

Testing Human Visual Detection with Xenon and Halogen Lamps as Used on Forest Machines

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ABSTRACT

The workspace around machines in forest operations is commonly illuminated by either halogen lamps or xenon (HID) lamps. Informal claims have been made that there is a large difference in subjective experience between using halogen lamps and xenon lamps. To obtain an objective quantification, human visual abilities were measured when illumination was provided by either xenon or halogen lamps with the same physical illumination as measured in Lux. Performance was measured as the number of correct identifications of test figures which depended on the color of test displays used, but the difference between lamp types was small. Overall, when differences could be measured between lamp conditions, somewhat better performance was obtained with the xenon lamps than with the halogen lamps. Furthermore, xenon lamps required much less energy: three halogen lamps (3 · 70 W) had an illuminance equal to one xenon lamp (35 W).

Keywords: *xenon lamp, halogen lamp, HID, forest operations, illumination, vision*

Introduction

Machines in forest operations are often maneuvered during night hours which requires artificial light. Two types of artificial lights dominate the market: halogen and HID (xenon) lamps. In xenon lamps, high voltage drives a discharge through the gas that emits a white light; halogen lamps glow with an orange light due to the electric current in a wire. Increasingly, xenon lamps are being used in forest machine applications since they are preferred by operators and suppliers. In general, lighting conditions are improved with the use of xenon lamps. The improvement is mainly due to the xenon light's higher color temperature, which is closer to daylight. Research on automotive forward lighting has shown that xenon light improves the off-axis low light visual performance,

i.e., the peripheral sight (Van Derlofske and Bullough 2003). In the Nordic *Ergonomic Guidelines for Forest Machines* (Gellerstedt et al. 1999), recommendations were given in physical luminosities, Lux. In the *European Ergonomic and Safety Guidelines for Forest Machines* (Gellerstedt et al. 2006), in order to reach the highest level of lighting, the color temperature must exceed 3500°K, which excludes halogen lamps.

Forest machine operators experience large differences between xenon and halogen lamps with a preference for xenon lamps, although the illuminance levels are the same (Nordén and Thor 2000a, 2000b; Cloutier 2003). This difference, however, has not been quantified. The purpose of the present study was to provide a method for testing human performance with various light sources and measure observer's visual performance under the same illumination levels using halogen and xenon lamps as used on forest machines. The measurements were performed with two kinds of displays, green and orange, to investigate possible differences in performance due to differences in reflected color in the two illumination conditions. Our first measurements (Study 1) took place indoors with 17 observers and were followed by more extensive measurements with 63 observers in the dark hours in a large barn (Study 2).

To achieve a valid measurement of the effects of lighting conditions on work performance, it is important that the test situation resembles as closely as possible the actual environment where machines are operated. In the initial development of the test, this was not practical. For example, in an actual forest setting light is scattered in an uncontrolled manner and ambient light may influence the results. Such variables are under control in indoor environments. Even so, a reasonable effort was made to simulate the lighting, distance, and some image resolving aspects of the forest setting. This study might be viewed as the first step in a more in-depth study that may include actual field settings.

Method

There are several standardized psychophysical methods available to measure visual performance. A common theme in these methods is that human observers are required to visually identify, discriminate, or quantify some property of test objects or test displays. The method of constant stimuli (Gescheider 1985) where the stimuli to be identified are made before the test, as opposed to the method of adjustment where the observer, or experimenter, adjust the stimuli to be barely detected,

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was considered appropriate for the intentions of this study. This method has been widely used, requires relatively little effort from the observers, and can easily be administered, although it requires more data collection than the method of adjustment. Test displays were arranged before the test session and observers were asked to identify some property of the test displays.

C-shaped test figures of low contrast printed on A4-sized paper (a version of the Landolt-C figures traditionally used to measure visual acuity) were used (**Fig. 1**) (Landolt 1905). These figures were randomly rotated so that the gap in the C pointed either up, down, to the right, or to the left. The outer diameter of these test figures were 16 cm, the thickness was 2.5 cm, and the gap was 8 cm wide. The task was to identify the orientation of the test figure by answering the question, posed in Swedish, "In which direction does the gap point?" The answers were assessed in terms of the proportion of correct identifications, where each response was coded as 1 when correct and 0 when incorrect. The C-shaped figures may not look similar to the things that a operator would see in a forest operation, but are nevertheless expected to capture general image resolving aspects.

Originally the intention was to use colors that matched those encountered by forest machine operators (i.e., green and wood-like hues). In practice, it was difficult to match the color from the printer with the color on the computer screen, and it was especially difficult to arrive at a wood-like hue on printed test displays. The decision was made to use orange and green colors. The colors from the xenon and halogen lights reflected from the orange and green test displays and a white paper were measured with a Konica Minolta Croma Meter CS 200 to obtain the CIE color coordinates, which is the color space used as a standard reference for defining colors. The brightness (Lux) measurements were made with a Hagner ScreenMaster. All Lux and CIE measurements were made from above the test displays, or a white paper, which were tilted 45° to reflect the incoming light from the lamps.

Study 1

Study 1 was conducted indoors in a basement corridor where it was possible to obtain complete darkness. To begin, physical brightness was measured in Lux levels in four lamp conditions as a function of distance using one xenon, one halogen, two halogen, or three halogen lamps. The Lux levels were measured as light reflected from a white matte A4 paper. The test figures were placed at five different distances from the light source (5, 10, 15, 20, and 25 m) which were the same distances as used in the measurements of human performances. The CIE X-Y color coordinates of the lights reflected from test displays and from a white paper were measured at 2 m from the lamps.

Preliminary inspections showed that the observers task at distances closer than about 5 m was too easy, making it impossible to distinguish possible differences between lamp conditions. As a comparison, the workspace around forest



Figure 1. ~ This is an example of a black and white photo reproduction of a display used in the test, with the gap in the C-figure pointing to the left.

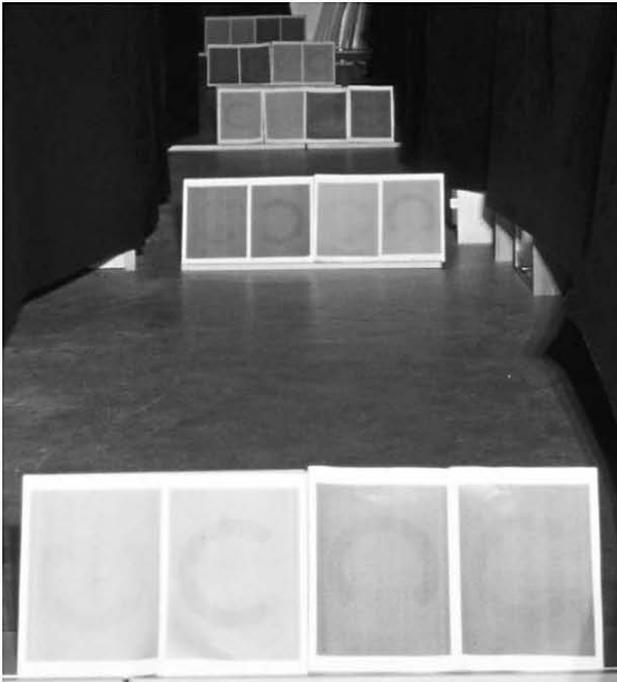
machines is below 10 m, but the operator may require a viewing distance up to 20 to 25 m (Gellerstedt et al. 1999). Four test displays were positioned at each distance: two green figures on a green background and two orange figures on an orange background (**Fig. 1**).

The two green and two orange test figures at each distance had different contrasts (high or low) specifying the C-figure. Both contrast levels were the same for the corresponding green and orange test figures. Different colors were used since the spectrum from halogen lamps and xenon lamps differ (i.e., their color temperatures differ). It was suspected that this may cause differences in performance depending on the colors of the test displays (Long and Garvey 1988). The viewing position was closely above and behind the lamps. The lamps were positioned about 170 cm above the floor. The test setting as seen from an observer's point of view is shown in black and white reproductions in **Figure 2**. The photos (top and bottom) are taken with three halogen and one xenon lamp, respectively. The images are indistinguishable but the original color photos, without any color balance adjustments, differed markedly since the correlated color temperature between the lamp types differed. The xenon lamp provided the most accurate color reproduction of the image. The walls were covered with black matte paper to reduce reflectance. The only available light source during the test was the lamp type under investigation. The xenon lamp was a Hella (35 W, 24 V) and the halogen lamps were Hella (70 W, 24 V).

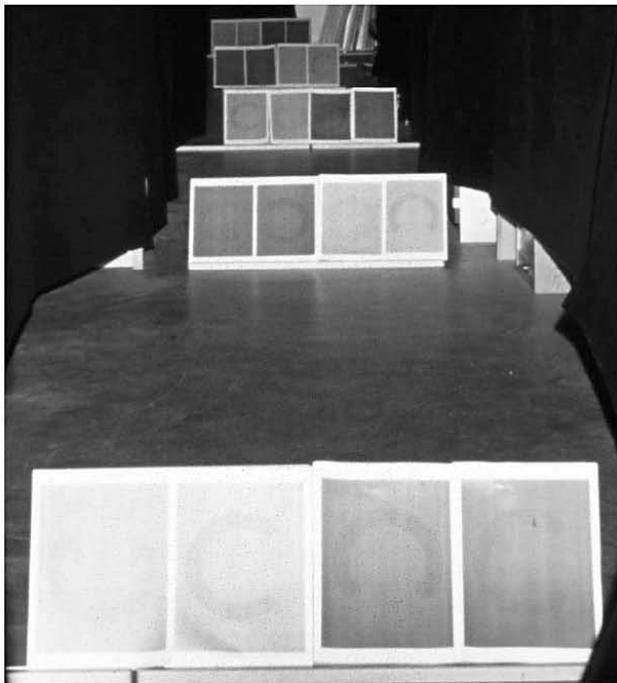
To measure human performance, each participant went through all test displays four times, one for each lightening condition (i.e., one, two, or three halogen lamps or one xenon lamp). The observers were allowed to adapt their scotopic vision (dark adaptation) for 5 minutes before the test.

Observers

The observers were 17 volunteers (2 female and 15 male) from the staff at Skogforsk in the age range of 25 to 62 years.



3 Halogen



1 Xenon

Figure 2. ~ Black and white photo reproductions of the test displays as seen from the observers' point of view illuminated by either three halogen lamps or one xenon lamp emitting light with the same physical brightness. As a consequence, the two photos are indistinguishable. The corresponding color photos, however, appeared with remarkably different hues since the color temperatures between the lamps differed (not shown here). The xenon lamp provided the most accurate color photo reproduction. At each distance, four test displays were placed: one low, one high contrast green and red test display, respectively.

Their visual abilities were normal or near/farsightedness corrected to normal. Observers with color vision deficits were excluded from participating in the study.

Results

The luminance measurements show that the Lux levels obtained from one xenon lamp was identical to the Lux measurements obtained with three halogen lamps across all distances (**Fig. 3**). These light levels are similar to that recommended by the *Ergonomic Guidelines for Forest Machines* (Gellerstedt et al. 1999). The correlated color temperature was 2600°K as measured from the halogen lamps and 3700 K as measured from the xenon lamp. Daylight, as a comparison, has a correlated color temperature of 5500°K. (Correlated color temperature is often labeled color temperature which is formally incorrect.) The CIE X-Y color coordinates were measured with one xenon lamp and three halogen lamps providing the same brightness as measured by the former Lux measurements. The white paper reflected halogen light with X, Y coordinates (0.45, 0.39) and the xenon light with (0.38, 0.37). The green test display reflected halogen light with X, Y coordinates (0.46, 0.46) and the xenon light with (0.41, 0.48). The orange test display reflected halogen light with X, Y coordinates (0.56, 0.38) and the xenon light with (0.46, 0.46).

The results, expressed as the proportion of correct responses from all of the participants across both colors and both contrasts, are shown in **Figure 4**. When one xenon lamp was used, performance was slightly better than with three halogen lamps, although the Lux levels in these conditions were the same. The difference, however, was not significant (sign test, $p = 0.14$).

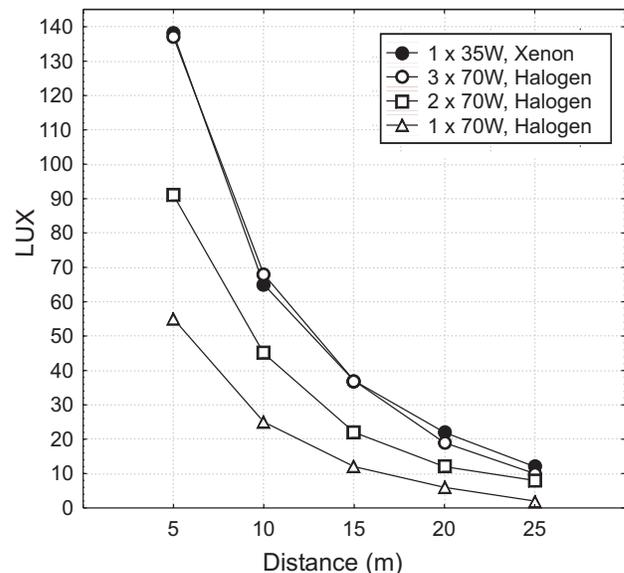


Figure 3. ~ Lux measurements. The Lux levels were indistinguishable for three halogen lamps (3 x 70 W, unfilled symbols) and one xenon (HID) lamp (35 W, filled discs) across all distances.

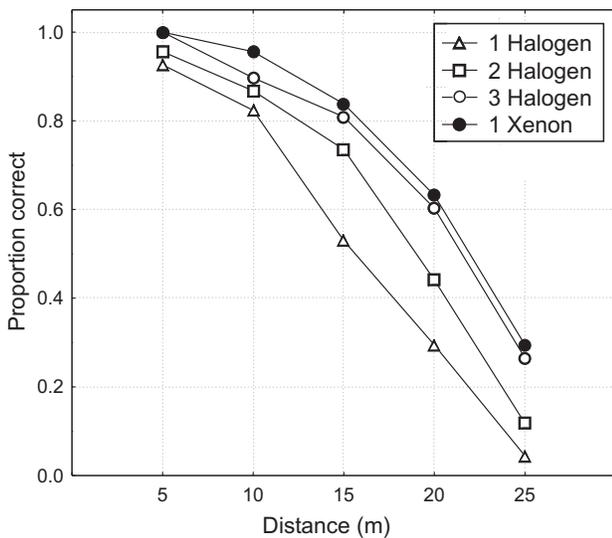


Figure 4. ~ The observers' performance measured as the proportion of correct identifications of the test figures as a function of distance and lamp conditions using one xenon (filled discs), one halogen, two halogen, or three halogen lamps (unfilled symbols). Each data point is the average from $17 \cdot 4 = 68$ responses, where each response was coded as 1 when correct and 0 when incorrect.

When green displays were used, the performance was almost identical for the xenon and the three halogen lamps (sign test, $p = 0.82$). When orange displays were used, performance was slightly better with the xenon lamp than with three halogen lamps, but the difference was not significant ($p = 0.10$) (Fig. 5). No significant differences between the xenon and halogen conditions were obtained when the results were separately analyzed for the low contrast displays (sign test, $p = 0.26$) and the high contrast displays ($p = 0.42$) (Fig. 6).

In conclusion, the results from Study 1 revealed no significant differences between the lamp conditions with the same Lux levels, although their correlated color temperatures differ and informal subjective reports claim such differences.

Study 2

In a second study, measurements were made in a big barn where observers were requested to identify test displays. The test figures were placed at five different distances (6, 8, 10, 12, and 14 m) from the light source and the observers. Six test displays were positioned at each distance: three green figures on a green background and three orange figures on an orange background (Fig. 1). The green and orange test figures at each distance had the same contrasts specifying the C-figure. Three halogen lamps ($3 \cdot 70$ W, 24V) and one xenon lamp (35 W, 24 V) was used providing the same Lux levels as described in Study 1.

Observers

The observers were 63 volunteers (8 female and 55 male) mainly from the staff at Skogforsk in the age range of 28 to 67

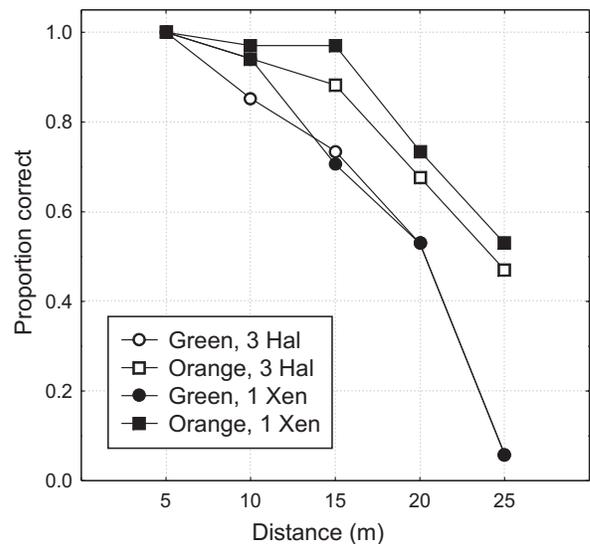


Figure 5. ~ The proportion of correct identifications for orange and green displays. Filled symbols show the proportion of correct responses in the xenon condition and unfilled symbols show the corresponding results from the halogen condition. Each data point is the average obtained from $17 \cdot 2 = 34$ responses.

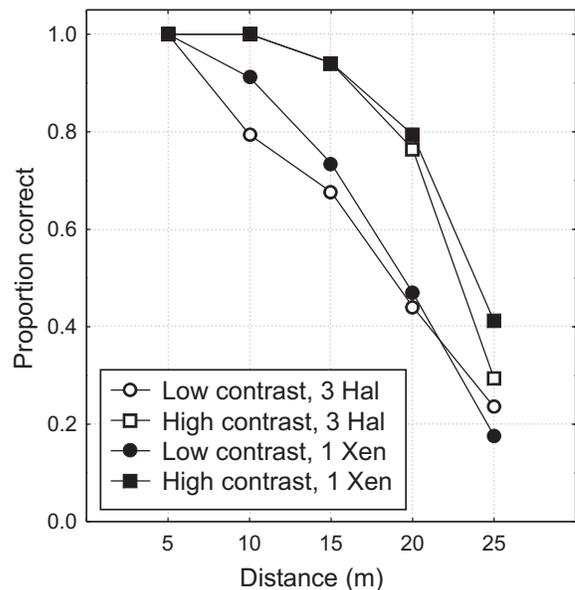


Figure 6. ~ Results split into displays with low and high contrasts. Filled symbols show the proportion of correct responses in the xenon condition and unfilled symbols show the corresponding results from the halogen condition. Each data point shows the average proportion of correct identifications ($17 \cdot 2 = 34$ responses).

years. Among these were the same observers who participated in Study 1. Their visual abilities were normal or near/farsightedness corrected to normal; observers with color vision deficits were excluded from the study. No control for possible differences between the observers in Study 1 and Study 2 were made.

Results

The difference between xenon and halogen lighting conditions as measured in percent correct identifications collapsed across orange and green displays (Fig. 7) was not significant (paired t-test, $p = 0.20$). For green displays, performance was significantly better ($p = 0.02$) when xenon lamps were used compared to the halogen lamp condition. No such significant difference could be measured with the orange test displays ($p = 0.79$). The error bars show the 95 percent confidence intervals calculated from each observer's mean score at each condition.

Discussion

The number of correct identifications at the same Lux levels for the xenon lamp (35 W) was equal to or somewhat better than the halogen lamps (3 • 70 W) depending on the color of the test displays. The results from Study 1 indicated that the xenon lamps resulted in somewhat better performance than halogen lamps when orange displays were used, although the difference was not significant. In the barn measurements from Study 2, the xenon lamps resulted in significantly better performance than halogen lamps for green displays whereas no such difference was obtained with orange displays. Test displays with colors other than those used here may reveal greater performance differences between lamp types, and some colors may even show an advantage when halogen lamps are used.

The correlated color temperature of the light emitted from xenon and halogen lamps differ, which is a possible cause of the difference in identification levels for certain colors of the test displays (Long and Garvey 1988). The color temperature during a bright cloudy day is 5500°K, containing light with a wide spectrum, which is desirable for achieving the best human performance (Sandström et al. 2002). Artificial light sources, with few exceptions, contain only part of this spectrum, and this is reflected by differences in the spectral curve and the color temperature. In a forest environment, there could be light from the periphery or reflected light which might affect the results. For instance, light in peripheral vision influences pupil constriction which is crucial for visual acuity (Berman 1992).

The first measurements were made indoors in a corridor which severely reduced peripheral input. It is possible that light reflected from the floor and ceiling influenced the results and that such reflections are dependent on the spectrum of emitted light. A disadvantage with the brighter xenon lamps is that reflections and glare occur more easily. It is a potential problem in harvesting (thinning) operations, but also occurs when two machines are operating at the same site. The problem can be minimized or avoided by well thought-out design of the machines, including hose protection, the color of machine parts, instruments, etc. Reflection and glare are not new problems, but have been addressed earlier (Nordén and Thor 2000a, 2000b; Teljstedt 1972).

When assessing lighting on a forest machine, it is desirable to have a measuring method that captures visual performance

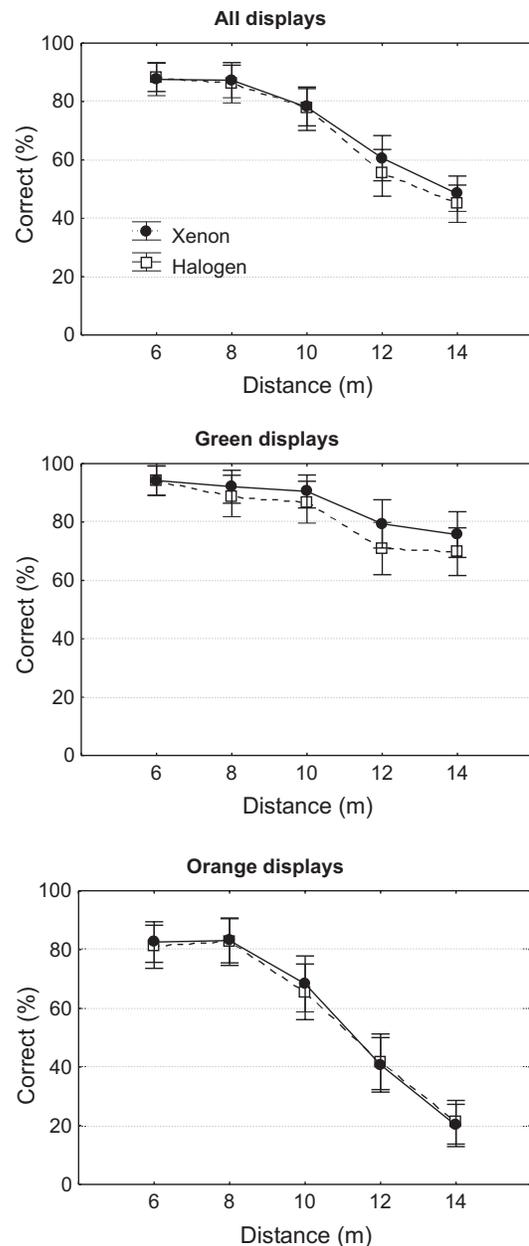


Figure 7. ~ The results obtained in indoor barn conditions with three halogen lamps compared to the performance with one xenon lamp having the same illumination as measured in Lux. Filled symbols show the percent of correct identifications in the xenon condition, and unfilled symbols show the corresponding results from the halogen condition. The performances for xenon and halogen lamps were the same when orange displays were used. When green displays were used, the performance was slightly better in xenon conditions. The error bars show the 95% confidence interval.

rather than a value of illuminance or luminance. There is, however, great complexity with photometry to assess differences in visual performance. The literature shows differences in experimental results. These differences are due to differences in visual tasks, whether or not tasks are off-axis, the light

level (scotopic vs. photopic which is the monochromatic vision of the eye in dim light vs. normal light such as daylight), and whether or not the task includes the detection of movement (Lewin 2001).

One problem with the current photometry system is that it remains unclear which luminous efficacy functions should be used for night-time lighting applications. A unified system proposed by Rea et al. (2004) characterizes light at all light levels using the parameter X , which describes the proportion of photopic light at any luminance. At high light levels, X equals 1, at scotopic levels, X equals 0. At mesopic levels, which occur in intermediate lighting conditions, X falls in between. Researchers express the value of X as a function of the photopic light level ($\text{candela} \cdot \text{m}^{-2}$) where candela is the SI base unit of luminous intensity) and the ratio of the photopic and scotopic efficacy for the light source. Lewin (2001) suggests LEM (Lumen Effectiveness Multipliers) to be used in lighting design. The value of LEM should be based on applicable conditions. A measure similar to LEM can also be found in the Swedish "rule-of-thumb factor" of 1.7 used as a multiplier when converting "halogen lux" to "xenon lux" (Löfroth et al. 2003).

Because we are evolutionary adapted to natural light, Wurtmann (1975) suggests that physiological processes are optimally working in such light and non-optimally in other light. Other researchers have pointed out the difficulty in finding any straightforward connection between the color temperature during a bright day 5500°K light source and the observer's identification levels in visual tests (Veitch and McColl 2001). No study was found that conclusively shows that physical measurements of the light spectrum of artificial light sources can be used as a base for light source recommendations. Therefore, it seems necessary to measure human performance in a visual test at various light sources.

What conclusions can be drawn about the informally reported preferences by forest machine operators for illumination by xenon over halogen lamps (Nordén and Thor 2000a, 2000b)? The measurements in the study were made in controlled conditions which resulted in indoor settings. Although we avoided the restrictions for peripheral vision in Study 2, compared to Study 1, there is a possibility that the results can not be generalized to real forest operations. But, we believe that the crucial image resolving aspects are not affected by such matters. Forthcoming studies in actual field settings may be needed to resolve this issue. Besides the performance measures presented in this paper, it is possible that light sources with different color temperatures are experienced as exhausting to different degrees which may affect operator performance (Sandström et al. 2002). Further, xenon lights are more expensive than halogen lights but provide more intense and more uniform lighting which facilitates navigation in the forest during night operations (Cloutier 2003). Thus, although similar levels of performance are obtained with the same illumination levels, it seems that the xenon lamp outperforms halogen lamps when used on forest machines during night

operations (Cloutier 2003). When, in the future, other light sources arrive on the market, it is important to have a standardized method of evaluating them in terms of human performance and measures of well being.

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