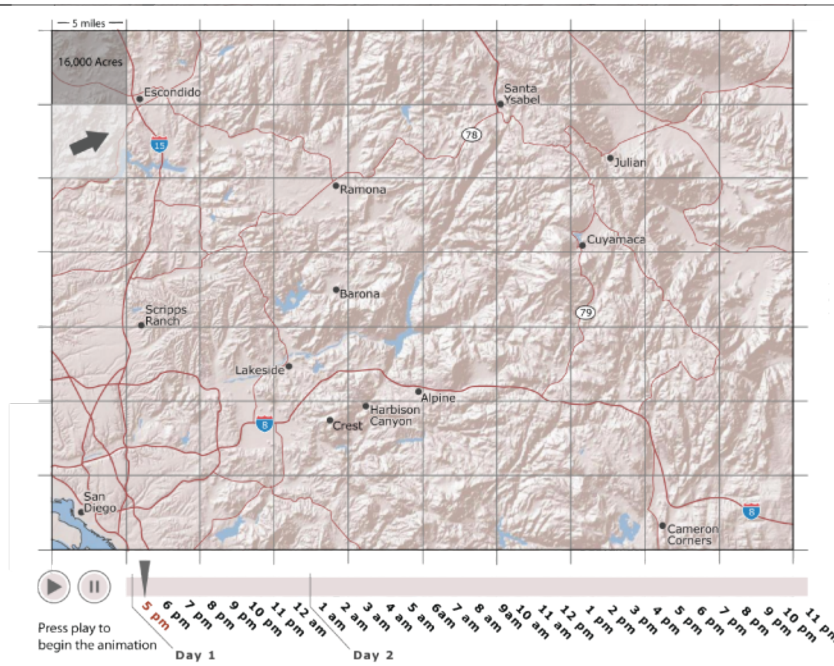
Skip



The fire spread faster at 7pm than 8pm on day 1.

True False

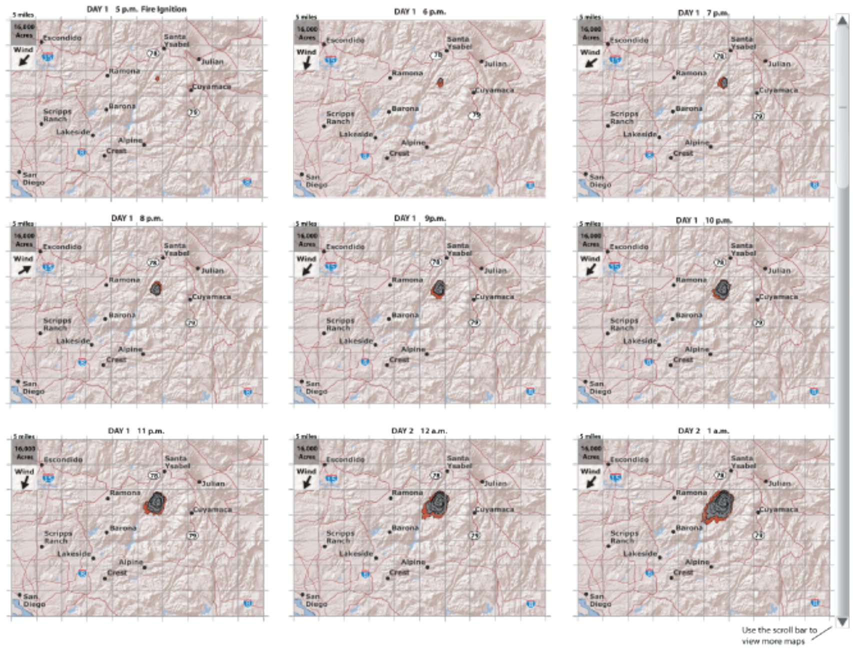
Skip



The dominant direction of the fire progression shifted from 6am to 7am on day 2.

True False

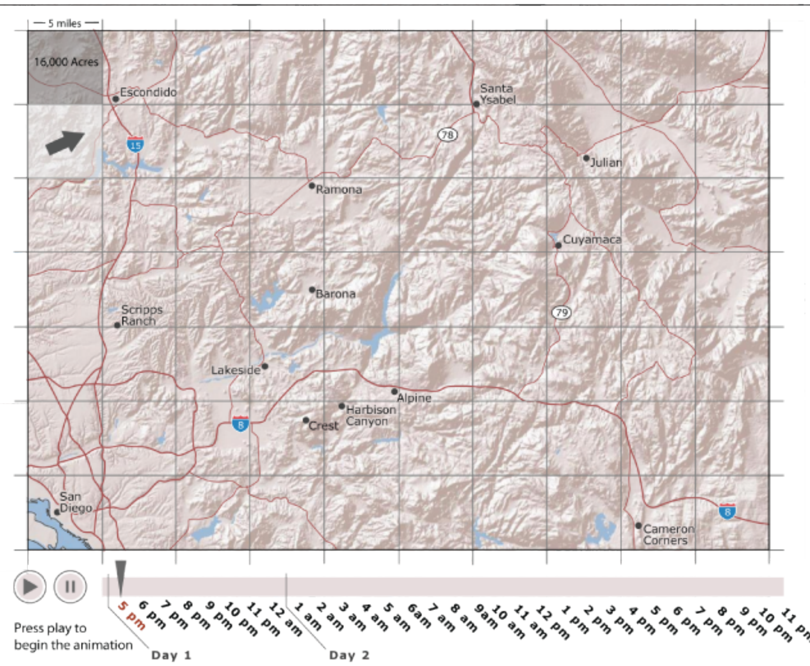
Skip



The fire affected over 16,000 acres total, by 4am on day 2.

True False

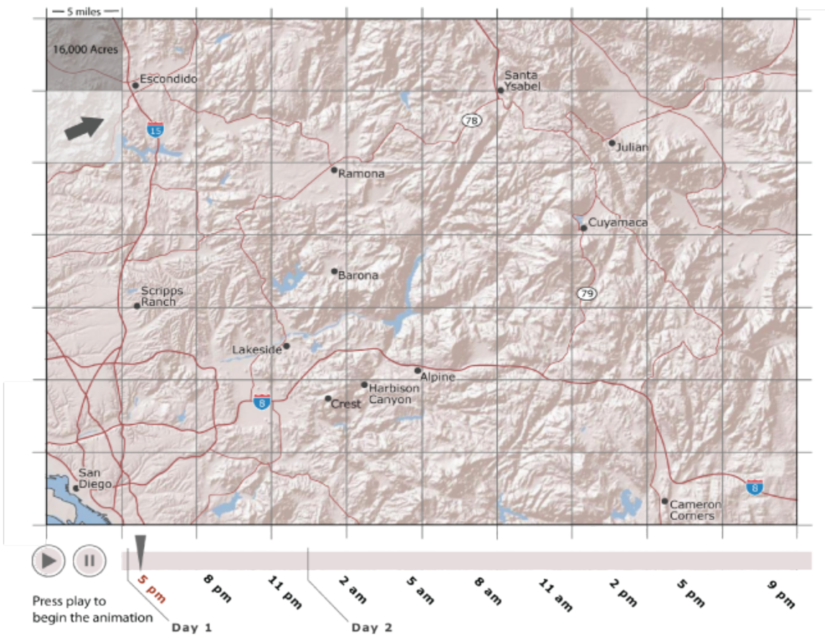
Skip



Was the fire burning south of Interstate 8 by 5pm on day 2?

Yes No

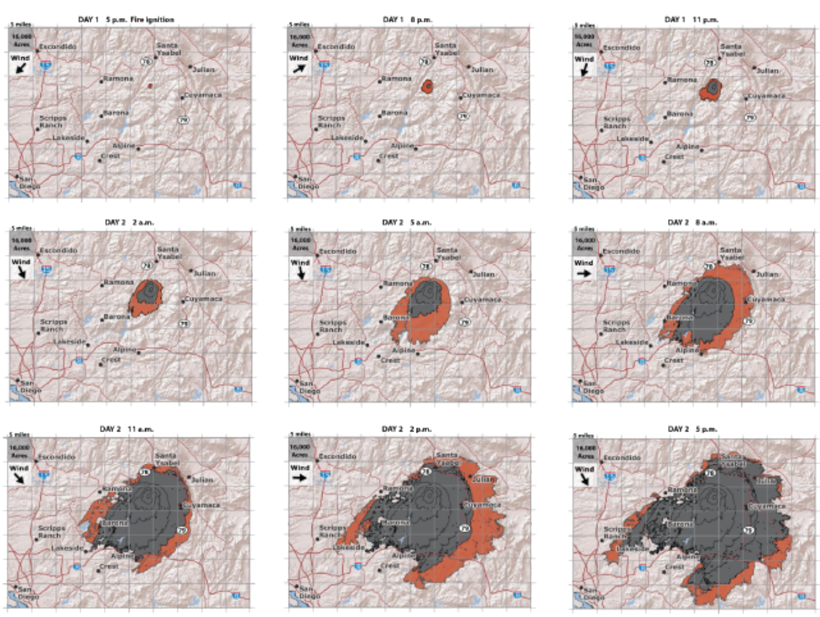
Skip



Did the fire reach the town of Julian on day 1?

Yes | No

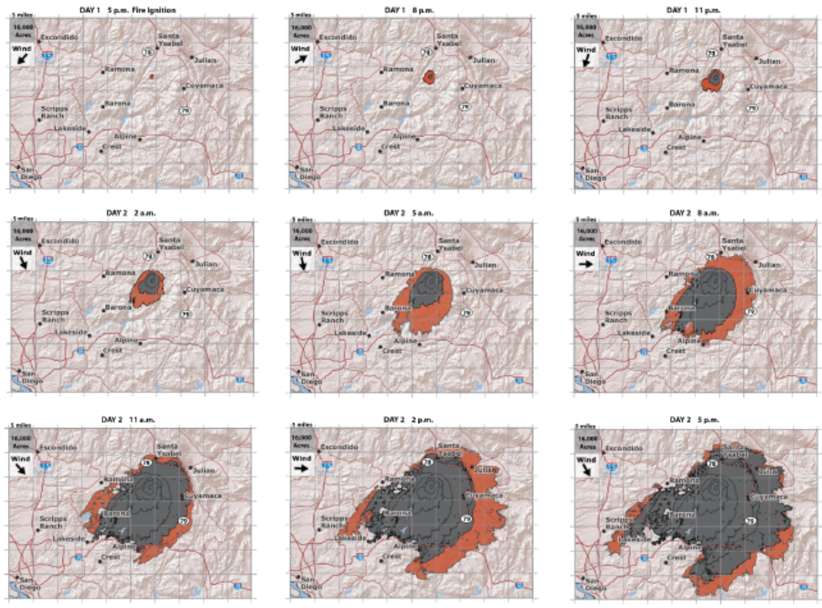
Skip



The fire burned less than 16,000 acres total, by 10pm on day 1.

True | False

Skip



The fire had crossed over Interstate 15 by 5pm on day 2.

True False

Skip

You have completed the test and will begin the **post-test**.

Continue

Have you ever taken a test like this before?

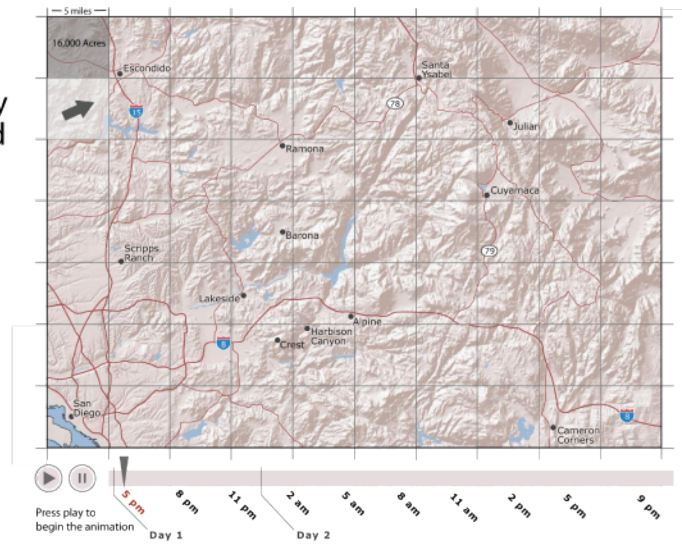
Yes No

Do you think you were provided with enough background information to help you understand the questions?

Yes No

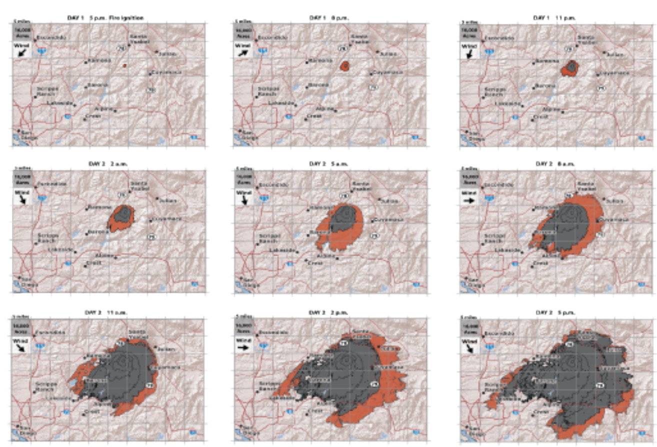
Please explain your overall strategy to answer the questions associated with the **animated maps**:

Submit



Please explain your overall strategy to answer the questions associated with the **small-multiple maps**:

Submit



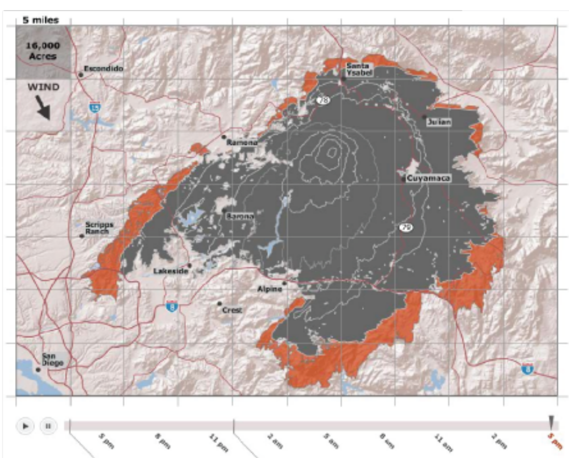
Which type of map would you prefer to use to look at other wildfire events?

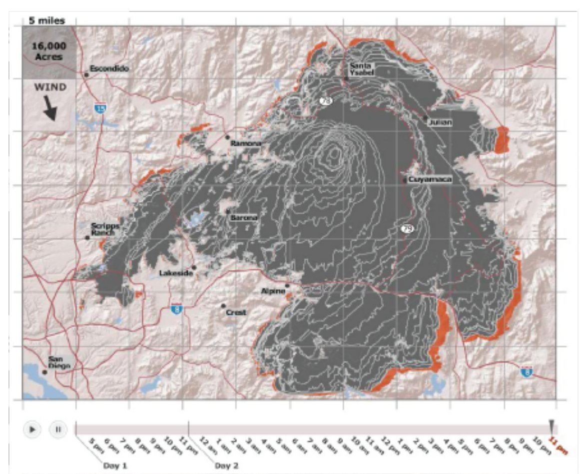
Animated Map

Small-Multiple Map

Neither Map

Which **animated map** did you prefer?

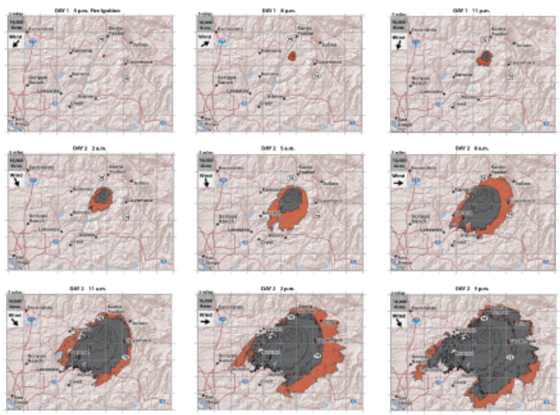


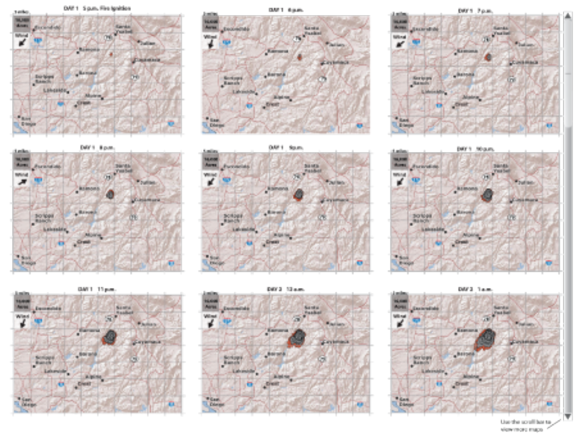


Animated map with 9 scenes

Animated map with 31 scenes

Which **small-multiple map** did you prefer?





Small-multiple map with 9 scenes

Small-multiple map with 31 scenes

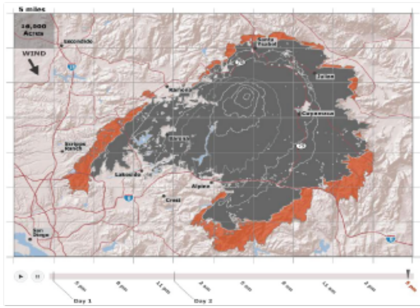
Do you feel that one of the four maps helped you understand and interpret the wildfire progression easier?

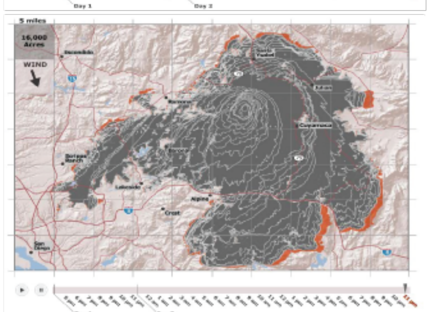
Please explain which one and why.

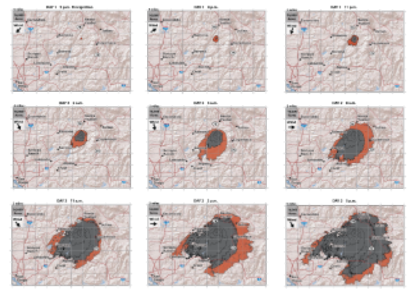
These are the 4 maps you viewed:
1. Animated map with 9 scenes
2. Animated map with 31 scenes
3. Small-multiple map with 9 scenes
4. Small-multiple map with 31 scenes

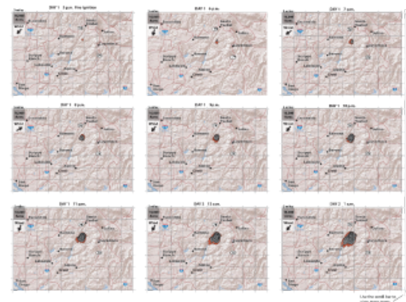
Submit

Overall, which map did you prefer?









Animated map with 9 scenes

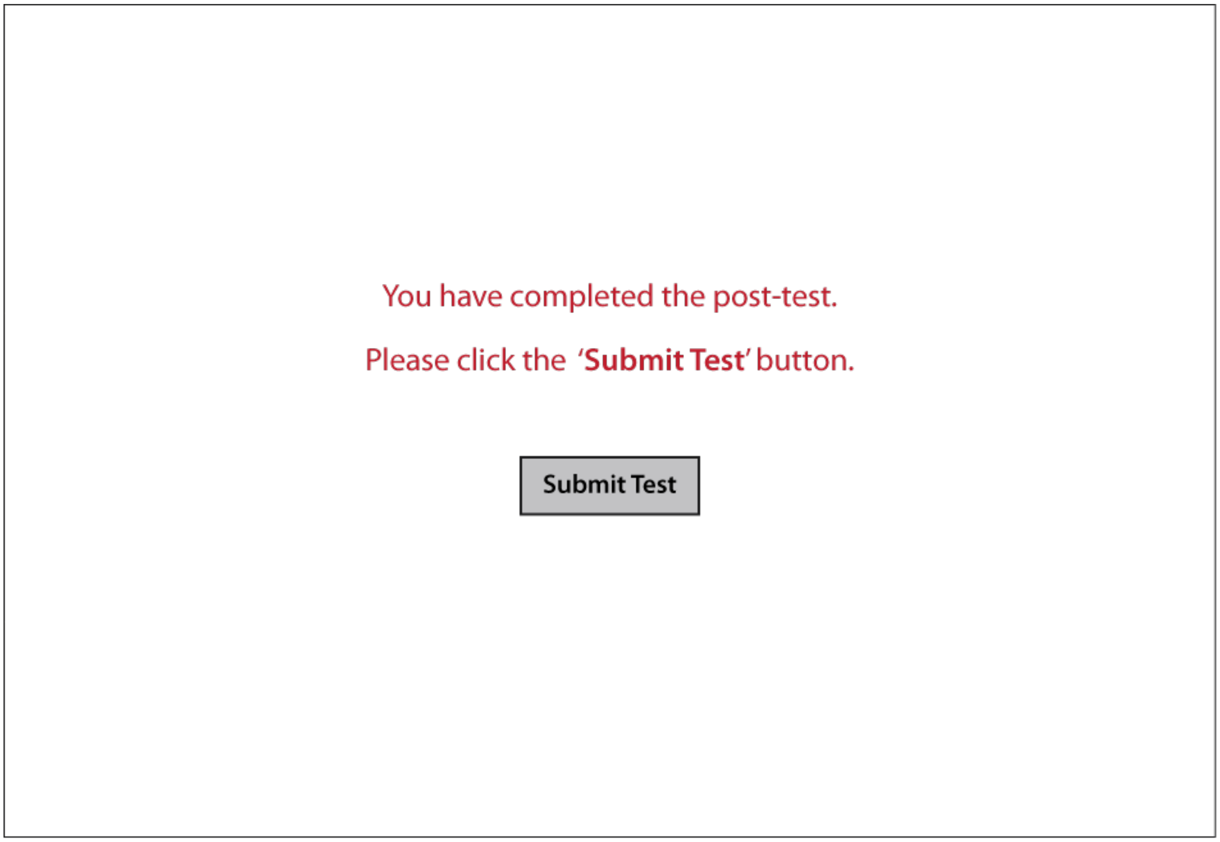
Small-multiple map with 9 scenes

Animated map with 31 scenes

Small-multiple map with 31 scenes

Please provide any additional comments about the test or the maps that may help with future studies like this one:

Submit


You have completed the post-test.
Please click the 'Submit Test' button.
Submit Test


Thank you for your participation!
Please see the researcher to receive $10

APPENDIX C.

ADVERTISEMENT

Participants needed in

MAP READING STUDY

Earn $10

Read maps, make $10. It's that simple!

Contact: Kristie, sociakri@msu.edu

Must be 18 years or older to participate
Posted: 1/21/11
Expected study completion date: 2/11/11

Requires approximately 30 minutes of your time.
You will be compensated $10 cash.
Study will be in the Geography Building.

Map Reading Study
Contact: Kristie Socia
sociakri@msu.edu

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sociakri@msu.edu

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sociakri@msu.edu

APPENDIX D.

CONSENT FORM

Research Participant Information and Consent Form

1. EXPLANATION OF THE RESEARCH and WHAT YOU WILL DO:

You are being asked to participate in a research project about map reading. This study investigates the effectiveness of animated maps compared to a coordinated layout of a series of small, static maps in the context of wildfire visualization. From this study, the researchers hope to learn about the qualities each type of map provides, and integrate them into future designs of maps. Your participation in this study will take approximately 30 minutes of your time. You must be at least 18 years old to participate in this research.

You will be asked to view four different maps on the computer screen and answer questions about what you see on the map. If you agree to participate in this study you will be asked to complete a pre-test, test and post-test. In the pre-test you will be asked simple questions about your background and map-reading experience. In the test, you will view two animated maps and two static maps and will be asked a series of questions about each map. In the post-test you will indicate your map preferences and viewing strategies.

2. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW:

Participation in this research project is completely voluntary. You have the right to say no. You may change your mind at any time and withdraw. You may choose not to answer specific questions or to stop participating at any time. Whether you choose to participate or not will have no affect on you.

3. COSTS AND COMPENSATION FOR BEING IN THE STUDY:

You will not incur any costs for participating in this study. You will be compensated $10 for completing your participation.

4. CONTACT INFORMATION FOR QUESTIONS AND CONCERNS:

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher, Kristie Socia (Graduate Student, Department of Geography, Michigan State University, 116 Geography Building, East Lansing, MI 48824, sociakri@msu.edu, 517-355-4649) or Dr. Kirk Goldsberry (Assistant Professor, Department of Geography, Michigan State University, 116 Geography Building, East Lansing, MI 48824, kg@msu.edu, 517-353-0308)

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

5. DOCUMENTATION OF INFORMED CONSENT.

Your signature below means that you voluntarily agree to participate in this research study.

____ ______________________________
Signature Date

Your signature below means that you have received $10 for participating in this research study.

____ ______________________________
Signature Date

You will be given a copy of this form to keep.

APPENDIX E.

t-TEST RESULTS

Influence of Map Type

		Mean	Mean Difference	95% Confidence Bound	Standard Deviation of Difference	t	df	p-Value
H_0: No difference between task accuracy vs. H_1: Small-multiples will elicit higher task accuracy rates.								
Accuracy	Small-Multiples	0.854	0.050	0.028	0.091	3.867	49	0.000
	Animation	0.804						
H_0: No difference between response times vs. H_1: Small-multiples will elicit faster response times.								
Response Time (s)	Small-Multiples	21.832	-4.267	-3.097	4.937	-6.112	49	0.000
	Animation	26.099						
H_0: No difference between confidence levels vs. H_1: Small-multiples will elicit more confidence responses.								
Confidence	Small-Multiples	0.861	0.020	-0.001	0.088	1.605	49	0.057
	Animation	0.841						

Table 17. One-tailed *t*-test results for the influence of map type.

Influence of Temporal Resolution

		Mean	Mean Difference	95% Confidence Bound	Standard Deviation of Difference	t	df	p-Value
H_0: No difference between task accuracy vs. H_1: Fine resolution will elicit higher task accuracy rates.								
Accuracy	Fine Resolution	0.885	0.112	0.09	0.09	8.765	49	0.000
	Coarse Resolution	0.773						
H_0: No difference between response times vs. H_1: Fine resolution will elicit faster response times.								
Response Time (s)	Fine Resolution	24.592	1.254	2.407	4.864	1.822	49	0.963
	Coarse Resolution	23.339						
H_0: No difference between confidence levels vs. H_1: Fine resolution will elicit more confidence responses.								
Confidence	Fine Resolution	0.926	0.15	0.121	0.122	8.662	49	0.000
	Coarse Resolution	0.776						

Table 18. One-tailed *t*-test results for the influence of temporal resolution

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