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Pilot Perception of Light Emitting Diodes Versus Incandescent Elevated Runway Guard Lights

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PILOT PERCEPTION OF LIGHT EMITTING DIODES VERSUS INCANDESCENT ELEVATED RUNWAY GUARD LIGHTS

by

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This thesis was prepared under the direction of the candidate's thesis committee chair, Jonathan French, Ph.D., Department of Human Factors & Systems, and has been approved by members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

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Summary

Pilots must understand and be aware of the purpose of each airport sign, light and marking, for there are numerous. The Federal Aviation Administration (FAA) is planning on replacing the current incandescent lighting with far more economical LED airport lighting. In preparation for this change, two experiments were conducted for this thesis. Experiment 1 attempted to determine what pilots know about the meaning of the signs, markings and lights on the taxiways and runways through a questionnaire that was developed with the FAA. Experiment 2 evaluated pilot perception of LED lighting compared to current incandescent elevated runway guard lights.

The meaning of airfield lights is not often stressed in pilot training and many pilots are unsure as to the intended purpose of specific lighting. Experiment 1 attempted to evaluate the uncertainty of these caution lights. In experiment 1, a knowledge survey about runway lighting and markings was created. The survey was developed by a flight instructor and approved by the Federal Aviation Administration. The surveys were given to about 150 pilots with varying flight ratings and experience levels. Experiment 1 results determined that there is a need for more intensive or remedial training on some airport signals. Results also showed that some runway signals need to have greater cue salience. Experiment 2 was designed to replace the existing elevated runway guard lights at a local airport from incandescent lights to light emitting diodes.

Permission to cross onto the runways from a taxiway at airports must be given by the air traffic (ground) controller. The demarcation between taxiway and runway is indicated by the elevated runway guard light (ERGL), which signals to the taxiing pilot to hold short at the border of the runway until permission to cross the intersection is obtained. Incandescent lights are currently installed in the ERGLs. Experiment 2 of this thesis was designed to evaluate pilot's

perceptions of the elevated runway guard lights if they were to be changed to light emitting diodes (LED). Experiment 2 was conducted to determine if pilots distinguish a difference in brightness, and noticeability as well as the level of distraction of both the incandescent and LED ERGLs.

Results of the ERGL survey indicated that the ERGL which, was LED, wasperceived to be brighter, less distracting and more noticeable than the current incandescent lights. Additionally, pilots preferred the LED ERGL over the incandescent. These results argue that LED bulbs will certainly be as good as current incandescent bulbs in alerting pilots and in many cases may be better than current bulbs.. Besides the potential to increase the salience of the taxiway lighting, LEDs are dramatically less expensive to use and maintain. For example, their lifespan is ten times the life of an incandescent light. Replacing the considerable number of lights on an airport with LED fixtures will bring a significant savings to operations.

These studies were part of a sponsored project by the FAA (Airport Safety Technology Research and Development Sub-Team, AJP-6311) in preparation for introducing LED technology to airport lighting.

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Introduction

Since airports require efficient use of limited funding, reducing annual operations costs is an important concern. A potentially dramatic way to reduce the cost associated with airport operations is to replace current incandescent lighting with light-emitting diodes (LEDs). Currently, incandescent lights are used at airports worldwide as approach, taxiway, centerline, and touchdown zone lights, as well as other lighting needs. Data from commercial packaging of typical lights indicates that the average lifespan of an LED is about 60,000 hours compared to about 1,500 hours for the incandescent lights. The cost in the reduction of replacement lights alone would make switching to LED more cost effective than retaining the current incandescent lights (Casserly, 2008). In addition, the cost per kilowatt hour for incandescent lights is about 10 times more than LEDs, further supporting a switch to light emitting diodes (Van Horn, 2004). The FAA is considering a new LED Elevated Runway Guard Light (ERGL) fixture with an alternate flash rate of LED illumination for at runway intersections. An ERGL is a specific light used to indicate a holding position before crossing a runway. The primary purpose of these guard lights is to reduce the occurrences of runway incursions.

A good deal of research on the luminosity and perceptual effects of LED runway lights under controlled laboratory conditions has been conducted at the Rensselaer Polytechnic Institute (RPI) in Troy, NY (Bullough, et al, 2007, Bullough et al., 1999, Bullough, et al, 1998). If it could be shown that no loss of pilot awareness of the ERGL occurred with an LED, then LEDs might replace other runway lighting fixtures at substantial cost reductions for airport operations. The purpose of Experiment 2 was to evaluate pilot awareness of LED ERGL under typical runway conditions and under different ambient illuminations, which was needed to prove situational awareness was maintained.

History of Lighting. In the early 1920's, when aviation was in the early stages of development, the only safe flights were considered to be during daylight and good visibility (Komons, 1978). Aviation gained popularity due to the United States Airmail Service. Before the advent of commercial airlines in the 1930's, planes were considered unsafe and used primarily to transport letters. There was no way for the pilots to see where they were going at night, and there were no reliable ground based navigation aids. The brave pilots often got lost, and the government lost money due to the mail that was not delivered, along with the plane and pilot that were not recovered (Van der Linden, 2002). In order to make flight a realistic business and method of transportation, flying needed to be accomplished safely during all hours. Pilots needed to see where they were going, especially in critical phases of flight, such as take offs and landings.

Aerial lighting came from the basic idea of marine lighting, although there were significant differences between the two types of transportation (Komons, 1978). Ships were on the surface and only relied partially on lighting due to accurate navigation instruments. Planes relied heavily on identifying towns, which was often difficult to do, because of an abundance of city lights in certain areas. In order to travel safely along a designated route, airway beacons were developed and used in December 1929. Beacons were placed on a tower, rotated and had different colors to verify locations. Various rotating speeds and degrees of brightness were tested for efficiency. Finally, in 1931, the 1000 watts incandescent light was decided as the standard beacon. (Komons, 1978)

Airstrips along the routes of flight needed to be identified easily to pilots, as well as the runway lengths and edges. In order for pilots to recognize fields from the air, centerlines and edges of runways were marked by paint and by lights. Approach lights, boundary lights to mark the field's boarders, and obstruction lights were used all in effort to increase safety. By the mid 1920's, airmail routes were shortened and mail was being transported much more quickly due to the 289 lighted beacons that allowed for night flight (Brady, 2000). By 1933, two lighted federal airways existed along 18,000 miles with easily identifiable airfields along the route (Komons, 1978) .

Night flying is now safe and common due to the increase in runway and airport lighting. The runway has edge lights and centerline lights to identify all the boundaries and center of the runway. Along the taxiway are blue edge lights to aid a pilot's ground navigation as well. There are rotating airport beacons that are colored depending on whether the airport is designated for military, civilian, helicopters or seaplanes. Lights at an airport change color depending on the distances of a runway. For example, near the departing end of a runway, the lights eventually change from white to red. The change in color lets the pilot know the runway is ending. In order to fly safely, colors and types of lighting need to be known, easily identified and understood.

A large number of taxiway and runway lights have been developed to increase the safety of flight on airport property. These are expensive to maintain. Additionally, the meaning of airport lighting is not stressed in pilot training. Experiment 1 evaluated the general knowledge pilots have about airport runway lighting and other signals. This information could help determine how much remedial education the FAA needs to consider regarding airport cues. It may also help to identify which signals are in greater need of cue salience for safe airport operations. Experiment 2 determined if the LED ERGL was at least as salient as the current incandescent ERGL and to determine the extent of an LED distraction. This experiment required the FAA to deliver a manufactured LED ERGL for the sole purpose of this research.

Experiment 1: Airport Lighting Questionnaire

Background

While waiting for the delivery of the prototype LED elevated runway guard lights, a questionnaire was used to evaluate how much pilots know about the lighting at airports. The name and purpose of taxiway and runway lighting is not stressed in pilot training and is frequently redundant with paint and other markings. The only structured knowledge tests that focus on airport lighting in the FAA written exam are to demonstrate adequate aeronautical knowledge. There are only about ten questions that deal with lighting in a bank of hundreds of questions regarding other aspects of flight, such as weather, flight planning, performance and aerodynamics. Sixty questions are drawn at random in the current FAA exam and given to the pilot applicant. A pass rate of 70% is required. Therefore, it is possible for a pilot to be dangerously unfamiliar with runway lighting and still pass the FAA written exam.

The FAA question bank is available to pilots prior to taking the test and has been since the mid-1980s (Casner, Jones, Puentes, & Irani, 2003). This creates some concern that the answers are memorized, instead of being studied and understood. There was an experiment conducted in 2003, by Casner, Jones, Puentes and Irani that created alternate knowledge questions. Pilots took the alternative questions that discussed similar information as the published FAA questions. There were significant differences between the unaltered questions, which were answered 87.9% correct, as compared to the new questions, which were answered 73.8% correct. This difference suggests a practice effect and pilots with different ratings taking answering the same knowledge question may not result in more accurate responses.

Since the FAA test bank of questions was determined to be inadequate for the study by the FAA sponsors, the questions used in Experiment 1 were independently designed and approved by the FAA sponsors as adequate to show general knowledge of airport lighting and markings. Additionally, there is a wide variety of experience levels pertaining to airport cue signal knowledge and familiarity. Accordingly, for this experiment, a variety of flight hours was used to organize pilots into more or less experienced pilots.

Gender may also be a factor in test scores. Males are often encouraged to study math and science and typical excel in spatial orientation exercises (Pearson & Ferguson, 1989). Females have not been as encouraged to get involved in most math and computer classes. This has led researchers to believe there may be a reduction the females' technical background and produce a shallower learning curve in regards to flight, which relies heavily on technical knowledge and spatial orientation. Although there may be a difference in background for most pilots based on their gender, the knowledge survey is not technical in nature. Females are equal if not better at remembering facts, even if they are not inclined to have greater spatial awareness as compared to males (Turney, 2004). Gender differences therefore were not considered important in the general knowledge survey.

Hypothesis and Design

The hypothesis for Experiment 1 was that there would not be any difference in questionnaire results compared to experience level, or flight hours. The questionnaire used a multiple choice format, Since the sample size for this questionnaire was small compared to the number of pilots licensed in the US and the Gaussian distribution properties of the sample was uncertain, a non-parametric statistical test was used to compare each of the independent variables separately.

For this experiment, experienced pilot were categorized as having more than 200 hours of flight time. This is the approximate amount of hours needed to attain the flight ratings in order to teach someone how to fly. In most flight training environments, a student first gets their private pilot certificate, followed by the instrument rating, then the commercial certificate and sometimes lastly the certified flight instructor rating (CFI). Typically, the more advanced certificates held, the more flight hours that have accumulated. This is not always the case though. For this reason, this experiment determined experience by the amount of flight hours as a good indication of the experience with airport cue signals.

Methods for Experiment 1

Participants

A list of questions was designed and approved by the FAA sponsors of the study. It was administered to pilots with a variety of flight histories to determine how much general knowledge they had about airport cues. The list of questions is located in Appendix A, and only considered airport lighting and markings. The surveys were distributed among various ground school classes and the data was collected and evaluated. Ground schools included those at Embry-Riddle Aeronautical University (ERAU) and those from local Flight Based Operators. At Oshkosh AirVenture in 2010, there were also a limited number of questionnaires collected.

Apparatus and Procedure

The questions were compiled from aeronautical knowledge in text books that all pilots are required to be familiar with in order to pass their knowledge exam. The questionnaires were given to pilots in training at ERAU and at different flight schools off campus. The pilots were only allowed to take the questionnaire one time, as not to skew data with practice effects. The majority of conditions of completion were standard paper and pencil, but some data were collected using online survey techniques. No attempt was made to evaluate these different question formats. The main focus was on the responses to the general knowledge questions.

Results and Discussion

Below is a chart of the correctly answered questions of the all participants. There were twelve questions based on airport lighting and marking knowledge. The first nine questions were logistic and the next thirteen were analyzed below. The question numbers correspond to the questions in the survey located in Appendix A.

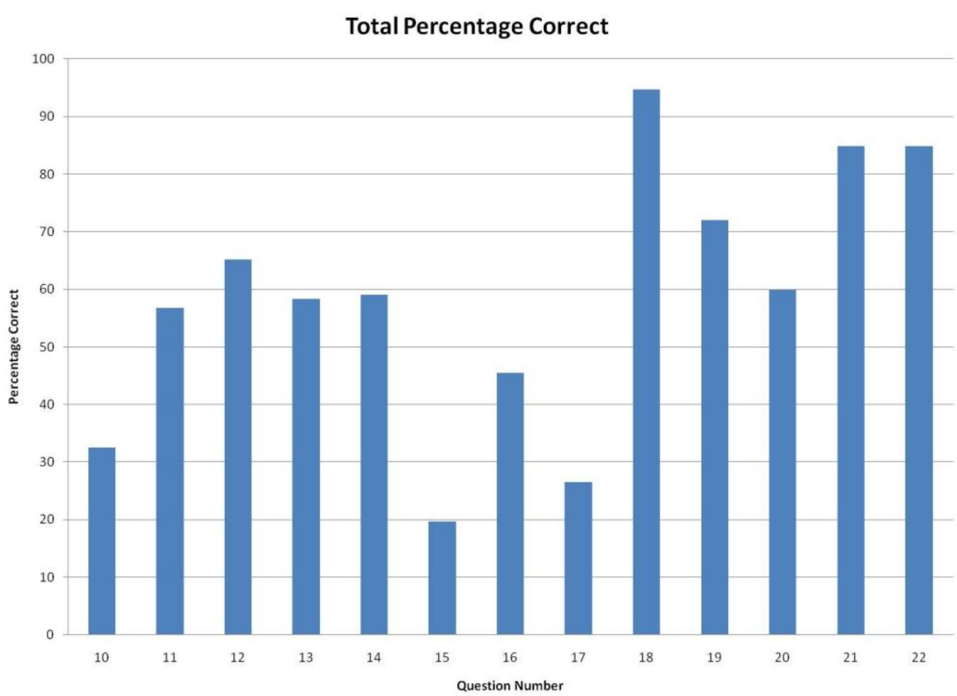

Figure 1. Correctly Answered Knowledge Questions. Only four of the twelve questions were answered more than 70% correct.

The questions which most participants answered incorrectly were 10, 15, 16 and 17. These are assumed to be the most difficult questions. The questions were:

10. Runway centerline lights are located on one side of the white centerline markings for what reason?

a. Identifies direction of nearest taxiway
b. Identifies where the tower is located compared to the runway
c. Identifies where the terminal is located compared to the runway

15. Which lighting system consists of red and white lights?
    a. Runway edge lights
    b. Runway centerline lights
    c. Runway End Identifier Lights

16. Land and hold short lights are
    a. Always on at the hold short point
    b. white and only lit when LAHSO is in effect
    c. Alternating red and white at the hold short point

17. Regarding runway centerline lights,
    a. Lights are placed every 75 feet along the centerline
    b. Only red lights are throughout the last 2000 feet of runway
    c. Red lights begin 3000 feet from the departing end of the runway

These questions were mostly concerning to runway centerline and edge lighting. The correct answers are in bold. Land and hold short lights are not commonly encountered at airports; therefore, it is not unusual for pilots to answer that question incorrectly. After discussing with the FAA, question 10 was going to be discarded, for the answer is not certain at all airports.

Each pilot must be on a runway at least two times for each flight; one time to take off and one time to land. This demonstrates that pilots are extremely familiar with the environment. This may infer that the pilots' have a limited amount of knowledge of the runway environment or perhaps that the different colors on a runway are not very important. Ultimately, most pilots know where the runway is and how to get to and from the area safely. Pilots have airport diagrams to determine runway lengths and are required to calculate the amount of runway required for take-off and landings. On certain runways there are also runway remaining markings to tell the pilot how many thousands of feet remain available. This may be another reason why distance remaining lights are not known by all pilots.

The data was also analyzed to identify whether the level of pilot rating correlated to the number of correctly answered questions. Pilots with more experienced certificates, such as Commercial and Certified Flight Instructor (CFI) had more correct answers than those less experienced pilots who had a Student and Private Pilot certificate. These results are displayed below in Figure 2. Due to the unequal number of each rating, the totals are in percentages. There were 132 surveys collected with a total of 13 knowledge questions. Almost all the questions are more likely answered correctly by those participants with a more experienced rating. Questions 10,11 and 19 are the questions that do not show this trend. Again, question 10 is thrown out. Question 11 and 19 are based on knowledge and not as heavily on practicality. There is no need to understand the lighting and reasons behind them in order to safely move around the airport. Knowledge is focused on in the early stages of flight training and forgotten. In order to solve this, continuous flight education is required.

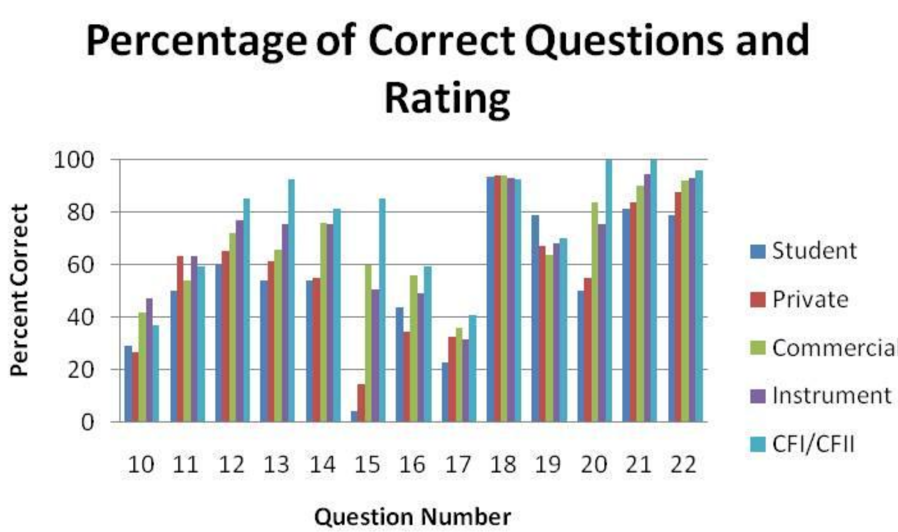

Figure 2. Correctly Answered Knowledge Questions Compared to Ratings Held

Due to the fact that the FAA considers 70% correct, a passing grade, the questions that have been answered less than 70% correct are looked at more closely in Figure 3. Each question is compared to flight hours in Appendix A. All but questions 18, 19, 21 and 22 were answered less than 70% correct. Questions 16 and 17 are the two questions that do not show the trend of increased percentage with an increase in flight hours. When looking at the flight hours next to ratings, there is no consistency in correctly answered questions.

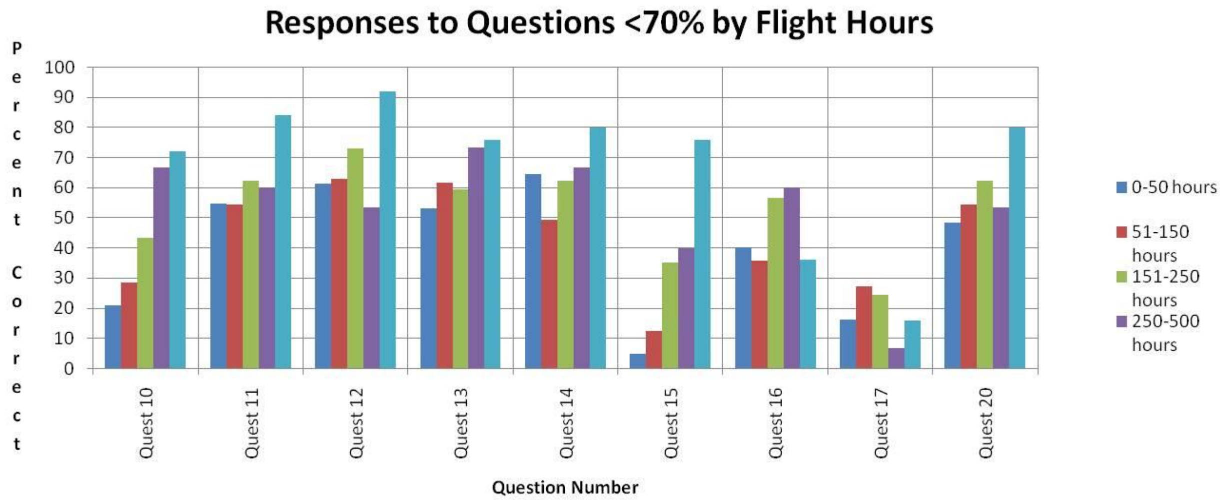

Figure 3. Correctly Answered Knowledge Questions by Flight Hours

Typically there is a correlation with flight hours and flight ratings. The more flight hours, the more experienced rating is usually attained. At a flight training school, such as one that most of the surveys were collected from, may have slower learners that require more time to get a more experienced rating. On the other hand, some students may have fewer hours and a higher rating. Comparing this chart to the flight ratings, there is no consistency shown. Although flight hours are usually shown in similar trends to flight ratings, the numbers are not precisely correlated.

Experiment 2: Elevated Runway Guard Lights

Background

Incandescent light bulbs are currently used to illuminate most major taxiway and runway lighting in all United States airports. This practice was set in place before LED lighting was discovered to be more economical and practical than incandescent lighting. Extensive testing and caution are required to switch light source on airports. This study was designed to determine if LED lighting was equally or more effective in getting pilot's attention compared to current lighting. The economic and maintenance benefits are well known. This research assisted in evaluating the applied test of the LED bulb in typical runway operations.

This study evaluated the Elevated Runway Guard Light (ERGL). The elevated runway guard lights are intended to bring the pilot's attention to the entrances and exits of runways; thereby, reducing runway incursions at airports. A runway incursion is defined by the Federal Aviation Administration (FAA) as, "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft," (Determination of Runway Incursions, 2007). Any incorrect position of aircraft on or near the active runway can be considered an incursion. Ultimately, runway incursions can, but do not have to, result in an accident or incident. Ideally, reducing runway incursions will increase airport safety. Elevated runway guard lights are designed for this purpose.

The elevated runway guard lights are located abeam the hold short line at the edge of the runway to attract a pilot's attention that there is a runway ahead. Figure 4 is a picture of the ERGLs at a local airport, Daytona Beach International Airport (KDAB). The International Civil Aviation Organization (ICAO) formally named these "runway guard lights" to increase situational awareness (Runway Incursions, 2009). Runway guard lights are located at most airports, especially those with high traffic.

Figure 4. Incandescent Elevated Runway Guard Lights

The early expansion of safe flight required lights, and incandescent lights were most readily available. Currently, the same is true at airports around the world. However, newer, more efficient lighting sources are now available. These newer LEDs would dramatically decrease cost and increase efficiency. Figure 5 is the LED ERGL developed by the FAA, used for this experiment.

Figure 5. FAA Developed LED ERGL. Daytona Beach International Airport maintenance installed the ERGLs.

A comparison of LED and incandescence will be instructional for the full benefits of switiching to LED to become apparent.

Light Emitting Diodes and incandescent lights. Incandescent lights contain a filament that heats up when electricity is applied. The heated filament creates light. Because incandescent lights burn at extremely high temperatures, upwards of 3000 degrees Fahrenheit, most of the energy is consumed by this. On the other hand, light emitting diodes are solid state semiconductors that have a current running through it to produce light. Being that the LEDs are solid state, they are less likely to be disrupted by vibration or a change in voltage. This is one of the many advantages seen in light emitting diodes. (Haitz, Kish, Tsao, & Nelson, 1999)

The technological differences in LEDs also offer a number of advantages. The most attractive attribute is the economic benefit. Light emitting diodes last on an average of fifty times longer than incandescent lights, which are currently being used (Fleischer, 2001). Other than the longevity, LEDs use less electricity. Because of the LED technology, they produce almost no heat, which results in all the energy being used for light. The continual cost to run the lights would be reduced substantially. LED traffic lights have been reported to cost 80%-90% less than those using incandescent lights (Energy Crisis Conservation Program and Resolution, 2001). LEDs are being used in a wide variety of fields, including road transportation, all noting the benefit of lower costs (Haitz, Kish, Tsao, & Nelson, 1999). Table 1 compares the output of a light emitting diode to an incandescent light, based on lumens that are being emitted. At some illuminations, LEDs are more than ten times more efficient in using electricity.

Table 1. Light Output (Comparison Chart, 2009)

	Light Emitting Diodes (LEDs)	Incandescent Light Bulbs
Lumens	**Watts**	**Watts**
450	**4-5**	**40**
800	**6-8**	**60**
1,100	**9-13**	**75**
1,600	**16-20**	**100**
2,600	**25-28**	**150**

Not only would the LED lights need to be replaced less often and cost less to maintain, but the maintenance fees and cost of having a trained airport operator manually update and ensure the working capability of the lights would be reduced drastically. With the decreased need for maintenance personnel to change the lights, safety would also increase. There would be less people on active taxiways and runways, which would result in a lower probability of accidents and runway incursions.

LEDs have been successfully tested and are currently used in traffic signals, vehicle headlights, flashlights, lamps and other light sources that focus on illuminating one area (Ton, Foster, Calwell, & Conway, 2003). LEDs vary in brightness and color, but there are manipulations and various combinations of technology that can be created to have LEDs resemble the present lighting (Derlofske & McColgan, 2002). If there is no difference perceived in the two lights or if the LED is preferred, then the savings and other benefits should influence the decision to use LEDs in airport ERGLs. With an increase in noticeability, the lights would hope to also serve as an increase to pilot awareness and not as a distraction.

Perception of luminance. There is no standard measurement of visibility, because visibility is what can be seen by the eye. Not only does the human determine visibility, but it is argued that contrast is also influential. In this experiment, both contrast and luminance are taken into consideration. Luminance can be measured in luminous flux in units called lumen (lm). This measurement is the power emitted by the light. Luminous intensity, which is in units of candela (cd), can also be used to measure brightness. A candela is the lumens measured at a particular angle. (Sanders & McCormick, 1993)

Each person sees the brightness of a light differently, especially during the different times of day. This research is evaluating the spatial threshold, which looks at the ability to perceive an object from its background and visual acuity (Boyce, 2003). When two objects are similar in luminance, they are less likely to be seen as two independent objects. On the other hand, if the brightness or colors of the two objects contrast greatly, they are seen as separate items. This theory is known as luminance contrast, which is the main factor in determining one's visual spatial threshold (Boyce, 2009). Visual acuity, which also helps define the threshold, is the measure of detail able to be seen. Daylight would bring a lower light contrast between the environment and the ERGL. With the lower contrast, visual acuity reduces, and the differences in lights at this time will most likely go unnoticed (Boyce, 2009). As the contrast between the ERGL and the environment increase into the night, acuity increases and the lights may become more noticeably different.

Depending on the time of day, the eye uses different photoreceptors. During the day, with more than 3 candelas per square meter, photopic vision is primary and the majority of photoreceptors used are cones. Below .001 candelas per square meter at night scotopic vision is primary and more rods are used. Mesopic vision is used between light and dark conditions, where a combination of rods and cones are used. Rods and cones have different spectral sensitivities. Rods peak at about 507nm wavelength, which is considerably lower than cones, which peak at 555nm (Bullough & Rea, 2004). There is only one type of rod, so they do not see color, but there are three types of pigment within cones in the retina (Goldstein, 2010). The cones see red, green and blue. The rods, which are used more at night, should be able to identify the difference between lights more easily because the elevated runway guard light is amber.

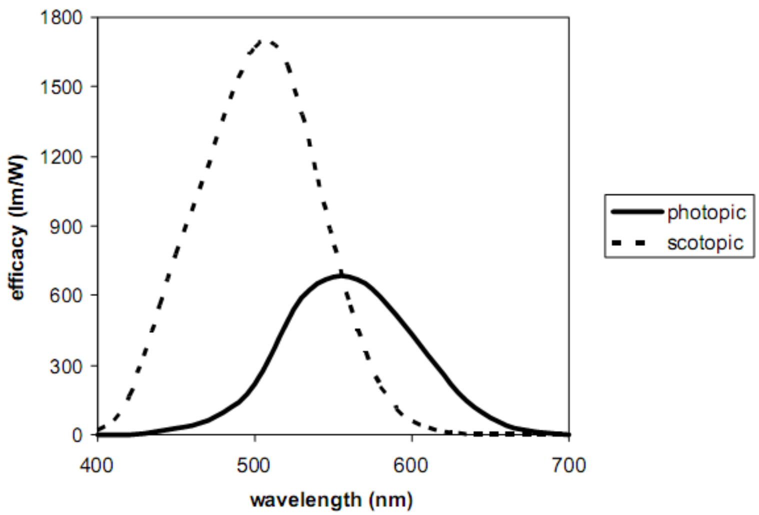

Figure 6. Luminous Efficacy Functions (Bullough & Rea, 2004)

When referring to Table 2, each color occurs at a different wavelength. Depending on the wavelength, the lights will match the eye's wavelength. Cones pick up short (blue), medium (green) and long wavelengths (red). At night, when the rods are mostly used, peripheral vision is lead. Rods are in the periphery of the retina. At night there will be a higher contrast and rods will be used, while during the day, cones will be the primary photoreceptor and during dusk and dawn, both rods and cones will be utilized. (Goldstein, 2010)

He, Rea, Bierman and Bullough conducted a study in 1997 to measure reaction time during mesopic visual conditions. The study was designed to ultimately increase knowledge of human response to light sources during night time. As a determination of visual accuracy, reaction time was recorded. The experiment utilized a method where the background was darker than the lights that needed to be noticed. This condition was referred to as high contrast. The background light as well as the angle of view was changed. The background luminance was initially bright, but decreased throughout the experiment, to increase the contrast between the light trying to be seen and the amount of sunlight in the background. During high contrast conditions, at night, as well as in direct view, when the rods were being used, efficacy increased. The efficacy functions are displayed ahead. (He, Rea, Bierman, & Bullough, 1997) This confirms scotopic vision and rods were primarily used when the environment simulated night, as mentioned earlier. In regards to this experiment, a difference is more likely to be noticed at night due to the light contrast and photoreceptors being used.

In 2005, the FAA contracted researchers to develop a limited test of LEDs. LEDs replaced parts of an approach lighting system at an airport and pilots were questioned on whether or not they saw a difference in the lighting and if there was a difference noted, did it negatively impact their attention. The study was conducted in Pheonix, Arizona, and Grand Forks, North Dakota, by Kahne and Zeitlik to evaluate perceptions of general aviation pilots in extreme weather environments (Kahne & Zeidlik, 2005). Almost half of the responses were collected at night, with the other half being split between dusk, dawn, and day. Overall, results showed that maintenance cost was greatly reduced, the energy cost was reduced by over a factor of four and although most pilots noticed a difference, the difference was not distracting. Of those who participated, 59% of the pilots reported noticing a difference in approach lights due to either color or brightness; no pilot described the LEDs being too bright. A full 98% stated there was no confusion and the lights were at least as easy to see as at other airports. There were some considerable intensity differences between lamps, but there was no negative pilot feedback. In conclusion, there were no problems reported with the changed lighting(Kahne & Zeidlik, 2005).

The FAA was encouraged by these results to conduct a larger scale evaluation, hence the current research.

Rensselaer Polytechnic Institute was contracted by the FAA to create a prototype LED runway guard light that was installed at Daytona Beach International Airport (Skinner, 2010). Flash rate, brightness and configuration were varied to determine the most noticeable and least distracting combination. There were nine participants asked to record their opinions on the lights that they passed. There were no significant differences found between the various flash rates. As a result, the elevated runway guard light chosen as the preference was that which had the highest noticeable rating and the lowest rating for distraction. The participants were asked during the day and night, but only during good weather conditions. A flash rate of 90 flashes per minute and 180 flashes per minute with a 70% duty cycle of the current incandescent ERGL were preferred. At Daytona Beach airport, all conditions of weather, with a larger pool of subjects with the preferred ERGL will be used for this research.

Experience. Both experienced pilots and inexperienced students may have an advantage in this research. Novices may tend to be more tedious in searching their surroundings because of the bottom-up problem solving and decision making procedures (Smith, 2003). Experts, on the other hand, are able to determine more relevant information and environmental cues to formulate decisions due to the experience they have (Chi, Glaser, & Rees, 1982). The information-reduction hypothesis states that experts are able to process more relevant information, resulting in a more accurate conclusion (Haider, 1999). The airport environment can be overwhelming to new aviators, while the more experienced aviators are able to observe the area and gather the necessary information for safe flying.

Experts use various techniques that novices may use incorrectly while formulating conclusions (Jarodzka, Scheiter, Gerjets, & Van Gog, 1999). Due to the fact that perception and perceptual results cannot be taught, even individual experts may not come to a decision in the same manner. Results of the study may vary between experts and novices due to the perceptual strategies used. This study evaluates pilots' perceptions to determine a variation between incandescent and LED ERGLs; therefore it is unlikely for experience to be a variable in this study.

The participants were asked the same questions of how they perceive the two sets of runway guard lights. The study is to determine if the prototype LED ERGL is preferred by measuring perception of brightness, noticeability and distraction. The cognitive method used is simpler than in many experimented cognitive tasks and will rely less on experience and more on personal perception. The participants' attention were drawn to the lights, as indicated on the attached survey; therefore there was limited information being processed. Because the answer in question in this light research was if the pilot perceives a difference is a low functional decision, it is believed that the level of expertise should not be a factor.

Hypothesis. This study evaluated pilots' perceptions of brightness, distraction and how noticable LED elevated runway guard lights and the incandescent lights are comparatively. Student pilots during flights at Daytona Beach International Airport were asked in a training environment by their flight instructors who also filled out their perception of the lights. These pilots were asked at different lighting conditions; twilight, day time and night. At various times of day, the luminance contrast is greater, and it was decided to isolate this possibility by evaluating the different ambient luminosity during different times of the day. The questions used in this evaluation are shown in Appendix A.

Research that has been gathered asking participants the same questions in the same manner. Pilots were asked to look particularly at the lights while on the ground, in the airplane. The survey was handed to the student while the instructor taxied to answer the questions immediately and as honestly as possible. There has been a similar study by Kahne and Zeidlik to support this hypothesis. Pilots noticed a difference in lights, but explicitly said they were no more distracting nor had any negative influence on their attention than the prior incandescent lights (Kahne & Zeidlik, 2005).

The specific hypothesis is that none of the pilots will have negative perceptions about the LED light fixtures and prefer them over the incandescent. Also, experts and novices will have the same perceptions during all times of the day. The brightness will not vary between the two lights. The LEDs will be more noticeable; however, it will not be distracting to the pilots.

Flight instructors were trained on the procedure used to survey the pilots, who were their students. The flight instructors also surveyed themselves. They were briefed as though there may have been a change in the ERGLs. The questioning took place in the plane while the pilot answering the questions in Appendix A was asked. When the plane passed the set of ERGLs at the taxiway intersection, the pilot was asked to fill out the survey and rate distraction, brightness, noticeability and preference of the lights at each runway. The figure of the airport intersections were attached to the survey and located in Appendix B. The flight instructors conducting the survey were not informed what the difference was or what had been changed.

Methods for Experiment 2

Procedure

After the LED prototype ERGLs were installed at the Daytona Beach International Airport, one on the right and left of the 16-34 taxiway intersection identified in Appendix B. The surveys were created, with the help of the FAA sponsor to be as close as possible to a survey used by RPI for a similar study. The surveys are presented in Appendix A. Each of the two intersections (16-34 and 25R-7L) which the student pilot participants would likely pass by were identified in the survey and the exact same questions were asked for each. The surveys were given to the Embry-Riddle Aeronautical University flight instructors for the student pilot participants and the instructor pilots were briefed on how to collect the data. This procedure was as follows: The students were instructed to take the survey and answer the questions while the instructor taxied passed the elevated runway guard lights identified in the survey. The student pilots were not told about the specific differences in the lights. This location of the two intersections was strategically planned, so that the pilots would pass them at the beginning of every flight. The surveys asked the same questions about the brightness, noticeability and distraction of the lights using a Likert scale for the incandescent and the LED ERGLs. All pilots answered the same questions for both lights on a Likert scale of 1 to 5, only the order of ERGL presentation (incandescent or LED) was randomized. They were asked additionally, which set of lights they preferred.

The Likert scale was created by Rensselaer Polytechnic Institute, a research facility that did primary research while developing the prototype LED ERGL (Skinner, 2010). In the RPI study, approximately 9 participants were asked the questions and only some of them were pilots. The questions also were not asked in the same environment. For example, those participants were not in an aircraft, nor did they have two sets of lights to look at. The 15 ERAU flight instructors selected for this study had 8 student pilot participants each. Each student was asked the same Likert scaled survey questions for the LED and the incandescent bulb (intersections 16-34 and 25R-7L) during 3 types of ambient lighting conditions; daylight, twilight (either dusk or dawn) and during cloudy conditions (either fog or low daylight level due to clouds). The

ERGLs on the DAB runway were set to regulator to Step 3 (high intensity) for daylight operation and to Step 1 (low intensity) for night operation. In this way, the LED illumination could be compared under different intensity settings depending on ambient lighting conditions.

Participants

The participant population would be any person involved in crossing a runway at an airport. The participants in the study were randomly selected in the experiment. Each participant was a pilot, varying in flight experience and flight hours. The participants also varied in age and gender. Participants were be asked if they are color blind, as not to skew results with variables that may end up manipulating data.

Design

There are three possible independent variables in this experiment. First is the type of light, which has two levels; incandescent and LED. This variable is within subject, since all participants will see both lights. The two other variables are between subject. Because of the various photoreceptors used throughout the day, the current research conducted in this thesis will be divided by the time of day. Time of day has three levels; day, dusk (sunset to civil twilight), and night. The other independent variable is pilot experience, which has two levels, expert and novice. Experienced participants are the instructors and those pilots with more than 200 flight hours. Novices are the other students, who have less than 200 flight hours.

There are a few dependent variables. The participants were asked to determine the brightness, whether too bright or too dim, on a scale of 1 to 5. The amount of distraction, from 1 to 5 was asked, as well as how noticeable the lights were. The last variable was personal preference between the LED and the incandescent. The surveys are located in the Appendix. Although the lights were not directly compared, because the same exact questions were asked for each light, the results showed a comparison.

Since Likert scaled data were used to evaluate pilot ratings of the LED-ERGL and the Incandescent ERGL (I-ERGL) and because a relatively small sample was obtained (N=86), non-parametric statistics were used to evaluate the hypotheses.

Each pilot rated the LED ERGL or the I-ERGL first during the taxi and then the other, either the I-ERGL or the LED-ERGL, respectively. The subjective features of noticeability, distractability and brightness were evaluated using a Wilcoxon matched pairs test with the two tailed alpha level set at $p<0.01$. A Spearman correlation statistic was used to determine if the pairing was effective and if the observations were correlated. In other words, Spearman test was used to measure the strength of the possible connection between lights and the tested feature.

Hypothesis

First, the overall data were evaluated. All the observations were compared and then these subjective features were subdivided and two additional conditions were considered; low visibility conditions and conditions of weather. These additional pairings reduced the sample sizes further. The specific hypotheses tested were as follows:

1. Overall, the LED ERGL will be rated as more noticeable than the I-ERGL taxiway lights.
2. Overall, the LED ERGL will be rated as less distracting than the I-ERGL taxiway lights.
3. Overall, the LED ERGL will be rated as brighter than the I-ERGL taxiway lights.
4. Overall, the LED ERGL will be preferred over the I-ERGL taxiway lights. First, a Mann-Whitney U test for unpaired samples was used to determine if seeing the LED-ERGL first influenced the preference score compared to seeing it second, after seeing the I-ERGL. Then a single sample Wilcoxon signed rank test was conducted on the

dichotomous variables of prefer LED or prefer incandescent lights to determine if the pilots preferred one over the other. In both of these cases, the one-tailed alpha level was set at $p<0.01$.

Hypotheses 5-7: During dark conditions; the LED ERGLs will be rated as more noticeable, less distracting and brighter than the I-Taxiway lighting.

Hypotheses 8-10: During low visibility conditions; the LED ERGLs will be rated as more noticeable, less distracting and brighter than the incandescent lighting.

The null hypotheses in all cases were that there would be no differences between LED-ERGL and I-ERGL lights.

Apparatus and Procedure

At the airport where the research was being conducted, there were incandescent lights in most ERGLs. There were only two LED ERGLs, which were moved once a week for three weeks. The surveyor, who was the flight instructor, asked the participant if they saw a difference, as if there were possible changes in the elevated runway guard lights. At various times of the day, the trained flight instructor surveyed the pilot. The surveyor was be briefed on what was being evaluated for the purpose of this experiment. The surveyor gave the participant the survey and was told to circle a number on the Likert scale, then write a reason to support the response. Attached, in Appendix A, is the questionnaire that were be filled out by the surveyor, which explains the process of questioning and possible responses. The participant had a pencil and the paper survey to record the responses.

Results

There were 86 total participants; 26 student pilots, 23 private pilots, 14 of whom had their instrument rating, 12 commercial rated pilots, all of whom had their instrument rating, and 25 CFI/CFII. 82 of the sample size were male pilots. The flight hours of the participants were separated as follows: 21 pilots had less than 50 hours, 17 people with 50-150 hours, 16 participants with 151-250 hours, 11 with 251-500 hours and 21 pilots with more than 500 hours. All pilots were surveyed within the same few weeks of each other.

The pilots were asked to evaluate the LED-ERGL and the I-ERGL on 4 subjective features; noticeability, distractibility, brightness and preference. With all partipants in all conditions tested, the pilots felt that the LED-ERGL lights were more noticeable than the I-ERGL lights as seen in Figure 8. There was a significant difference between ratings for the LED-ERGL compared to the I-ERGL ($W=-1179$, $p<0.01$). In parametric data, $p<.05$ is typically used. Lowering the value made it less likely to have a type I error, or rejecting the null hypothesis when it is true. On the other hand, having a type II error, failing to reject the null hypothesis when it is true, is increased. Lowering alpha will help attain certainty in rejecting the null hypothesis when $p<.01$. The pairing of the LED and Incandescent observations was effective in reducing scatter (r_s 0.24, $n=86$, $p<0.01$).

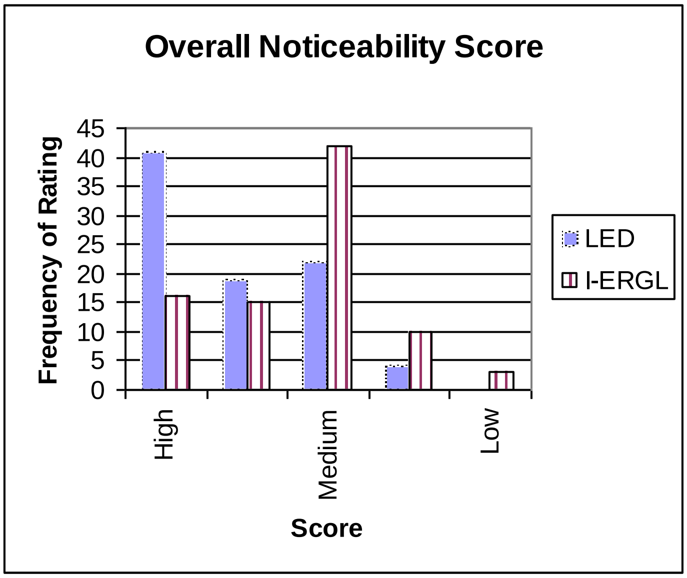

Figure 7. The LED and Incandescent ERGL lights were ranked differently. Pilots rated the LED as more noticeable.

Throughout all conditions, the pilots indicated that the LED ERGL lights were more distracting compared to the I-ERGL as indicated by the graph in Figure 9. The LED distraction scores were different than those for the incandescent elevated runway guard lights ($W= -315$, $p<0.01$). Similarly, the repeated measures pairing was also effective (r_s 0.58, $n=86$, $p<0.01$).

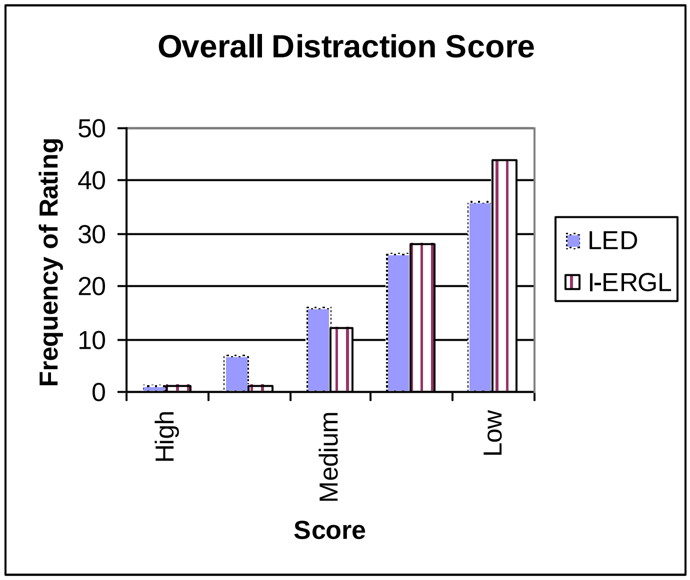

Figure 8. The pilots rated the LED and I-ERGL differently in their distractibility during taxi.

The rating for brightness when gathered from all participants was similarly greater for the LED-ERGL compared to the I-ERGL (W= -836, $p<0.01$) as shown in Figure 10. The pairing was not effective in reducing the variability of the data (r_s 0.06 n=86, $p<0.29$).

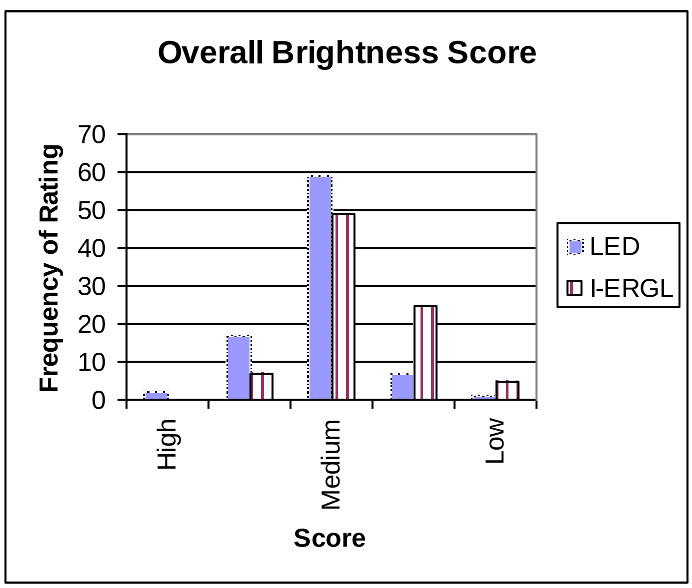

Figure 9. The LED-ERGL lights were rated brighter than the I-ERGL lights

Finally, the pilots indicated a preference for the LED-ERGL over the incandescent as shown in the graph in Figure 11. A Mann-Whitney U test was used to determine if seeing the LED-ERGL first influenced the preference for the LED. The Mann-Whitney U test does not assumer normality and compares two independent variables using non-parametric means. There was no difference in preference scores that depended on the order of seeing the LED-ERGL because after calculations, the U value was less than the p value ($U=-687.5$, $p=0.47$). There was however, a significant difference in preference for the LED-ERGL over the I-ERGL as shown in Figure 11. Expecting the median preference for the LED-ERGL to be better than random (50%) a one sample dichotomous test, a Wilcoxon rank sum test was conducted. The pilots preferred the LED-ERGL ($W=-1400$, $p<0.01$).

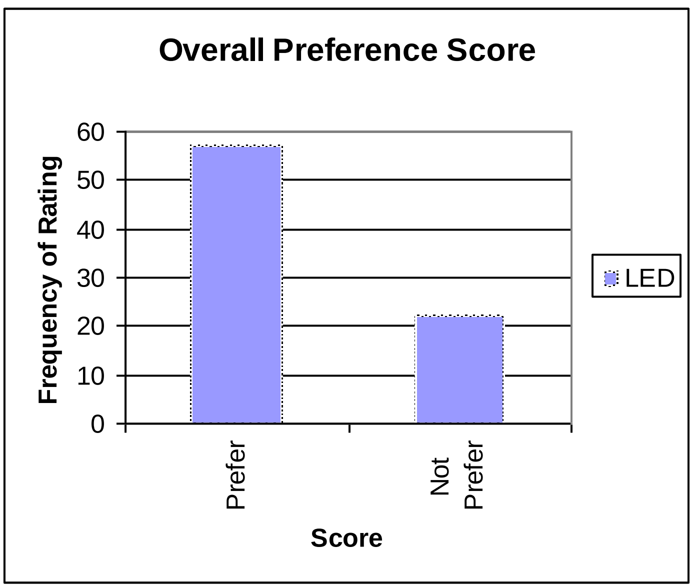

Figure 10. The overall preference totals for LED-ERGL.

A Wilcoxon matched pairs test was conducted on a subset of the data for those pilots observed the elevated runway guard lights during dark and during low visibility (less than 3 miles). The results are shown in Table 2. The distraction and brightness findings on at dark runway are shown in Figure 12.

Table 2. The results of comparing LED-ERGL and I-ERGL lights during conditions of darkness (low light) and reduced visibility (<3 miles) at the airport.

	Noticeabilty	**Distraction**	**Brightness**	**Preference**
Low Light n=14	Not Significant	p=0.01	p=0.008	64%
Low Visibility n=9	Not Significant	Not Significant	Not Significant	71%

There were nine of the 14 pilots in the low light condition who reported a preference for the LED ERGL and five of the seven participants in the low visibility condition who reported preferring the LED-ERGL.

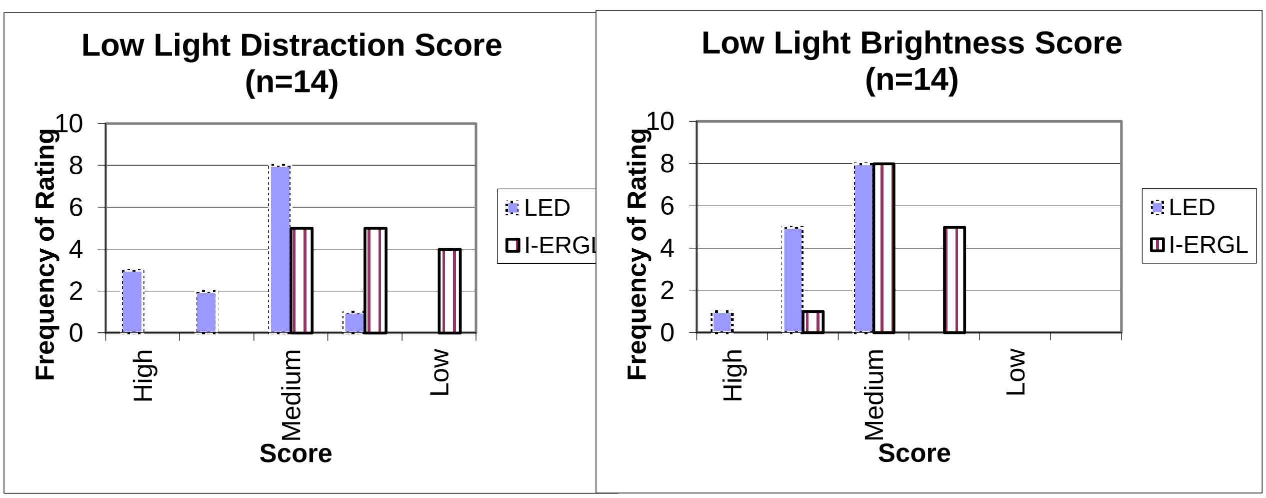

Figure 11. The subjective reports of a small subsection of the pilots who observed the ERGL lights under low light (dark) conditions. See text for explanation.

Discussion

The results argue that the LED ERGL lights are more noticeable, brighter but may be slightly more distracting. The data show an increase in distraction, possibly because of the flash rate and angle of the lights. Appendix D is a compilation of the participants' comments, which help explain why there was an increase in distraction. The most important conclusion however, seems to be that the majority of pilots evaluated preferred the LED ERGL over the incandescent ERGL. This preference was found even in low light (dark) conditions and in low visibility due to weather. The majority of pilots indicated a preference for the LED ERGL.

There is a correlation between noticeability and distraction. It is likely that the more noticeable the light is, the more distracting it may be as well. The FAA researchers took this largely into consideration when choosing the LED ERGL. The small subsection of pilots who observed both ERGLs in dark illumination (n=14) reported the LED ERGL were distracting in those conditions. Given that the overall conditions chart (Figure 9) showed a slight elevation of distraction scores, leads to the possibility that some pilots will be distracted by the brightness of the LED ERGL. Still, the majority of pilots under all conditions, in low light and low visibility preferred the LED-ERGL. Some of the comments, located in Appendix D, regarding the LED ERGL are relevant.

It may be that the angle needs to be positioned better to help reduce the intensity of the light. LEDs are used only at specific angles due to the limited angle at which they can be seen. Adjusting the angle towards or away the designated plane's path may reduce the amount of distraction, while still grabbing the pilot's attention. The angle at which the LED ERGLs were positioned was the same at which the incandescent were angled.

The rate at which the incandescent and LED elevated runway guard lights flashed was different, which may have also had an effect on results of the experiment. Previous research was conducted by Rensselear Polytechnic Institute and the FAA to determine the most appropriate flash rate and brightness that is most noticeable and least distracting. (Skinner, 2010)

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Appendix A

Airport Lighting Knowledge Survey

This is an FAA Sponsored Research project. Please answer the following questions to the best of your ability on the attached scantron. Turn in your questionnaire and your scantron (both with your student ID number on them and today's date) to the instructor.

1. Student ID: ____ DATE: _______________

2. FAA Pilot ratings currently held (mark all that apply):
   a. **Student** b. **Private** c. **Commercial** d. **Instrument** e. **CFI/CFII**

3. Total flight hours:
   a. **0-50** b. **51-150** c. **150-250** d. **250-500** e. **above 500**

4. Total Night flight hours:
   a. **0-20** b. **21-40** c. **41-80** d. **81-100** e. **above 100**

5. Total Instrument hours (simulated and actual):
   a. **0-20** b. **21-40** c. **41-80** d. **81-100** e. **above 100**

6. Do you require contacts or glasses for flight? A. **YES** b. **NO**

7. Is your vision color deficient? A. **YES** b. **NO**

8. Age: a. **Under 20** b. **21-25** c. **26-30** d. **31-40** e. **above 40**

9. Gender: a. **Male** b. **Female**

10. Runway centerline lights are located on one side of the white centerline markings for what reason?
    - **a. Identifies direction of nearest taxiway**
    - **b. Identifies where the tower is located compared to the runway**
    - **c. Identifies where the terminal is located compared to the runway**

11. Which of the following is not true about runway edge lights?
    - **a. The control tower can vary their intensity**
    - **b. Runway edge lights are only white**
    - **c. Lights are classified by their brightness, high, medium and low.**

12. Approach lighting systems do not
    - **a. Differ in distances depending on precision and non-precision runways**
    - **b. Contain lights such as sequenced flashing lights and runway alignment indicator lights**
    - **c. Start before the runway threshold**

13. Which of the following is true about precision approach path indicator (PAPI)?
    - **a. PAPI can be seen five to twenty miles, depending on time of day**
    - **b. PAPI lights are located vertically**

c. **PAPI is usually located on the right side of the runway**

14. Runway touchdown zone lighting
    a. **consists of alternating white and yellow lights**
    b. **start at the runway threshold and extend 3000 feet**
    c. **are along the centerline of the runway at the threshold**

15. Which lighting system consists of red and white lights?
    a. **Runway edge lights**
    b. **Runway centerline lights**
    c. **Runway End Identifier Lights**

16. Land and hold short lights are
    a. **Always on at the hold short point**
    b. **white and only lit when LAHSO is in effect**
    c. **Alternating red and white at the hold short point**

17. Regarding runway centerline lights,
    a. **Lights are placed every 75 feet along the centerline**
    b. **Only red lights are throughout the last 2000 feet of runway**
    c. **Red lights begin 3000 feet from the departing end of the runway**

18. What color are taxiway edge lights?
    a. **Green**
    b. **Amber**
    c. **Blue**

19. Airport beacons are
    a. **Always on when visual flight rules are not met**
    b. **Yellow and green at military airports**
    c. **Used to help identify airports at night and in low visibility**

20. What areas cannot be used for landing or takeoff?
    a. **Blastpad**
    b. **Stopway**
    c. **Displaced Threshold**

21. When approaching taxiway holding lines from the side with the solid lines, the pilot
    a. **May continue taxiing**
    b. **Should not cross the lines without ATC clearance**
    c. **Should continue to taxi until all parts of the aircraft have crossed the lines**

22. When turning onto a taxiway from another taxiway, what is the purpose of the taxiway directional sign?
    a. **Indicates direction towards active runway**
    b. **Indicates designation of from runway to taxiway**

Appendix B

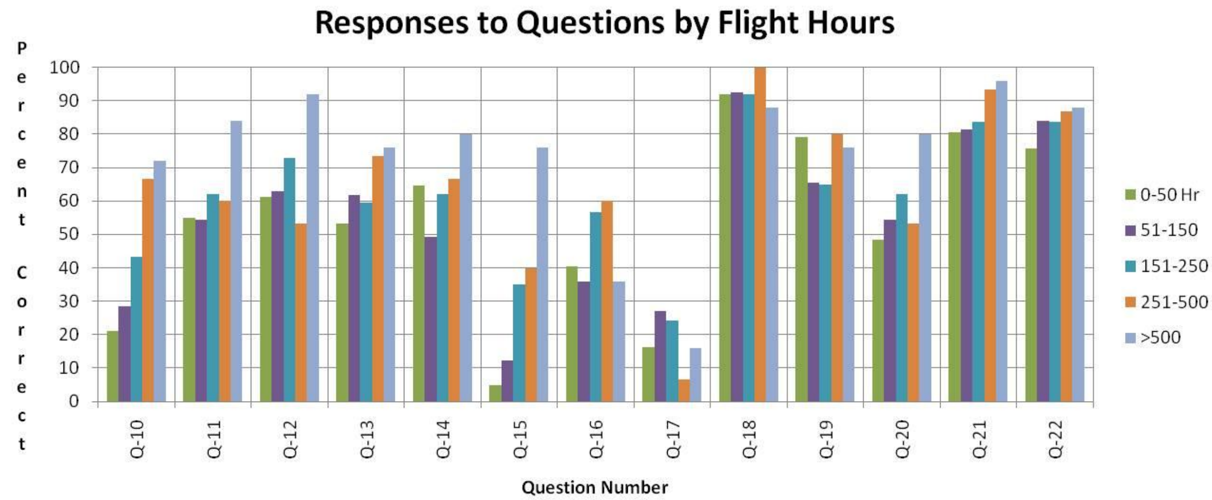


Figure 12. Correct Responses of All Knowledge Questions to Flight Hours. The total number of participants are displayed above. There were not an equal number of participants in each category of flight hours, so the numbers are displayed in percentages. As mentioned earlier, the trends of each question except question 16 and 17 show an increase of accuracy as an increase in flight hours. The knowledge questions are particular to lights, while practical flying does not require exact information to be understood, although knowledge is required at various stages of a flight.

Elevated Runway Guard Light Survey

ERGLs on 16-34

As a flight instructor, take the flight controls while taxiing and passing a set of elevated runway guard lights (wigwags). Hand this survey to the student and have him/her circle the number.

Taxi at a slow and safe speed,(about 10 knots) creating enough time to make an educated decision. Please fill out one answer sheet per person.

1. Noticeability:
   I think that the visual appearance of the ERGL is:

1	2	3	4	5
Very Noticeable		**Satisfactorily Noticeable**		**Not Prominent Enough**

Reason:____.

---

2. Distraction:
   I think that the visual appearance of the ERGL is:

1	2	3	4	5
Very Distracting		**Somewhat Distracting**		**Not Distracting At All**

Reason:____.

---

3. Brightness:
   I think that the brightness of the ERGL is:

1	2	3	4	5
Too Bright		**Acceptable**		**Too Dim**

Reason:____.

ERGLs on 25R-7L

As a flight instructor, take the flight controls while taxiing and passing a set of elevated runway guard lights (wigwags). Hand this survey to the student and have him/her circle the number.

Taxi at a slow and safe speed,(about 10 knots) creating enough time to make an educated decision. Please fill out one answer sheet per person.

1. Noticeability:
   I think that the visual appearance of the ERGL is:

1	2	3	4	5
Very Noticeable		**Satisfactorily Noticeable**		**Not Prominent Enough**

Reason:____.______

2. Distraction:
   I think that the visual appearance of the ERGL is:

1	2	3	4	5
Very Distracting		**Somewhat Distracting**		**Not Distracting At All**

Reason:____.______

3. Brightness:
   I think that the brightness of the ERGL is:

1	2	3	4	5
Too Bright		**Acceptable**		**Too Dim**

Reason:____.______

4. I prefer the ERGLs on:
   a. 16-34 **b. 25R-7L**

Reason:____.______

THE FOLLOWING QUESTIONS ARE LOGISTIC and are for the participant who answered the previous questions.

Only answer these questions in low to no workload conditions.

5. FAA Pilot ratings currently held (mark all that apply):
   a. **Student** b. **Private** c. **Commercial** d. **Instrument** e. **CFI/CFII**

6. Total flight hours:
   a. **0-50** b. **51-150** c. **150-250** d. **250-500** e. **above 500**

7. Gender: a. **Male** b. **Female**

8. Outside sunlight while taxiing: a. **Daylight** b. **Dusk** c. **Dark**

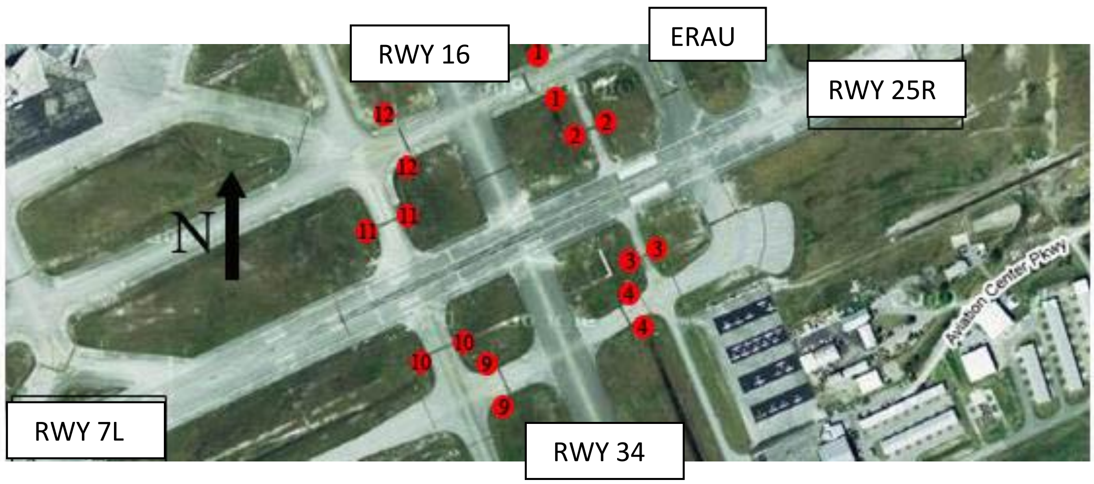
9. Visibility: a. **<3 sm** b. **>3 sm**

10. Other weather conditions(if any): A. **Haze** b. **Smoke** c. **Fog** d. **Mist**

11. Student ID Number:.____.

Appendix C

Airport Intersections with Elevated Runway Guard Lights



Appendix D

COMMENTS

LED-ERGL

Easier to see, maybe because flashing pattern
At a bad angle
Lights are aimed well and at a good height
The LED looks brighter than the other ones
Could be easily seen
Flashing lights catch attention
LED not as bright or as noticeable as regular lights and angled up slightly more
Can't see from the side
Clear and constantly flashing
Bright and flashy
It should be distracting enough to get your attention, which it is
Not distracting
Did not notice them while on taxiway
good indication of what you are coming up to
Frequency pattern different, but NOT distracting
Noticeable enough, only thing is in the morning (sunrise) when the sunlight hits them, it makes them more faint and tought to see. 25R-7L don't have that effect with the sun
For night time it would be too bright
Could be brighter
Can't really see them on taxiway echo
Not too bright or dim, just right
A little too dim for daytime
Very noticeable during the day
Can't see at an angle
Great head on/bad from the side
not at easy to see as older style during the day
Seem brighter from straight on, but not from side
Good, little dim in the sunlight
GREAT
Noticeable
Perfect brightness
Brightness just right

COMMENTS

I-ERGL

Was able to see them from the ramp
Height was lower and could not really see from a far distance
Good attention grabber
Good as is
On/Off Tempo too slow
I always see them in the morning
The diameter of the lens could be slightly larger
Too dim and low
Saw lights easily
Easy to see during night, not bright enough during day
Can still see light, but dull at a distance
Weren't distracting because they weren't bright
Not distracting
Good part of runway/taxiway environment
Good, not distracting, but DOES catch our attention
Light flashing, not too fast
Almost too easy to not notice
Not distracting because I didn't notice them
Didn't distract, but still caught eye
They bring attention when getting close
Could be brighter to catch pilot's attention
Should be a little brighter
Good level of light
Perfect for daytime
Could be brighter
Seems dim
Should be brighter to catch pilot's eye
In comparison to the other lights, these are quite dim
Dim in the sun
Could be slightly brighter
Perfect brightness

Comments on BOTH LED-ERGL (16-34) and I-ERGL (25R-7L) for Preferences

16-34 were brighter and more noticeable. 25R-7L were visibly older
Less distracting
Brighter, a little more noticeable, especially when the sun's not shining on them
The rate they blink is not too fast and not too slow and also not too bright on the taxiway
They were easier to see due to the taxiway providing a backdrop
I can see them better
Looked too similar
Due to LED, I think they are more noticeable day and night
More noticeable and pointed for a lower cockpit
They seem to "pop" more than the others
These are awesome!
None
More effective
They are a more clear and decisive warning
Different than other ones, brightness makes it noticeable
Not quite as bright. Both work very well but 25R don’t glare on windscreen as much
The ERGLs were brighter on 25R-7L, where the ones on 16-34 were a bit dim
Brightness
They are brighter and easier to see
NONE
NONE/EITHER bc they look the same to me
They are brighter and alternate faster. More prominent in capturing attention
Easier to see,more noticeable
They are less distracting, but still noticeable
NONE
Gets my attention more
Flash a little faster and grab attention. Both work well
They flash a little quicker, making them slightly more noticeable. Mostly it's just preference.
Neighter are distracting, both are noticeable.
Brighter and faster flash making them easier to see
I like the display better
Saves money
16-34 are not as obvious or as prominent
Much easier to notice at night
They are less distracting, but still noticeable
NONE
Gets my attention more
Flash a little faster and grab attention. Both work well
They flash a little quicker, making them slightly more noticeable. Mostly it's just preference.
Neighter are distracting, both are noticeable.
Brighter and faster flash making them easier to see

I like the display better
Saves money
16-34 are not as obvious or as prominent
Much easier to notice at night
I like old school
NONE- hard to tell a difference
Newer, brighter, more noticeable
The ERGLs on 25R-7L are good enough in day VFR but the ones on 16-34 are brighter and easier to see, even with bright sun shining on them. Whereas the ones on 25R-7L can appeap washed out in direct sun.
clear and crisp
The LEDs are too bright
Better flash pattern, 16-34 had awkward flash pattern
Doesn't matter during the day, night ops may be different.
They do not fade in and out. One light is always on and blink irregularly which brings more attention
They are more noticeable
They are more noticeable and brighter. They look cool!
The pattern that the lights switch make it look more urgent and noticeable
I don't think they are different enough to really care or have a preference
Stand out more than 25R-7L
Better attention getter
Less prone to light failure