Visual performance for trip hazard detection when using incandescent and led miner cap lamps

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A B S T R A C T

Introduction: Accident data for 2003-2007 indicate that slip, trip, and falls (STFs) are the second leading accident class (17.8%, n = 2,441) of lost-time injuries in underground mining. Proper lighting plays a critical role in enabling miners to detect STF hazards in this environment. Often, the only lighting available to the miner is from a cap lamp worn on the miner's helmet. The focus of this research was to determine if the spectral content of light from light-emitting diode (LED) cap lamps enabled visual performance improvements for the detection of tripping hazards as compared to incandescent cap lamps that are traditionally used in underground mining. A secondary objective was to determine the effects of aging on visual performance. *Method:* The visual performance of 30 subjects was quantified by measuring each subject's speed and accuracy in detecting objects positioned on the floor both in the near field, at 1.83 meters, and far field, at 3.66 meters. Near field objects were positioned at 0 degrees and ± 20 degrees off axis, while far field objects were positioned at 0 degrees and ± 10 degrees off axis. Three age groups were designated: group A consisted of subjects 18 to 25 years old, group B consisted of subjects 40 to 50 years old, and group C consisted of subjects 51 years and older. *Results:* Results of the visual performance comparison for a commercially available LED, a prototype LED, and an incandescent cap lamp indicate that the location of objects on the floor, the type of cap lamp used, and subject age all had significant influences on the time required to identify potential trip hazards. The LED-based cap lamps enabled detection times that were an average of 0.96 seconds faster compared to the incandescent cap lamp. Use of the LED cap lamps resulted in average detection times that were about 13.6% faster than those recorded for the incandescent cap lamp. The visual performance differences between the commercially available LED and prototype LED cap lamp were not statistically significant. *Impact on Industry:* It can be inferred from this data that the spectral content from LED-based cap lamps could enable significant visual performance improvements for miners in the detection of trip hazards.

1. Introduction

Approximately 619,000 people (U.S. BLS, 2008a) are employed, directly and indirectly, in the United States mining industry. Coal mining is of particular importance to the U.S. economy given that coal-fired electrical generation plants provide about 57% of the electricity for the United States. Proper lighting is critical for miner safety, particularly in underground mines, as miners depend heavily on visual cues to see mine hazards that include slip, trip, and fall (STF) hazards (Cornelius, Steiner, & Turin, 1998). A main conclusion from a study addressing the role of mine illumination in reducing risk was that a number of STF accidents could have been avoided if proper lighting was provided (Rushworth, Talbot, Von Glehn, Lomas, & Franz, 2001). Foster's (1997) analysis of mining risks stated that lighting improvements could reduce mine STF accidents. Our analysis of Mine Safety and Health Administration (MSHA) accident data for 2003-2007 indicates that for underground mining, STFs are the second leading accident class (17.8%, n = 2,441) of lost-time injuries. For 2003-2007, STFs resulted in 158,861 non-fatal days lost of work for underground mining operations (MSHA, 2007). The 17.8% distribution of STFs for mining are quite comparable to that of private industry, where STFs are a leading event for injury and account for 17.7% of all non-fatal occupational injuries (U.S. BLS, 2007). However, mining STF accidents are not unique to the United States. An analysis of British coal mining accidents indicated that STF accidents occurred more frequently than any other accident category (Foster, 1997). About 49% of these STF accidents occurred while walking and not carrying any objects.

The underground mining environment is dynamic and harsh and poses significant challenges in terms of detecting STF hazards. The mine layout changes as mining progresses and machinery is moving throughout the environment. Floor conditions can degrade due to

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material that has spalled from the walls, fallen from the ceiling, or from moving machinery. For coal mining, the environment is of low reflectivity and low contrast. As a result, objects associated with slip, trip, and fall hazards are also typically of low contrast and reflectivity. Mine floors are often uneven and can be wet or contain standing water with submerged tripping hazards. Mine lighting is limited, thus making it more difficult for miners to see hazards. Mesopic conditions (low lighting) are typical. Often, the only lighting a miner has is from a battery-powered cap lamp worn on the miner's helmet. Traditionally, miner cap lamps used an incandescent bulb as the light source. Today, light-emitting diode (LED) light cap lamps are gaining acceptance and seem poised to supplant incandescent lighting technology.

Prior safety research involving mine lighting aimed to improve safety by increasing the light output. It was noted that overall accident rates decreased as much as 60% when the overall illumination was increased (Sanders & Peay, 1998). Other researchers noted dramatic increases in the ability of miners to see loose rock as illuminance increased from 500 to 1500 lux (Trotter & Kopeschny, 1997). Research, specific to the lighting of underground metal/nonmetal mines, determined that increasing the illuminance could improve visual performance for detection and recognition of trip hazards (Merritt, Perry, Crooks, & Uhlaner, 1983). The strategy of increasing overall illumination has shown to improve visual performance and safety; however, this strategy has the undesirable consequences of increasing disability glare and increasing the electrical power drain on battery-powered lighting.

The primary objective of this study was to determine if new LED-based cap lamp technology has an impact on visual performance in the context of detecting trip hazards for the visual environment of an underground coal mine. Our approach was to focus on improving the spectral content of light rather than increasing illumination. The spectral sensitivity of the eye for mesopic (twilight) conditions differs from that of photopic conditions (daylight) in that the eye is more sensitive to the shorter wavelengths of visible light. Some LEDs, classified as cool white, have more short-wavelength energy thus giving the appearance of bluish-white light versus traditional warm-white incandescent bulbs that emit a yellowish light and have more longer-wavelength energy. Prior research findings indicated that light having more short-wavelength energy enables improved detection of off-axis objects when the visual environment is mesopic (He, Rea, Bierman, & Bullough, 1997; Van Derlofske, Bullough, & Watkinson, 2005; Bullough & Rea, 2000). Results from a pilot study investigating visual performance for detecting mine trip hazards indicated that there was merit in using LEDs having more short-wavelength energy (Sammarco & Lutz, 2007). A secondary objective of this research was to determine the affect of aging on visual performance in mesopic conditions, especially with respect to these lighting technologies. Mesopic conditions pose additional visual challenges for older people. This is an important factor given an aging U.S. coal mining workforce that averages about 46 years old (U.S. BLS, 2008b). The physiology of the human eye is such that visual performance degrades as a person ages. These physiological changes include reduced pupil size, cloudier lenses, and reduction in the amount of rod photoreceptors that play a dominant role in vision as light levels decrease. These factors may all have a significant impact on visual performance at mesopic conditions.

2. Methods

2.1. Subjects

National Institute for Occupational Safety and Health (NIOSH) personnel from the Pittsburgh Research Laboratory (PRL) were the subjects. None were specifically involved with this cap lamp research, and most of the subjects were not familiar with miner cap lamps or they had used them infrequently. Only the subjects that passed vision tests for distance visual acuity, contrast sensitivity, and peripheral vision were accepted for the study. Subjects that had radial keratotomy, monocular vision, glaucoma, or macular degeneration were excluded. Miners were not used because of potential expectancy biases that could confound empirical data. Miners could immediately determine that the bluish-white light from an LED cap lamp is very different from the yellowish light of an incandescent cap lamp; thus a negative bias could exist because the light is not what they are accustomed to, or a positive bias could exist if the person perceives something new as better.

Twenty-four male and six female subjects participated. While gender was not a variable in this study, given that visual performance is not dependent on gender, the percentage distribution for gender is representative of the U.S. miner population. Three age categories were established and each had 10 subjects: Group A = 18 to 25 years old, Group B = 40 to 50 years old, and Group C = 51 years old and over. The average ages where 22.6 years, 47.3 years, and 57.6 years, respectively. The average age of all participants was 42.5 years This is representative of the average U.S. coal miner's age of 46 years.

Subjects signed an informed consent form and were instructed about their right to withdraw freely from the research at any time without penalty. The protocol for this study was approved by the NIOSH Human Subject Review Board.

2.2. Experimental Design

A within-subjects design was employed in this study. Presentation of cap lamps were randomly assigned to subjects and a restricted randomization was used for stimulus order presentation within cap lamps. Due to the expected presence of censored observations (i.e., trials where subjects would not be able to identify all objects in the given time-frame), a Cox regression analysis was employed. Cox regression is considered a full-information technique for data containing censored observations (Klein & Moeschberger, 1997). A number of covariates were investigated for inclusion in the model. The following independent variables were investigated:

- 3 Age categories: Group A = 18-25 years old; Group B = 40-50 years old; Group C = 51+ years old.
- 3 Cap lamp sources: LED cap lamp, Incadescent cap lamp, and a Protoype LED cap lamp;
- 4 Object patterns (Fig. 1).

Each independent variable was coded using indicator variables. For Age Group, Group A (young subjects) was treated as the referent category. For cap lamps, the incandescent cap lamp (the traditional

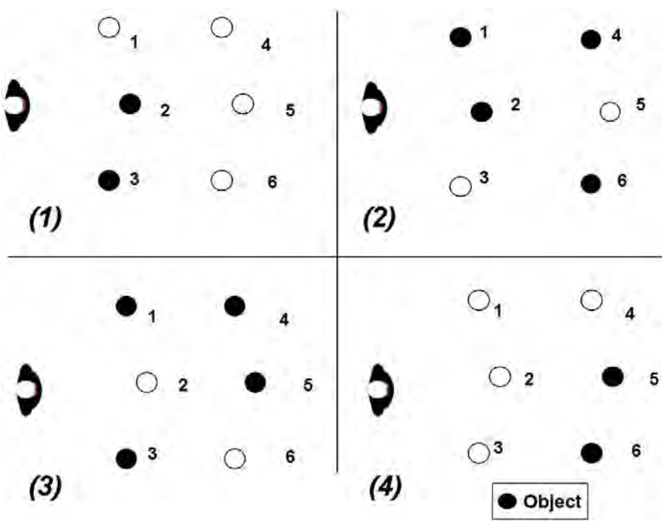

Fig. 1. The four object patterns: (1) near field; (2) mixed; (3) mixed; (4) far field.

cap lamp used in mining) was chosen as the referent. Finally, object pattern number 1 was chosen as the referent condition among the four object patterns. Selection of the latter referent category was somewhat arbitrary; however, authors wanted the referent category to have a mix of near and far field objects because this would be encountered in a mine. All 2-way and 3-way interactions between these variables were also tested for inclusion in the model. Significance of the model for each step of the forward selection procedure was determined using Likelihood Ratios. Wald statistics were used to detect differences between specific levels of a variable. The proportional hazards assumption was tested for each successive block in the model building process. DfBetas were run as a diagnostic to examine estimated changes in coefficients if a case were to be removed.

The primary dependent variable was the time taken to detect all of the objects presented. Trials in which objects were not all located during the allotted time were treated as right-censored observations. Alpha levels were established at 0.05 for variable inclusion in the model. In interpreting the results of the risk ratios (RRs) generated in the survival analysis, it should be noted that in many survival analysis studies, the event of interest has a negative connotation (death, for example). In such studies, a higher RR for a factor conveys a higher risk of a negative event happening. In the current study, however, the event of interest is positive in nature. The event in this study consisted of finding all of the objects presented (a good thing). Thus, a higher reported RR in our study indicates a situation where more rapid detection of the STF objects was achieved (i.e., a higher RR denotes a benefit and a lower RR represents poorer performance).

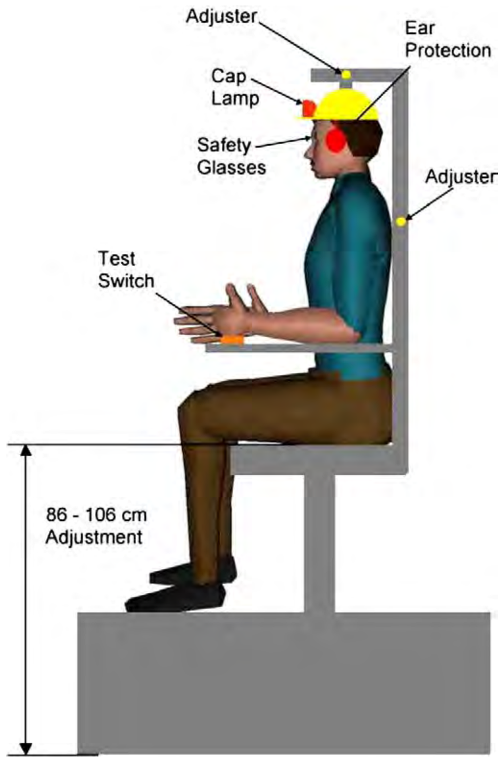

Fig. 2. The observation station.

3. Experimental layout and apparatus

3.1. Mine Illumination Laboratory

The testing was conducted at the Mine Illumination Laboratory (MIL) of NIOSH PRL. The MIL is a simulated, underground coal mine environment that is equipped with various test equipment, data acquisition and control systems, and networked computers. The interior is 488 cm (192 in) wide by 213 cm (84 in) high and is coated with a rough-textured material that has a color and spectral reflectivity representative of a coal mine.

3.1.1. Observation Station

It was important to have each subject at a fixed, known coordinate with respect to the test apparatus, and to have each subject's position fixed so that their point of view was the same regardless of their body size. This eliminated data confounding from variations in the subjects' point of view. Hence, NIOSH personnel designed and constructed an observation station (Fig. 2) to enable each subject to be tested at an eye height of 165.1 centimeters (cm). This eye height, with reference to the floor, was based on the 50th percentile standing male (USDOT, 2003). Seat height was controlled using electric actuators and the seat was designed to accommodate testing of subjects ranging from the 5th percentile female to the 95th percentile male. The height of the miner's helmet was independently adjustable from 68.6 cm to 84.8 cm to accommodate varying torso lengths. The observation station and all of its components were painted a flat black color to eliminate reflections and to prevent distractions during testing.

3.1.2. Cap Lamps

Each cap lamp was brand new and was powered using a regulated power supply rather than a cap lamp battery to eliminate voltage fluctuations as the battery discharged. The power supply voltages for the cap lamps were set according to the specifications for the particular make and model of cap lamp. These voltages were representative of fully-charged batteries. The first cap lamp was MSHA-approved and used a single incandescent bulb as the primary light source. This served as the referent cap lamp. The second was an MSHA-approved cap lamp with a single phosphor-white LED as the primary light source. The third cap lamp was a laboratory prototype that was jointly developed by the Lighting Research Center of Rensselaer Polytechnic Institute and NIOSH. This prototype uses two phosphor-white LEDs as the primary light source. The prototype LED cap lamp meets the photometric requirements specified by MSHA (Code of Federal Regulations [CFR] 30, 2005). The application of diffusion filters was necessary to normalize the light output for each cap lamp because initial illuminance distribution measurements revealed significant variations among the trip objects. For example, preliminary measurements indicated that the illuminance of certain objects was about 42% less with the prototype LED cap lamp than with the incandescent cap lamp. Controlling the object illuminance distributions throughout the experiments ensured that the lighting research was contained to the spectral content of the cap lamps rather than a combination of several underlying factors that would confound the data. Each cap lamp was characterized in terms of its electrical data and its spectral power distribution (SPD) (Fig. 3). The cap lamps' electrical and photometric data are listed in Table 1. Both LED cap lamps use a cool-white type of LED characterized by a correlated color temperature (CCT) between 5000 K and 10000 K. The incandescent cap lamp light source is categorized as warm white having a CCT that is typically 2600 K to 3700 K.

3.1.3. Experimental Layout

The general layout is depicted in Fig. 4. A motorized curtain was installed .91 m in front of the observation station to prevent the subject from gaining an advantage in finding the objects while the researcher changed object location patterns. This curtain was connected to a microcontroller programmed to control the curtain and time the duration of each test. Two location categories were established for this experiment: near-field 1.83 meters (m), about the distance of two strides for the average male, and far-field 3.66 m, a common visual attention location for a walking person. Table 2 lists the near-field and far-field illuminances. The objects were made from

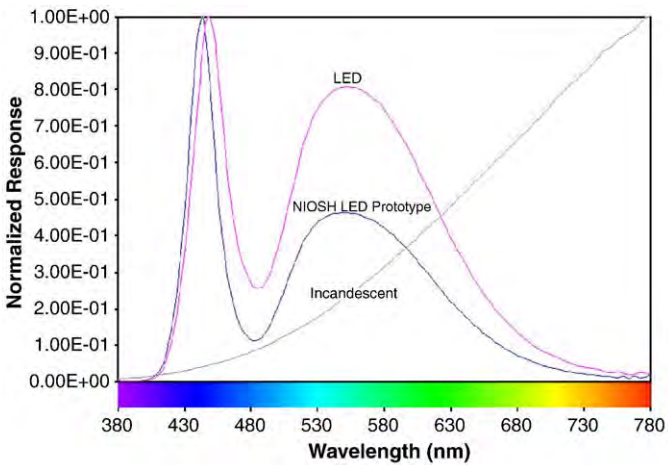

Fig. 3. The spectral power distributions for each cap lamp.

sections of PVC electrical conduit. Each object (Fig. 5) was 6.4 cm long with a 3.3 cm outer diameter and 2.2 cm inner diameter. The objects were painted a dark color such that they would have a very low contrast (-0.11 to 0.09) and a reflectivity (5%) very similar to an object that was coated with the material on the coal mine floor. Four object location patterns were presented (Fig. 1) to each subject: (1) two objects in the near field; (2) two objects in near and far field; (3) two objects in the near and far field; (4) two objects in the far field.

3.2. Procedure

The subjects sat in a darkened environment for 15 minutes to enable retina dark adaptation. Next, subjects were seated on the observation station and adjustments were made such that each person had the same eye height of 165.1 cm (65 in) from the floor. While seated, the subjects wore a miner's hardhat with a cap lamp. The procedure was to close the black, electrically-powered curtain and arrange objects according to the corresponding object patterns selected for each subject. The presentation order for the four object location patterns of Fig. 1 was counterbalanced. The subjects were instructed to point at each object using a laser pointer and count it out loud when the curtain opened. Prior to the test, subjects were told how many objects would be in the visual scene because pilot testing revealed that some subjects would stop the test before all objects were found or some subjects continued to search for objects although all objects were detected. When the subject was ready, the curtain was opened and the PC-based data acquisition system started recording time. The curtain was closed once all objects were detected, or after a 10-second period expired. The time was recorded when the last object was detected or the 10 second period expired. If a subject did not detect an object, the object location and pattern were recorded.

Table 1
Cap lamp electrical and photometric data.

Cap Lamp	Electrical Characteristics			Photometric Characteristics	
	Voltage (Vdc)	Current (amps)	Power (watts)	Peak wavelength (nm)	Correlated color temperature (K)
Incandescent	4.0	0.63	3.84	780	2880
Commercial LED	6.0	0.42	2.56	448	5855
Prototype LED	8.0	0.113	1.56	444	6844

4. Results

Results of the Cox regression analysis can be found in Table 3. The analysis indicated that object pattern was the most influential factor in terms of detection time, followed by the type of cap lamp used and then age group. No significant interactions were detected. The proportional hazards assumption was satisfied for both cap lamp and age group effects; however, hazards related to the object patterns were found to change with respect to time. This necessitated inclusion of an interaction term between the object factor and the natural logarithm of time in the model, as reflected in Table 3. No cases were found to exert undue influence on the results.

Table 4 provides survival times at the mean of the covariates for object patters, cap lamp, and age group. As can be seen in this Table, object pattern 4 (objects all in far field) was associated with the most rapid detection of the STF objects, on average. Object patterns 2 and 3 (where objects were placed in both near and far field locations) were found to result in increased detection time, on average. Object pattern 1 (objects all in near field) was associated with the second fastest detection.

In the comparison of cap lamp effects, both LED cap lamps (prototype and commercially available) led to more rapid detection of objects compared to the traditional incandescent cap lamp ($p<0.001$). Fig. 6 illustrates survival functions for the three cap lamps employed in the study. As can be seen, the incandescent cap lamp was associated with a consistently higher cumulative survival curve (indicative of increased time required to detect objects) compared to the LED cap lamps, which resulted in very similar performance. Using the INC cap lamp as the baseline for comparison, the prototype and commercial LED cap lamps respectively resulted in 12.7% and 14.4% faster detection times than the incandescent cap lamps. The prototype LED resulted in slightly slower detection time than the commercial LED cap lamp; however, the difference was not statistically significant. The LED-based cap lamps enabled detection times that were an average of 0.96 seconds faster.

The middle age group was found to have increased detection times compared to younger subjects ($P<0.01$). However, the older age group had detection times not significantly different from the young age group ($p>0.05$).

5. Discussion

5.1. Object Location

The location of objects on the floor, the type of cap lamp used, and the age of the subject all had significant influences on the time required to identify potential STF hazards. In terms of object location, subjects were able to most rapidly identify objects when they were all in the far field and it took significantly longer for subjects to identify objects in the near field. This may have been the result of a slight increase in the average far-field illuminance as compared to the average near-field illuminance that was about 9.7% less. The search strategy may have played a role given that the far-field would be a more natural visual attention location as compared to near field. However, the longest detection times were found to take place when subjects had to search for both near and far field objects during a trial. This is likely the result of the search strategy subjects used to locate the STF objects and that four objects were to be detected rather than two objects for near or far-field tests.

5.2. Cap Lamps

Compared to the incandescent cap lamp that is current standard in the mining industry, the LED cap lamps resulted in detection times that were, on average, more than 0.96 seconds faster. As seen in Table 4, the prototype resulted in slightly more rapid mean detection

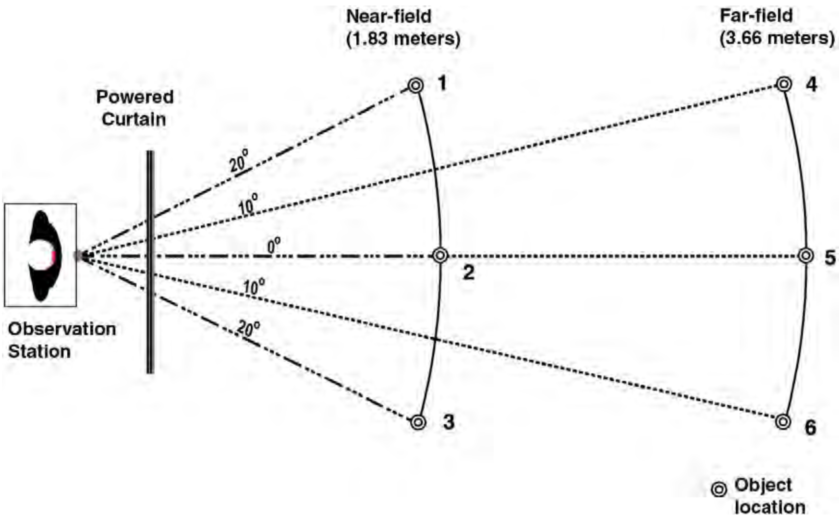

Fig. 4. The experimental layout.

time; however, the difference was not significantly different compared to the commercial LED cap lamp. We infer from the results that the LED cap lamps enabled better visual performance because of the spectral content: the LEDs were cool white that have more of the short wavelengths compared to the warm-white incandescent cap lamp. It is important to note that the results do not infer that all types of LEDs will enable visual improvements because there are various categories of white LEDs available: neutral-white LEDs have less short wavelengths (CCT is typically 3700 K to 5000 K) and warm-white LEDs have CCTs similar to incandescent lamps. Although our results indicate the importance of special content for visual performance, the levels of illuminance, contrast, and object size are other factors of importance. Note that the illuminances (average near and far-field illuminances of 1.21 lux and 1.43 lux, respectively) are very low with respect to illuminance levels for safety that have been established for hazards requiring visual detection. When there is a high degree of hazards requiring visual detection, the absolute minimum illuminance level is 22 lux when activity levels are low and 54 lux when activity levels are high. This value should be increased if the effective reflectance of the ceiling, walls, and floor are less than 0.5, 0.1, and 0.1, respectively (Rea, 2000). Typically, coal has a reflectance of .03 or .04 so the recommended illuminances should be increased. In general, visual performance increases with increases in illuminance. Thus, we anticipate that significant visual performance improvements would be realized if the cap lamps provided the recommended illuminance for safety.

5.3. Subject Age

Younger subjects were able to detect objects significantly faster than the middle age group. Surprisingly, the older age group was not significantly different from the young age group in terms of detection time (though the older group's average was half a second slower than the young age group, on average). One would anticipate a constant deterioration in performance with increasing age. The current findings may be the result of sampling older individuals with better than average vision and/or a middle-age cohort with poorer than normal vision. This possibility is supported by the fact that in a study of peripheral motion detection using the same sample, the older age group also performed somewhat better than the middle-age group (Sammarco, Reyes, Bartels, & Gallagher, 2008). Given the substantial amount of research showing progressive decrements in visual performance with age, one might fairly question whether the current results would be replicated in future samples.

5.4. Visual Performance

Visual performance was defined as the speed and accuracy of detecting trip hazard objects; thus, visual performance is a function of time so the results could vary given the time duration of each experiment. A 10-second time limit was imposed to bound the experiments. The selection of this time was subjective given the visual task. The data analysis and results described in this paper were strictly bound to the 10-second time limit; however, data collection continued. Analysis of all the collected data yielded the same result in that the LED-based cap lamps enabled visual performance improvements, and that there was not a statistically significant difference between the LED-based cap lamps. The magnitude of improvement did change. The prototype LED cap lamp enabled the fastest average detection time that was 14.4% faster than the incandescent cap lamp. Collectively, the LED-based cap lamps enabled detection times that were an average of 0.96 seconds faster as compared to the incandescent cap lamp. Given an average walking speed of approximately 1.5 m/s suggest that that the quicker detection of objects that may cause slips, trips, or falls may allow enough increased time and distance for a miner, using an LED cap lamp, to avoid hazards that might be in his path.

5.5. Limitations

Two main limitations of this study existed. The testing was conducted in a laboratory environment that closely emulated an underground coal mine; but it did not include factors such as wet floor conditions or the presence of airborne dust. Additionally, the subjects

Table 2
Average Near and Far-Field Illuminances.

Location	Average vertical illuminance (lux) with diffusion filter			Average vertical illuminance (lux) without diffusion filter		
	Incandescent	Commercial LED	Prototype LED	Incandescent	Commercial LED	Prototype LED
Near-field	1.28	1.17	1.17	0.68	0.38	0.29
Far-field	1.27	1.49	1.26	1.06	0.94	0.56

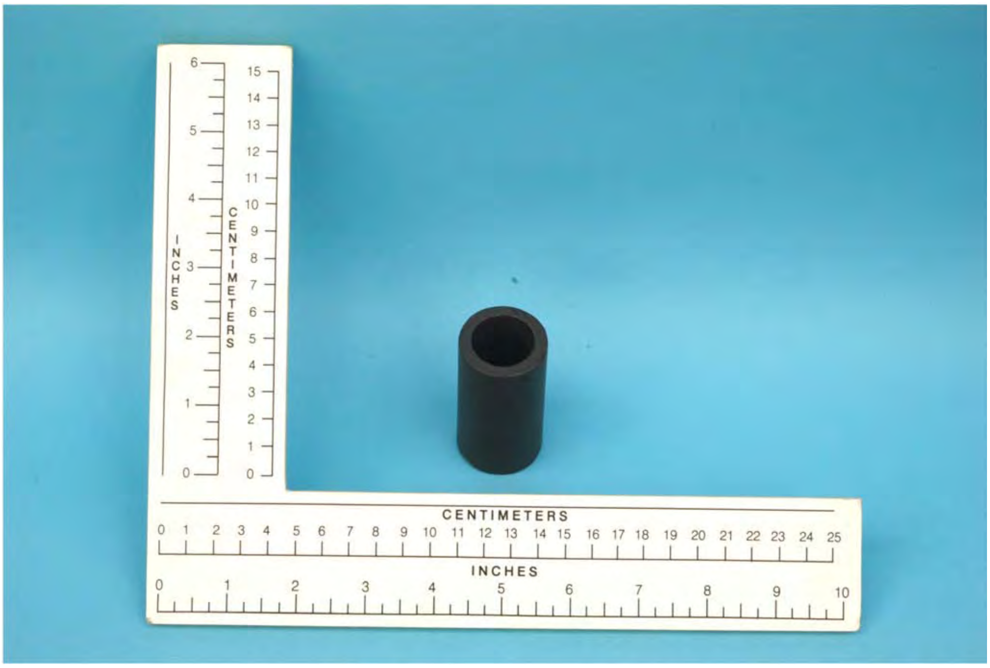

Fig. 5. A test object.

were stationary when tested and each person's viewpoint was fixed by seating them in the observation station and adjusting for the same eye height from the floor. While this test situation reduced the likelihood of data confounding and the tripping risks associated with subjects walking in a dark area, it did not emulate typical activities such as walking. Although the subjects were not miners, we do believe this reduced potential expectancy biases that could confound empirical data. Our experiences, while anecdotal, suggest that these expectancy biases are likely. Some miners with many years of experience with incandescent cap lamps initially do not like the light from LED cap lamps, while relatively new miners feel they can see better. The second limitation is that the cap lamps functioned at optimal performance given the ideal conditions of fully-charged battery power and new light sources. Our research has indicated that there are significant differences between INC and LED cap lamps for real-world conditions and that LEDs have significant advantages that include significantly less spectral composition shift, and more constant light output as the battery discharges due to the electronic drive circuitry commonly used for LEDs (Sammarco, Freyssinier, Zhang, & Bullough, 2008). Additionally, after aging the INC bulb, the light output decreased about 35% while over the same aging condition the LED light output decreased about 3%. Generally, visual performance decreases as the light output decreases and when the spectral content contains more of the longer wavelengths; thus, it is reasonable to expect that the visual performance improvements, enabled by LEDs, would be even greater than the INC cap lamp under real-world conditions. Lastly the spectral content of cap lamp light was the independent variable; so the likely visual performance improvements from increasing cap lamp luminance is unknown.

Table 3
Final Cox regression model.

	B	SE	Wald	df	Sig.	RR	95.0% CI for Exp(B)	
							Lower	Upper
Object Pattern			76.707	3	.000			
Object Pattern 2	-3.824	.900	18.065	1	.000	.022	.004	.127
Object Pattern 3	-3.551	.895	15.742	1	.000	.029	.005	.166
Object Pattern 4	3.576	.743	23.144	1	.000	35.720	8.322	153.315
Cap lamp			14.367	2	.001			
Commercial LED	.514	.139	13.633	1	.000	1.673	1.273	2.198
Prototype LED	.383	.141	7.355	1	.007	1.467	1.112	1.934
Age			13.364	2	.001			
Middle Age Group	-.504	.138	13.364	1	.000	.604	.461	.791
Older Age Group	-.238	.138	2.989	1	.084	.788	.602	1.032
Object*T_COV_			52.321	3	.000			
Object Pattern 2*ln(time)	1.932	.486	15.828	1	.000	6.905	2.665	17.890
Object Pattern 3*ln(time)	1.738	.482	12.986	1	.000	5.684	2.209	14.624
Object Pattern 4*ln(time)	-1.777	.483	13.554	1	.000	.169	.066	.436

5.6. Impact on Industry

The results of our study indicate that the spectral content of cool-white LED cap lamps could enable visual performance improvements for the detection of trip hazards in mesopic conditions typically encountered in underground coal mines. These results could prove useful for other industrial applications where trip hazards exist in a visual environment characterized to be within the mesopic luminance region.

Table 4
Survival times at the means of model covariates.

Variable	Condition	Mean time to detection (S)	SE	95%CI
Object	Pattern 1	6.337	0.265	5.817 – 6.856
	Pattern 2	7.556	0.210	7.138 – 7.994
	Pattern 3	7.696	0.231	7.243 – 8.148
	Pattern 4	4.298	0.238	3.832 – 4.763
Cap lamp	Incandescent	7.116	0..244	6.637 – 7.595
	Prototype LED	6.217	0..227	5.744 – 6.690
	Commercial LED	6.089	0.139	5.645 – 6.533
Age Group	Young	5.972	0.237	5.508 – 6.436
	Middle-age	6.954	0.245	6.474 – 7.434
	Older	6.496	0.233	6.039 – 6.954

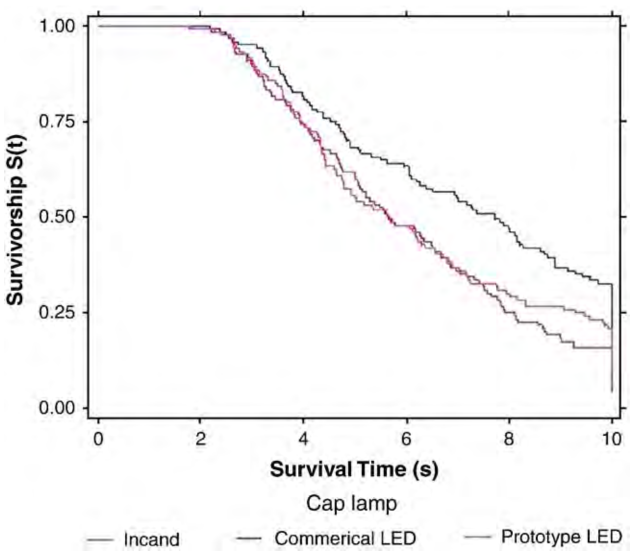

Fig. 6. Survivorship functions for the cap lamps.

6. Disclaimers

Mention of any company or product does not constitute endorsement by NIOSH. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Acknowledgements

The studies described in this paper were conducted with assistance from T. Dubaniewicz, T. Lutz, M.E. Nelson, A. Podlesny, J. Srednicki, and L. Williams of NIOSH PRL. Vision testing was conducted by M. A. Rossi R.N.

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