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Ouellette, M. J.; Rea, M. S.

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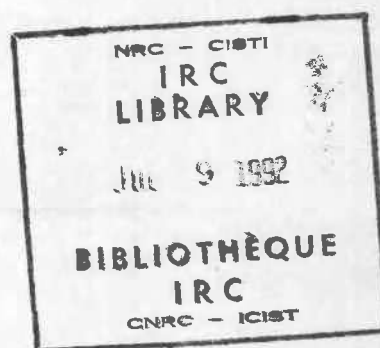# *Illuminance Requirements for Emergency Lighting*

by M.J. Ouellette and M.S. Rea

ANALYZED

NRCC 34060

Canada

Illuminance Requirements for Emergency Lighting

M.J. Ouellette, M.S. Rea

Introduction

One of the main purposes of emergency lighting is to "provide illumination of adequate quantity and quality along the escape routes sufficient to facilitate safe movement along them toward and through the exits . . ."[1] in the event of failure of normal power. Although there are a number of lighting parameters that can influence safety, the quantity of illumination is perhaps one of the most important. In order to determine how much illumination is actually needed to maintain safe escape routes, it is necessary to establish an operational definition of safety. In other words, "What do we mean by safety, and how do we measure it?"

Emergency lighting studies have, in the past, employed three very different operational definitions, which may have contributed to some of the existing confusion in illuminance requirements for emergency lighting. One operational definition equates safety with the ability to traverse a space without colliding with large obstacles. Another equates safety with egress time, while yet another describes safety in terms of subjective impressions of the lighting. The quantity of illumination in an escape route may, however, affect egress time, collisions, and subjective impressions in different ways.

In 1984, Webber[2] conducted a comprehensive review of emergency lighting studies which considered all three operational definitions. Since then, only two relevant studies have been published.[3,4] This review summarizes relevant issues in Webber's earlier review and includes the recent work of the newer studies.

There are many factors that may affect the illuminance requirements for emergency lighting. Among these are illuminance uniformity, ages of occupants, familiarity with the space, crowd size, length of escape route, presence of exit signs, and the presence of special hazards such as clutter and changes in level. These factors differed from one study to another.[3-7] This paper places, as much as possible, all studies in the same context to help rationalize seemingly conflicting findings and to clarify some of the technical foundations for the illuminance selection process.

The studies reported here apply only to smoke free conditions. Smoke filled spaces may have considerably different illuminance requirements, since room lighting scatters in smoke to reduce the visibility of exit signs, in the manner of automobile headlights in fog.[8,9]

Summary of experimental procedures

For ease of comparison, details will be reported in point form.

Experimenter:	Simmons (1975).[5]
Escape route:	Network of cluttered corridors with steps and large obstacles; no exit signs.
Mean illuminances:	0.02 to 300 lx at floor level.
Subjects	Mostly 50 years, or older; familiar with escape route.
Prior exposure:	1000 lx (floor level) for 2 min.
Crowd size:	One subject at a time.
Dependent variables:	Escape time for a single subject; number of collisions with large obstacles.

Experimenter:	Nikitin (1973).[6]
Escape route:	Cluttered office; no exit signs.
Mean illuminances:	0.1 to 0.8 lx at floor level
Subjects:	Ages undefined; familiar with escape route.
Prior exposure:	300 lx (floor level) for 20 min.
Crowd size:	Groups of four, six, eight, ten, and twelve.
Dependent variable:	Number of near collisions with large obstacles.

Experimenter:	Jaschinski (1982).[7]
Escape route:	Network of cluttered rooms and corridors with steps; exit signs either luminous or non-luminous providing guidance at junctions.

Authors' affiliations: National Research Council of Canada, Institute for Research in Construction

Mean illuminances:	0.24 to 7.7 lx at 20 cm above floor.
Subjects:	Either young (18 to 30 yrs.) or old (50 to 70 yrs.); unfamiliar with escape route.
Prior exposure:	Either 100 or 250 lx (20 cm above floor).
Crowd size:	One subject at a time.
Dependent variables:	Escape time for a single subject; number of collisions with large obstacles; subjective appraisals of difficulty and of satisfaction.

Experimenter:	Boyce (1985).[3]
Escape route:	Cluttered open-plan office and adjoining uncluttered corridor defined by furniture partitions; one luminous exit sign at end of corridor.
Mean illuminances:	0.01 to 580 lx at floor level (also ran a condition with the office space lighted solely and non-uniformly by the electric exit sign mounted in the adjoining corridor).
Subjects:	Age 18-57 years (mean = 33 yrs.), also ran a group of older subjects (mean = 55 yrs.) in a follow-up experiment; unfamiliar with escape route, and also ran a group of subjects familiar with the route in a follow-up experiment.
Prior exposure:	580 lx at floor level.
Crowd size:	One subject at a time in main experiment, and also ran groups of four people in a follow-up experiment.
Dependent variables:	Movement time in office; movement time in corridor; "delay" time (interval between dimming of lights to when the subject rounds the corner of a desk, after rising from a chair behind the desk); number of collisions with large obstacles; subjective appraisals of difficulty and of satisfaction.

Experimenter:	Webber and Hallman (1987).[4]
Escape route:	Straight uncluttered corridor. Repeated the experiment on a stairway.
Mean illuminances:	0.02, 0.2 and 1.0 lx at floor

	level.
Subjects:	Mixed ages ranging from under 30 to over 50 years.
Prior exposure:	500 lx at floor level.
Crowd size:	One subject at a time.
Dependent variables:	Travel time for a single subject on outward and return trips along the escape route; subjective appraisals of difficulty and of satisfaction.

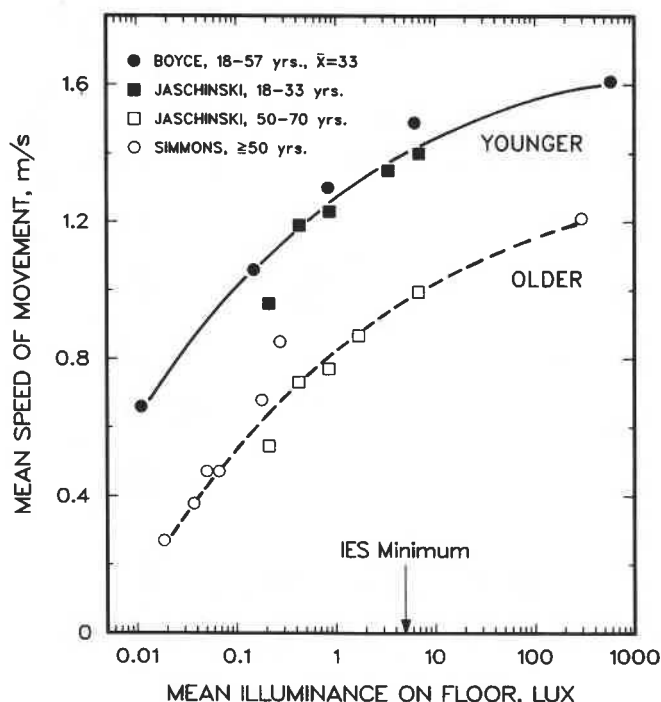## Discussion

Collisions with large obstacles

Simmons found that the mean number of collisions reduced rapidly when mean illuminances were increased above 0.019 lx, and no obstacles were struck at 0.28 lx or above. This is in good agreement with Jaschinski who found that 0.24 lx or above is sufficient to avoid obstacles. Similarly, Boyce observed that a mean illuminance level somewhere between 0.15 and 0.85 lx is sufficient to avoid striking obstacles. Perhaps surprisingly, he noticed fewer collisions when the subjects escaped in groups of four than when they escaped individually. He explained that his subjects escaped in single file, giving three subjects advance warning of obstacles from the movements of the person ahead. Nikitin, on the other hand, observed more collisions per subject with increased traffic volume. It is likely that his subjects did not escape in single file. Different definitions of collision may also explain the different conclusions drawn from these experiments. Boyce regarded a collision as a physical contact with any piece of common office furniture; whereas Nikitin regarded any close approach of about 30 cm or less as a collision. Nevertheless, Nikitin concluded that a mean illuminance of 0.3 to 0.5 lx will allow twelve people to leave a space without any near contacts with office furniture.

Based on the criterion of collisions with large obstacles, one might conclude that an average illuminance of 0.5 lx on the floor will provide a reasonable level of safety.

Escape time and average speed of movement

Based on the criterion of egress time, one might not arrive at the same conclusion. All experimenters found that egress time can be improved by increasing average illuminance higher than 0.5 lx (**Figure 1**). Based on the **Figure 1** criterion of egress time and supported by subjective appraisals discussed below, Jaschinski concluded that "an emergency illumination of 2 lx (measured 20 cm above the floor) seems reasonable" and advises that 4 lx is preferred when many elderly people are expected to occupy the space.

Simmons noticed a 30 percent reduction in escape time when raising mean illuminance from 0.28 lx to

Figure 1—Average walking speeds in cluttered or furnished spaces from three emergency lighting experiments. The curves have been fitted by eye. Older people (50 years or more) are represented by the dashed line, whereas younger people (mostly under 40 years) are represented by the solid line. Adjustments to Jaschinski's illuminance measurements are described in the text.

300 lx but suggested the improvement is not necessarily worth the additional expense.

Boyce identified 0.2 lx as absolute minimum and 1.0 lx as much better, adding there is no appreciable improvement in escape time above this lighting level. The conclusion is based on a subjective judgement of slope from a graphical representation of escape time versus average illuminance at floor level. Graphs can be, quite unintentionally, deceiving.[10,11] Judgments of slope are especially troublesome.[10] Boyce's figure is useful, however, for demonstrating the diminishing improvements in escape time with progressive increases in illumination levels.

Webber and Hallman[4] observed a 21 percent decrease in escape time in an uncluttered corridor when the mean illuminance is increased from 0.2 to 1.0 lx. Similar decreases were observed for the staircase route, however walking speeds were about two to three times greater in the staircase than in the uncluttered corridor, as might be expected.

Absolute escape time is not a useful measure for comparing the findings of the above studies, because the escape routes were of different length. Following Webber,[2] the average speed of movement will be used

as the common measure of performance. The value is calculated by dividing the length of the escape route by the escape time. Webber performed such calculations for the findings of both Jaschinski and Simmons. From a diagram in Boyce's report,[3] it is possible to determine the approximate speed of movement by his subjects. (The precise values used in **Figure 1** were actually obtained by correspondence[12]). **Figure 1** shows comparable egress speed data from all studies[3-5] plotted with logarithmic abscissa, as is conventional and appropriate when representing the wide range of stimulus magnitudes presented to the subjects. To compare escape speeds in the three studies[3-5] one should consider only those data collected under comparable conditions. Since none of the other experimenters used electric exit signs to provide guidance at junctions, Jaschinski's measurements collected in the presence of electric signs have been excluded.* Similarly, only conditions representative of furnished or cluttered spaces are represented in this figure. Thus, the curve representative of Boyce's work excludes data collected in the long, uncluttered corridor.** Similarly, the work of Webber and Hall is not represented in this figure, though it may be noted that their data for subjects of mixed ages in the uncluttered corridor agree well with the upper curve of **Figure 1**. All subjects in the Simmons and Jaschinski experiments began their escapes from a standing position. For this reason, Boyce's delay times have been excluded from **Figure 1**. Finally, Jaschinski's illuminance measurements at 20 cm above the floor were adjusted by a factor of 0.9 to approximate the expected illuminance at floor level. This factor is the ratio of illuminance measured at 20 and zero cm above the floor in a comparable installation. With these notes in mind, the following important points can be drawn from **Figure 1**:
• The rates of movement of people of similar age in cluttered spaces are consistent in all three studies.[3-5]
• Any reduction in illuminance level below normal ambient levels (300 lx or possibly greater) will lead to some reduction in escape speed. The rate of reduction increases as illuminance decreases.
• Based upon the collective data of Jaschinski and Simmons, the current minimum recommendation of the IES (5 lx on average) leads to an apparent reduction of about 20 percent in the average escape speed of 50 to 70 yr old people, relative to their average escape speed at 300 lx. At 1 lx and 0.2 lx, the reduc-

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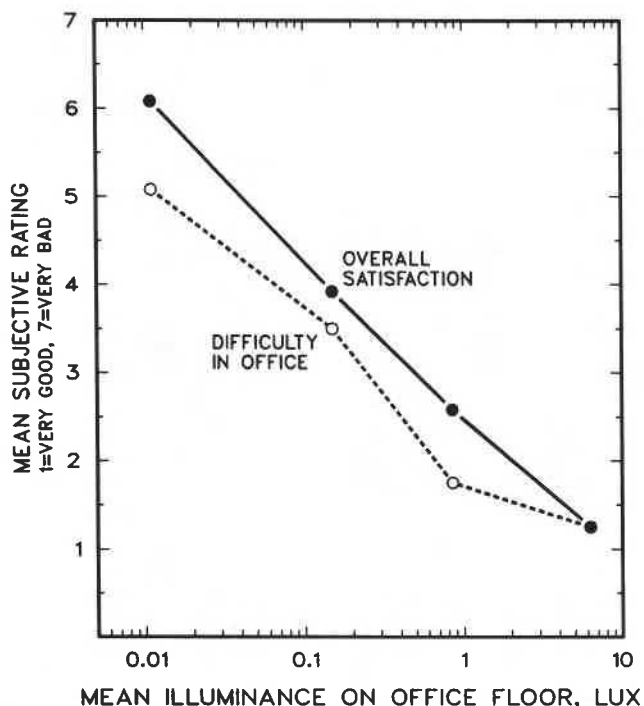*It should be noted, however, that escape times were improved with the use of electric exit signs.
**At lower levels of illumination, faster escape speeds were observed in the corridor than the office. At 7 lx, however, escape speeds were approximately the same in both spaces.

tions relative to 300 lx are about 31 percent and 50 percent, respectively.

• Based upon the collective data of Boyce and Jaschinski for younger people, the reductions in average escape speed at 5, 1 and 0.2 lx relative to 300 lx are about 12 percent, 20 percent, and 30 percent, respectively.

Subjective appraisals

The above points drawn from the measurements of egress speed are reinforced by subjective appraisals of occupant satisfaction and difficulty. This might suggest that escape speed is a more appropriate criterion for the measurement of safety than the criterion of collisions with large obstacles. **Figure 2** shows that the satisfaction of Boyce's subjects progressively increased with increasing illumination (even beyond his recommendation of 1 lx). Within the range of Boyce's experimental conditions, the satisfaction of British working people is maximum, and movement difficulty is minimum when the average illuminance is about 7 lx or higher. Webber and Hallman's subjects reported that at 1.0 lx, it was "easy to see" and they were "moderately satisfied." There was progressively greater difficulty and more dissatisfaction at the lower levels tested. Jaschinski observed general dissatisfaction at about 1 lx or lower, and satisfaction at about 3 lx for German subjects. No comparable measurements have been made in North America.

Figure 2—Subjective ratings of emergency lighting conditions, after Boyce, 1985.

Summary

Experiments using three different criteria for the assessment of safety under emergency lighting were reviewed. Studies which measure safety in terms of the number of collisions with large obstacles in the escape path consistently show good performance at illuminance levels as low as 0.5 lx. Although obstacles can be avoided at these low levels, people are still more hesitant as reflected in average walking speed, a potentially important measure of safety during emergency evacuation. Any reduction in average illuminance below 300 lx will compromise average walking speed to some degree. Thus, the recommendation of minimum illuminance levels, becomes a value judgement on resolving a compromise between inferred occupant safety and the cost of illumination. The current 5 lx recommendation by the IES implies a 20 percent reduction in the egress speed of 50–70 year old individuals, and a 12 percent reduction in that of younger people.

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Discussion

The authors are to be commended for their insightful analysis of the impact of illuminance levels on emergency egress. Their re-analysis of the data from several experiments provides a framework for assessing different studies of emergency egress behaviors. Their analysis deals only with egress in non-fire emergencies, however, one wonders what the impact of smoke might be on illuminance and walking speeds. In addition, one wonders what the effects of change in elevation such as stairs or ramps, might be in walking speed under emergency conditions. The impact under non-emergency conditions is to reduce speed—one wonders if a similar or greater reduction would apply under emergency conditions. Nonetheless, the paper presents a critical insight into emergency egress lighting requirements—one that will be invaluable to IES and NFPA.

Dr. Belinda L. Collins
National Bureau of Standards

This paper represents a significant landmark in the study of emergency lighting. It shows that data collected by three researchers, working quite independently, fit into a consistent and coherent pattern. That pattern demonstrates smooth increases in mean speed of movement with increasing log mean illuminance, certainly up to 10 lx and probably up to 1000 lx. My hesitation about the mean speed at the highest illuminances is due to the fact that there is only one point on each curve between 10 and 1000 lx and the point from my experiment may be subject to bias. The bias arises because the movement under the normal room lighting (80 lx) always took place after movement under the emergency lighting condition, i.e., after practice. Such practice, if it has any effect at all, is likely to increase the speed of movement. This quibble is supported by the results of the subjective appraisals. In my own work, the mean rating at 7 lx is 1.2, where a rating of 1 is the best available on the 7 point scale used. Thus the rating at 7 lx allows little room for improvement with higher illuminances. Similarly, the ratings given by Jaschinski's subjects are all close to unity at 3.85 lx and show no change up to 7.7 lx, the highest illuminance used. Such ratings suggest that either improvements in speed of movement at higher illuminances are slight or that people are quite insensitive to restrictions on their speed of movement, given that 11 percent and 20 percent improvements are apparently available at 300 lx for younger and older subjects respectively. Regardless of whether the trend with illuminance is continuous up to 300 lx or higher, there can be no doubt that the selection of a minimum illuminance for emergency lighting is indeed a matter for judgement. This is not only because there are different curves for younger and older people but also because the speed of movement measurements described were taken at a time when the subjects would be most sensitive to the illuminance on the escape route; that is, immediately following a step change in illuminance caused by the changeover from the normal lighting. At later periods, the visual system would have become more closely adapted to the new conditions, so speed of movement can be expected to increase, particularly at the lower illuminances. This point demonstrates that reactions to emergency lighting conditions are not simple matters. The present paper has analyzed the available information on speed of movement at different illuminances thoroughly and has produced a remarkably coherent picture. Little more work is needed on this particular problem. What is required is work on emergency lighting as a component in a system of evacuation. Specifically, the integration of lighting and signage needs to be examined. The influence of smoke on direction finding and speed of movement is also of interest and the use of specular reflecting and photo-luminescent material should be studied. Once information is available in these areas, then it should be possible to design an effective evacuation system in which emergency lighting can play its part.

Dr. Peter Boyce
Electricity Research Council

This paper represents a well-conceived and carefully implemented attempt to bring order to a broad range of research data, developed using several different methodologies from various countries around the world. In my view, it is an unqualified success and will become a strong reference for future emergency illuminance recommendations from the society, as well as code-making bodies in the US, Canada and elsewhere. One will find it difficult to quibble with the technical merits of the approach and I will refrain from doing so. I think this is an appropriate time, however, to make a short comment on the manner in which I hope the paper will be used. The facetious subtitle, "In Search of the Magic Number," used at the Mineapolis presentation of this paper hints at a very important point made strongly in the presentation.

There is no magic number—only a range of possible results requiring informed design judgments. In lighting (as in many other endeavors), there is a tendency in some circles to search for a number which can be used to represent a very complex set of interactions between humans and their environment. In this context, it is critical that this data be used to reveal and inform, and not in a manner that relieves designers and code-makers of their responsibility to assimilate a bigger picture in making responsible judgments. In a safety related area such as emergency lighting it has always seemed paradoxical to me that, in some countries, the search for the magic number is a danger that we must resist. This paper not only gives us a better perspective on what we give up as illuminance levels decline toward threshold levels, it clearly delineates where those levels are. Since a basic tenet of safety design is the margin of safety that protects us from the many unpredictables in real world situations, it will be very useful to know where the minimum limits lie so that we may recommend safe levels well above them. My primary question for the authors relates to their statement that "emergency lighting recommendations represent value judgments based upon tradeoffs between occupant performance and cost of lighting." In their opinion, where is the appropriate balance between cost and performance and what other factors should the designer or code-maker consider in selecting an appropriate (while less than magic) illuminance figure?

Ken Honeycutt
Lithonia Emergency Systems

Authors' response

We wish to thank Dr. Collins, Dr. Boyce, and Mr. Honeycutt for their kind remarks and hope our analysis provides some insight for making recommendations on emergency lighting.

To Dr. Collins

Dr. Collins is quite correct in noting the problem that smoke creates by scattering ambient illumination and, thus, reducing visibility. Several studies (Ouellette, 1988;[1] Rea et al. 1985;[2] Jin, 1978[3]) have shown this effect, but no one has established clear guidelines on how to deal with this issue in practice. More research directed to this goal is clearly important.

To Dr. Boyce

We are pleased that Dr. Boyce is in agreement with our analysis and recognizes the significance of value judgements when establishing recommendations from research results. We would be cautious, however, in making any simple generalizations from his (or other) subjective rating data. Several authors have pointed out the various biases associated with subjective scaling data (Rea, 1982;[4] Lulla and Bennett, 1981;[5] Poulton, 1979;[6] and Poulton, 1975[7]).

To Mr. Honeycutt

Mr. Honeycutt asks our advice about an appropriate illuminance value. During the past meeting (August, 1988) of the IESNA Emergency Lighting Committee, under his chairmanship, we suggested that the committee recommend a 0.5 lx minimum and a 5 lx average along the escape route. According to our review of the literature, the recommended minimum value should assure obstacle avoidance by occupants in cluttered spaces. Also based upon our review, we see no reason to lower the current IESNA recommended 5 lx average; this value represents a 12 to 20 per cent reduction in escape time relative to an ambient level of 300 lx. Naturally, these recommendations, or any other, will and should be evaluated by the entire committee.

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