AN OVERVIEW OF NIOSH MINE ILLUMINATION RESEARCH: PAST, PRESENT, AND FUTURE

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ABSTRACT

Illumination is essential for mine safety because miners depend most heavily on visual cues to detect hazards associated with slips/trips/falls and powered haulage. The National Institute for Occupational Safety and Health (NIOSH) is conducting mine illumination research to improve miner safety by enhancing a miner's ability to see mine hazards. Thus far, 16 papers have been published covering diverse topics such as cap lamps, machine-mounted lighting, glare, lighting maintenance, and light-emitting diode (LED) technology issues. NIOSH has also developed an LED cap lamp, LED area lighting, and a Visual Warning System (VWS). This paper provides an overview of the improvements from NIOSH-developed lighting that include: 94% faster trip hazard detection with the NIOSH LED cap lamp; 79% faster peripheral motion detection to detect pinning/striking hazards; no increase in glare; 71% faster machine movement hazard detection with the VWS. Current research is described concerning an LED cap lamp for metal/nonmetal miners, illumination for refuge alternative deployment and inspection, and whether lighting could be used to improve miner escape and rescue in smoke. Lastly, future possibilities of using lighting to improve miner safety are described.

INTRODUCTION

illumination has been essential to both safety and to the ability of the miners to perform their work. This is especially easy to understand given that 80% of perception is visual (Yarbus, 1967). Open flames were used from the earliest days of mining. Carbide lamps were developed in the 19th century and were used well into the 20th century. During the early 1900s the new technology of electric lighting began making its way into underground mines in the United States. Safety was the primary driver of electric lighting given the pervasive occurrences of explosions caused by mine gas ignition. During 1917, the incandescent (INC) Edison cap lamp was approved by the U.S. Bureau of Mines (Clark and Ilsley, 1917) which had a rich history of mine illumination research that dates to 1910 (Sammarco and Carr, 2010a). The new electric cap lamps gained acceptance and eventually replaced the older lighting technologies. Today, the newest lighting technology is the light-emitting diode (LED), and it is poised to revolutionize mine illumination. High-brightness LEDs are achieving up to 149 lm/W in comparison to about 15 lm/W for an INC bulb. LEDs are robust because they do not have a glass envelope or a filament that can break, and they can provide useful light in excess of 50,000 hours of operation as compared to about 1,000 to 3,000 hours for an INC bulb. The longer life and robustness of LED lighting systems can potentially reduce the frequency of mining injuries associated with maintenance, repair, and the catastrophic lamp failures occurring during operation (Yenchek and Sammarco, 2010). LED cap lamps have been compared to INC cap lamps to better understand the technology and to ensure proper application of LEDs for mining; specifically, the performance of LED and INC cap lamps were compared in terms of correlated color temperature, color rendering, light output, electric power, ambient temperature and air flow, and light source aging (Sammarco et al., 2009d). The results indicate the superiority of LEDs compared to INC light sources used in cap lamps.

In general, lighting can influence the performance of people in the industrial workplace by way of ten mechanisms that include visual performance, visual comfort, visual ambience, interpersonal relationships, job satisfaction, and problem solving (Juslén and Tenner, 2005). For the mining industry, miners depend most heavily on visual cues to see hazards associated with falls of ground, slips/trips/falls (STFs), moving machinery, and other hazards (Cornelius et al., 1998). These hazards pose substantial risks to miners. Mine Safety and Health Administration (MSHA) accident data for 2007-2011 indicate that slips, trips, and falls (STFs) are the second leading accident class (18.9%, n=2,301) of nonfatal lost-time injuries at underground mining work locations (MSHA, 2007-2011). For this period, STFs resulted in 141,960 total days lost from work. Pinning and struck-by accidents also occur frequently. An MSHA report (Colley et al., 2006) on remote-controlled continuous mining machine (CMM) accidents indicated that pinning and striking fatalities were increasing, with 12 fatalities between 2000 and 2004 compared to 17 fatalities between 1984 and 1999. Another MSHA report (Dransite and Huntley, 2011) indicated that 33 fatalities involving a CMM occurred from 1984 to March of 2011.

Age is an important factor in relation to a miner's ability to see mine hazards. With increased age can come decreased visual abilities, particularly in the low light conditions of a mine, thus making it more difficult to see mine hazards. NIOSH human subject testing of visual performance has indicated that age is a significant factor given the visual environment of a mine and the associated lighting from cap lamps and machinery (Sammarco et al., 2009a, 2009b, 2009c, 2010b; Reyes et al., 2009, 2011). A national survey of the mining workforce indicated that the average miner age is 43.3 years (McWilliams et al., 2012). As the mining workforce ages, the need for effective underground lighting becomes even more important for miner safety. Vision deteriorates with age. Physiological changes include reduced light to the retina because of reduced pupil size that reduces the field of view, a yellowing of the eye lens which reduces light to the retina, reduction in the amount of rod photoreceptors that play a dominant role in vision as light levels decrease, and more sensitivity to glare (Harvard Health Letter, 2006). Crouch (1982) reported that 78% of the miners interviewed complained or questioned the lighting systems relative to discomfort and disability glare, veiling reflections, and afterimages. From the study results, Crouch estimated that miners working within the existing illuminated coal mining face environments could experience as much as a 40% or more loss of visibility from glare. Finally, cap lamp research for a simulated coal mining visual environment indicated about a 50% increase in discomfort glare for subjects over 50 years old as compared to a group of younger subjects with a mean age of 22.6 years (Sammarco et al., 2009a).

This paper presents a summary of NIOSH mine illumination safety research for machine-mounted lighting, LED cap lamps, and lighting effects on the physical body. It also presents current research on an LED cap lamp for metal/nonmetal miners, illumination for refuge alternative deployment and inspection, and whether lighting could be used to improve miner escape and rescue in smoke. The results presented in this paper were from controlled human subject testing in the NIOSH mine illumination laboratory unless otherwise stated. Age was a factor in this research as well, so the following age categories were established: young (18-25 yrs.), middle (40-50 yrs.), and older (51+ years). The age group from 26 to 39 years was not used because there are generally minimal changes in vision for those ages (Blanco et al., 2005). Volunteers that had radial keratotomy, monocular vision, glaucoma, or macular degeneration were excluded. Only the volunteers that passed vision tests for distance visual acuity of 20/40 or better, contrast sensitivity of 1.72 to 1.92 values of log contrast sensitivity, the absence of color vision deficiency, and peripheral vision of at least 80° for each eye were accepted for the studies.