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**USER RECONFIGURATIONS OF
THE DE BOER RATING SCALE
FOR DISCOMFORT GLARE**

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16. Abstract <p>This study evaluated the de Boer rating scale for discomfort glare. The aim was to determine if the scale was effective in rating discomfort glare and, if not, what modifications are necessary to improve the scale. The hypothesis was that the de Boer scale was not optimal for rating the true psychological effect of discomfort glare by American observers. Two tasks were performed by each subject. The first task was an ordering of the verbal descriptors, in which the subject ordered the five verbal descriptors from the scale in the order they thought the scale should run. The second task was to number the scale they created.</p> <p>The results indicate that (1) there is a problem with the way the de Boer scale is numbered, and (2) some of the verbal descriptors are confusing and can lead to improper scaling of glare. These results are consistent with the hypothesis that the de Boer scale is not the optimal scale for rating discomfort glare by American observers, and research on an improved scale is necessary.</p>					
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INTRODUCTION

Bright light present in the visual field can result in a phenomenon called glare. There are many possible sources of glare in traffic situations. Vehicle headlamps, rear lights and signals, as well as street lighting, can all cause glare to a driver. Glare is believed to have two separate effects on the observer (e.g., Holladay, 1926; Hartmann, 1962; Adrian, 1968). The first effect--disability glare--is an objective impairment in visual performance. The second effect, the one of interest in this study, is discomfort glare. Discomfort glare is the subjective impression of discomfort, and is a function of at least three factors: (1) the amount of illumination from the glare source, (2) the observer's line-of-sight angle with respect to the glare source, and (3) the brightness of the surrounding field to which the subject is adapted (Bhise et al., 1975).

Discomfort glare has been measured in several different ways over the past fifty years. Two different broad approaches to measuring discomfort glare have arisen: the single-label method and the multi-label scale. Luckiesh and Guth (1949) used a single-label method for measuring discomfort glare called "borderline between comfort and discomfort" or BCD. Bennett (1977) also used this method to measure discomfort glare in industrial settings. The BCD was measured by allowing the subject to adjust a glare stimulus until the critical value was reached. A potential problem with using the single-label method was that the BCD must be accurately and unambiguously defined. Another problem was that it can be used only when the subject is able to manipulate the glare stimulus. When the experimenter controlled the amount of glare the subject received, this method was ineffective in measuring discomfort glare because the subject could not accurately rate where individual glare stimuli lie in relation to the BCD (de Boer, 1967).

Studies performed by Hopkinson (1940) and de Boer (1967) found that multi-label scales better represent the amount of discomfort a subject receives from glare. These types of scales allow the experimenter to pinpoint the actual discomfort of a particular glare stimulus. Hopkinson (1940) used a four-point scale, with each point labeled by a verbal descriptor (see Figure 1a). Adrian (1970) used a similar four-point scale (see Figure 1b). Two different tasks can be performed using these scales. The first is to rate a given glare stimulus using the scale and verbal descriptors. The second task consists of asking the subject to vary the glare stimulus to match each glare level on the scale. A believed advantage to using multi-label scales was that no further definition of terms (verbal descriptors) was necessary.

De Boer and his colleagues developed a widely used multi-label scale consisting of nine points with five verbal descriptors (e.g., de Boer, 1967; de Boer & Schreuder, 1967).

Hopkinson (1940)

- 1) Just Perceptible
- 2) Just Acceptable
- 3) Just Uncomfortable
- 4) Just Intolerable

(a)

Adrian (1970)

- 1) Just Noticeable
- 2) Borderline Comfort-Discomfort
- 3) Just Annoying
- 4) Just Intolerable

(b)

Figure 1. Four-point discomfort glare rating scales.

These descriptors are positioned on the odd numbers only (see Figure 2a). The scale is numbered so that the most discomforting glare has the lowest numerical value and the least discomforting glare the highest value. Over the years it has been repeatedly modified. The numbering of the scale has remained the same but the verbal descriptors have changed somewhat (see Figure 2b, 2c, 2d, 2e, and 2f). These changes in the verbal descriptors present a potential problem with between-study comparisons. The descriptors represent the amount of discomfort glare a person experiences from a stimulus. How individuals understand the meaning of the verbal descriptors will determine how they rate each glare stimulus. Because scale users may interpret the meaning of each verbal descriptor somewhat differently, it is only logical that a standardized scale (same verbal descriptors) be developed and used by all. As long as different versions of the 9-point scale are used, cross-study comparisons will contain noise in the results due to the variability of interpretation of the verbal descriptor meanings.

Hemion (1968) and Fisher (1974) utilized six- and seven-point scales (see Figure 3a and 3b). Fisher's work on his own scale indicated that subjects were inconsistent in their understanding of the verbal descriptors (see Figure 3b). After testing subjects, he presented them with 26 descriptive words and asked the subjects to number the words according to where they would most likely appear on the scale, if they were used as verbal descriptors. Certain words were easily placed in one specific position on the scale but other words caused confusion, and were placed in two or more spaces on the scale with equal frequency.

Olson and Sivak (1984) proposed a three-point scale (see Figure 3c) that contained descriptive phrases instead of words. It was designed as a condensed version of the de Boer scale, and was used to evaluate optimal designs for improving headlamps.

A review of the literature on the various scales used to rate discomfort glare indicates that further study of a standardized scale to quantify discomfort glare is both necessary and justified. The genesis of the current study lies in past experiments at The University of Michigan Transportation Research Institute (UMTRI) that used one of the versions of the de Boer scale--referred to here as the modified de Boer scale (Bhise et al., 1975)--(see Figure 2f). The debriefing of subjects after such experiments elicited various remarks about the logic of the de Boer scale. In addition, the experimenters themselves were prone to descriptor-sequence errors when reconstructing the scale from memory. Initiating a systematic evaluation from the user's point of view seemed prudent. A useful property of a user's scale is that it correspond, whenever possible, to user expectations (population stereotypes). These population stereotypes were investigated by presenting the elements of the de Boer scale--verbal descriptors in no particular order and no descriptor numbers

de Boer 1967 (de Boer, 1967; de Boer & Schreuder, 1967)

- 1) Unbearable
- 2)
- 3) Disturbing
- 4)
- 5) Just Admissible
- 6)
- 7) Satisfactory
- 8)
- 9) Unnoticeable

(a)

de Boer 1973 (de Boer, 1973)

- 1) Unbearable
- 2)
- 3) Disturbing
- 4)
- 5) Just Admissible
- 6)
- 7) Satisfactory
- 8)
- 9) Just Noticeable

(b)

de Boer 1974 (Schmidt-Clausen & Bindels, 1974)

- 1) Unbearable
- 2)
- 3) Disturbing
- 4)
- 5) Just Admissible
- 6)
- 7) Acceptable
- 8)
- 9) Noticeable

(c)

de Boer 1974 (Becker & Mortimer, 1974)

- 1) Unbearable
- 2)
- 3) Disturbing
- 4)
- 5) Just Acceptable
- 6)
- 7) Satisfactory
- 8)
- 9) Unnoticeable

(d)

de Boer 1974 (Mortimer & Olson, 1974)

- 1) Intolerable
- 2)
- 3) Disturbing
- 4)
- 5) Just Acceptable
- 6)
- 7) Satisfactory
- 8)
- 9) Not Noticeable

(e)

de Boer 1975 (Bhise et al., 1975)

- 1) Unbearable
- 2)
- 3) Disturbing
- 4)
- 5) Just Acceptable
- 6)
- 7) Satisfactory
- 8)
- 9) Just Noticeable

(f)

Figure 2. Various versions of the de Boer discomfort glare rating scale.

Hemion (1968)

- 0) No Problem
- 1)
- 2) Bothersome
- 3)
- 4) Quite Uncomfortable
- 5)
- 6) Practically Blinding

(a)

Fisher (1974) (Brightness / Discomfort)

- 1) Very Dim / Very Dull
- 2) Dim / Dull
- 3) Diffuse / Not Very Bright
- 4) Bright / Uncomfortable
- 5) Glaring / Very Uncomfortable
- 6) Intolerable / Unbearable

(b)

Olson & Sivak (1984)

- 1) Glare So Weak As To Produce No Sensation (~7 to 9 on DeBoer)
- 2) Glare That Produces Noticeable Discomfort But Tolerable (5 on DeBoer)
- 3) Glare So Intense It Causes An Avoidance Response (~1 to 3 on DeBoer)

(c)

Figure 3. Other multi-label discomfort glare rating scales.

attached--to naive potential users. The users were asked to construct a discomfort glare scale from these elements. Any deviations between the user constructions and the de Boer scale may provide clues for scale improvements.

The hypothesis in this study was that the de Boer scale was not optimal for rating discomfort glare by American observers, and that a better scale was possible. Two experiments were conducted. The first was a more formal experiment using naive subjects and individual testing. The second was a less formal experiment, using experts in human factors as subjects in a group paper and pencil test.

METHOD

MAIN EXPERIMENT

Tasks

Two tasks were performed by every subject. The first was an ordering task of the verbal descriptors, in which the subjects arranged the five verbal descriptors from the modified de Boer scale (Bhise et al., 1975) in an order they perceived the scale to run. The second task was a numbering of the descriptors. After the subjects had ordered the verbal descriptors, they were asked to report which way they believed the scale should run numerically (i.e., 1 to 5 from least discomforting to most, or 1 to 5 from most discomforting to least).

Equipment

Five 3"x5" plain white index cards, with a different verbal descriptor printed on each, were presented to a subject. The cards were shuffled each time to randomize the presentation order. The modified de Boer scale, on an 8.5" x 11" sheet of white paper, was presented to the subjects after completion of the tasks so that they might compare their reconfiguration to the original, and answer questions about the scale and contribute comments.

Subjects

Twenty-six subjects, thirteen male and thirteen female, participated in the study. Their ages ranged from 20 to 55 years. Subjects were employees of UMTRI and had no familiarity with scales used to rate discomfort glare.

Procedure

Subjects were tested individually. They were briefed with a short introduction and explanation of the study, and were then presented the cards and instructed to order them the

way they perceived the scale would run (descriptor sequence). Next they were asked in which direction the numerical scale would run in relation to the verbal descriptors (numerical assignment). After the two tasks were completed the experimenter recorded the subject's scale. The subjects were presented with the modified de Boer scale (Bhise et al., 1975) and given a brief explanation of it. They were asked "Do you think the spacing between all the descriptors is about the same," and, finally, were asked for any other relevant comments.

SUPPLEMENTARY EXPERIMENT

Tasks

The tasks performed in the Main Experiment were also performed here.

Equipment

An overhead transparency with the five verbal descriptors arranged at different angles in a random scatter was presented to the subjects (see Figure 4). Five short horizontal dotted lines stacked vertically on a piece of paper constituted the response sheet for each subject.

Subjects

Fourteen subjects, thirteen male and one female, participated in the study. Subjects were members of the Southeast Michigan Chapter of the Human Factors Society attending a technical meeting held at UMTRI. Five of the subjects had some familiarity with the scale and the rating of discomfort glare.

Procedure

Subjects were tested as a group. They were presented the overhead transparency with the five verbal descriptors (see Figure 4) and asked to write them on the dotted line sheets in the order they thought the scale should run (descriptor sequence). Next, by a show of hands, they were asked in which direction the numerical scale should run in relation to the verbal descriptors (numerical assignment).

Finally, they were asked if they had any familiarity with the scale and, if so, in what context (i.e., work, research, etc.), and were asked to write the answer on their response sheet also. The sheets were then collected and an overhead transparency of the modified de Boer scale (Bhise et al., 1975) was presented for comparison purposes.

JUST ACCEPTABLE
UNBEARABLE
JUST NOTICEABLE
SATISFACTORY
DISTURBING

Figure 4. Example of overhead transparency used in Supplementary Experiment.

RESULTS

The subject's task was to arrange the five descriptors into a preferred discomfort sequence from least to most, or most to least. Next, the sequence of descriptors was numbered in order 1 through 5, by deciding whether increasing numbers should signify increasing or decreasing discomfort. The de Boer numbering was reduced from 9 to 5 numbers by eliminating the scale categories without descriptors as follows: 1-*Unbearable* (U), 2-*Disturbing* (D), 3-*Just Acceptable* (JA), 4-*Satisfactory* (S), and 5-*Just Noticeable* (JN). Each subject's preferred scale can be compared to the de Boer scale by pairing the subject's numerical assignment with the de Boer numerical assignment for each descriptor in turn. If all five pairs of numbers match, then there is a perfect correspondence and the subject has reproduced the de Boer scale exactly (correlation coefficient = +1.0). The rank-order correlation, R , can be computed by taking the difference, d , between the numbers in each pair: $R = 1 - [\frac{6\sum d^2}{N^2(N - 1)}]$, where $-1 \leq R \leq +1$ (which is identical to the product-moment correlation, r , computed on these $N = 5$ pairs of integers). This correlation has useful properties. Its absolute value, $|R|$, reveals how closely the subject's descriptor sequence matches the de Boer descriptor sequence, disregarding the numerical assignment. Figure 5 displays the outcome. No subject's $|R|$ is less than 0.7, meaning that, in all cases, the descriptors tend to be arranged in a discomfort sequence that approximates the de Boer arrangement of descriptors. The sign of the correlation reveals whether subjects agree (positive) with de Boer that increasing discomfort should be numbered with smaller numbers, or disagree (negative). The majority disagree, since 17 of 26 subjects have negative correlations. Note the absence of +1.0 correlations; no subject duplicated the de Boer scale exactly. However, five subjects duplicated the de Boer descriptor sequence exactly while reversing the numerical assignment. As will be discussed later, an $|R| = 0.9$ occurs when a subject has exchanged the locations of two adjacent de Boer descriptors; 0.8 occurs when this happens twice with intermediate descriptors stationary; 0.7 occurs when three adjacent descriptors were rearranged (see Figure 7).

A confusion matrix can reveal which descriptors are changed from the de Boer sequence. In order that the confusion matrix reveal changes in descriptor sequences more easily, the numerical assignments were reversed for the minority of subjects who showed positive correlations. Thus, all subjects were treated as though larger numbers were assigned to greater discomfort (negative correlations). Table 1 shows the data. Note the vertical column for 4-*Satisfactory*. Only seven subjects agreed with the de Boer descriptor location (one step more discomforting than *Just Noticeable*), while 15 people chose to

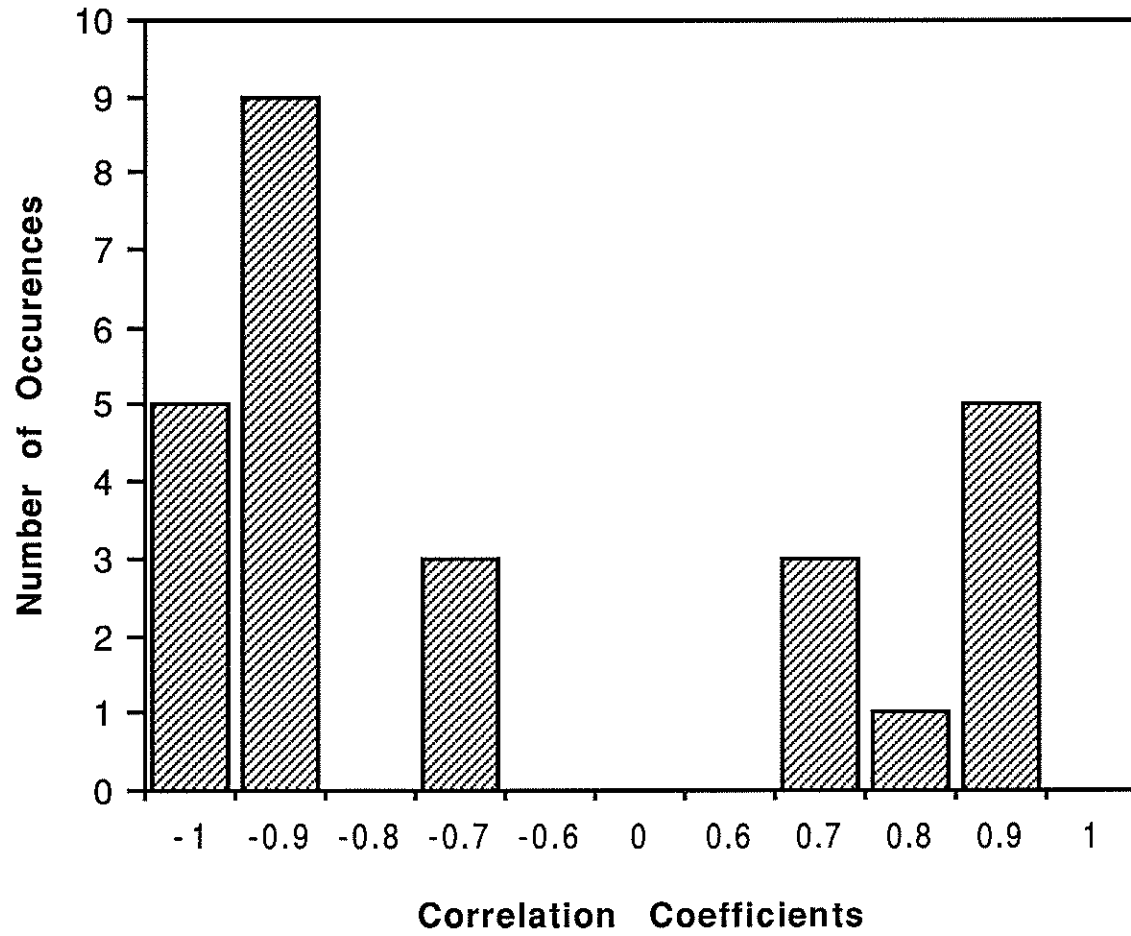


Figure 5. Rank-order correlation between subjects' ordering and de Boer's ordering.

Table 1. Subjects' confusion matrix of word placement.

Subjects' Preferred Scaling	(5)	25	1			
	(4)	1	22	2	1	
	(3)		3	15	3	5
	(2)			9	7	10
	(1)				15	11
		1	2	3	4	5
		Unbearable	Disturbing	Just Acceptable	Satisfactory	Just Noticeable

de Boer's Scaling

make it least discomfoting and four chose to make it even more discomfoting. Thus, the confusion matrix can highlight problem descriptors. *Satisfactory* is clearly a problem; *Unbearable* and *Disturbing* are much more stable from subject to subject.

The column means from Table 1 are plotted in Figure 6, which shows the average numerical assignment for each descriptor (again, all correlations have been switched to negative). For the means the descriptor sequence does not quite match the de Boer sequence; as was detectable in the confusion matrix, *Satisfactory* is out of sequence by a small amount.

It is not known how the final descriptor sequence was achieved by a subject. An informative way to represent changes is to display the de Boer sequence with arrows depicting displacements as in Figure 7. There are 120 (five factorial) possible sequences for ordering the five descriptors. However, half of these sequences are mirror images, that is, identical after the sequence order is reversed. Sequences are displayed in Figure 7 with the most discomfort topmost, so there are effectively 60 possible orders, of which only these seven were actually used. None approached a random order ($|R|$ near zero). In contrast to the confusion matrix, this diagram indicates the patterns of position exchanges subject by subject. For example, *Satisfactory* is often switched (by 19 of 26 subjects), most often displacing *Just Noticeable*, a notion to be pursued in the discussion.

The data from the experts in the Supplementary Experiment can be summarized simply. Expert opinion is not much at variance with the preferences of naive subjects. As depicted in Figure 7 alongside the data from naive subjects, the 14 experts preferred the de Boer descriptor sequence even less strongly (only one person with $|R| = 1.0$ correlation). The three lowest frequency sequences generated by naive subjects (two or fewer subjects) were never generated by experts. Interestingly, the triple switch involving *Just Noticeable* was most used. (Is *Just Noticeable*, rather than *Satisfactory*, the problem descriptor?) Among the experts, five of 14 were familiar with the rating of discomfort glare, including use of the de Boer scale. Nevertheless, none reproduced the de Boer scale exactly ($R = +1.0$), only one matched the de Boer descriptor sequence ($R = -1.0$), and only one voted for the de Boer numerical assignment (smaller numbers signifying greater discomfort).

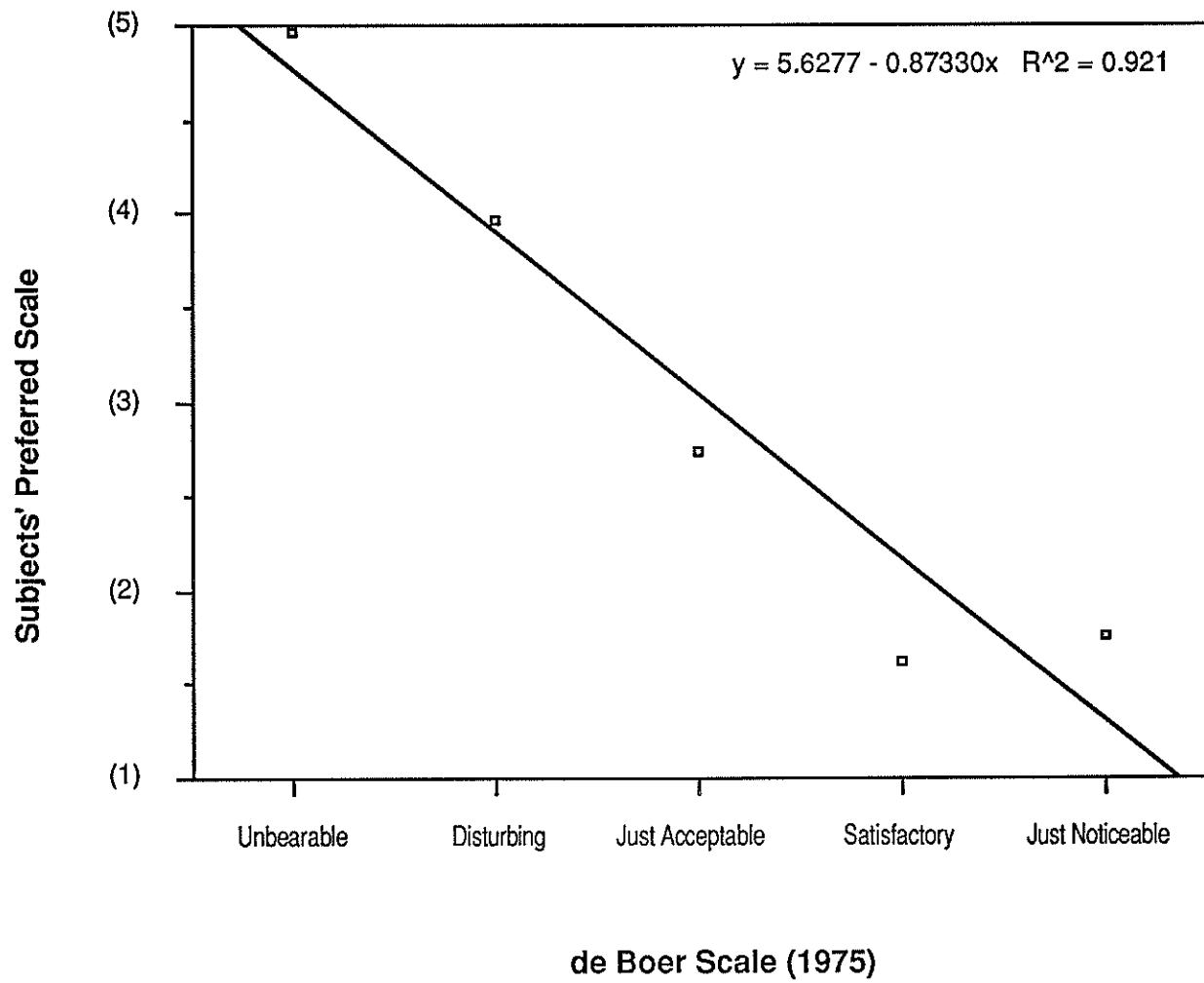


Figure 6. Relation of subjects' preferences to the de Boer scale (1975).

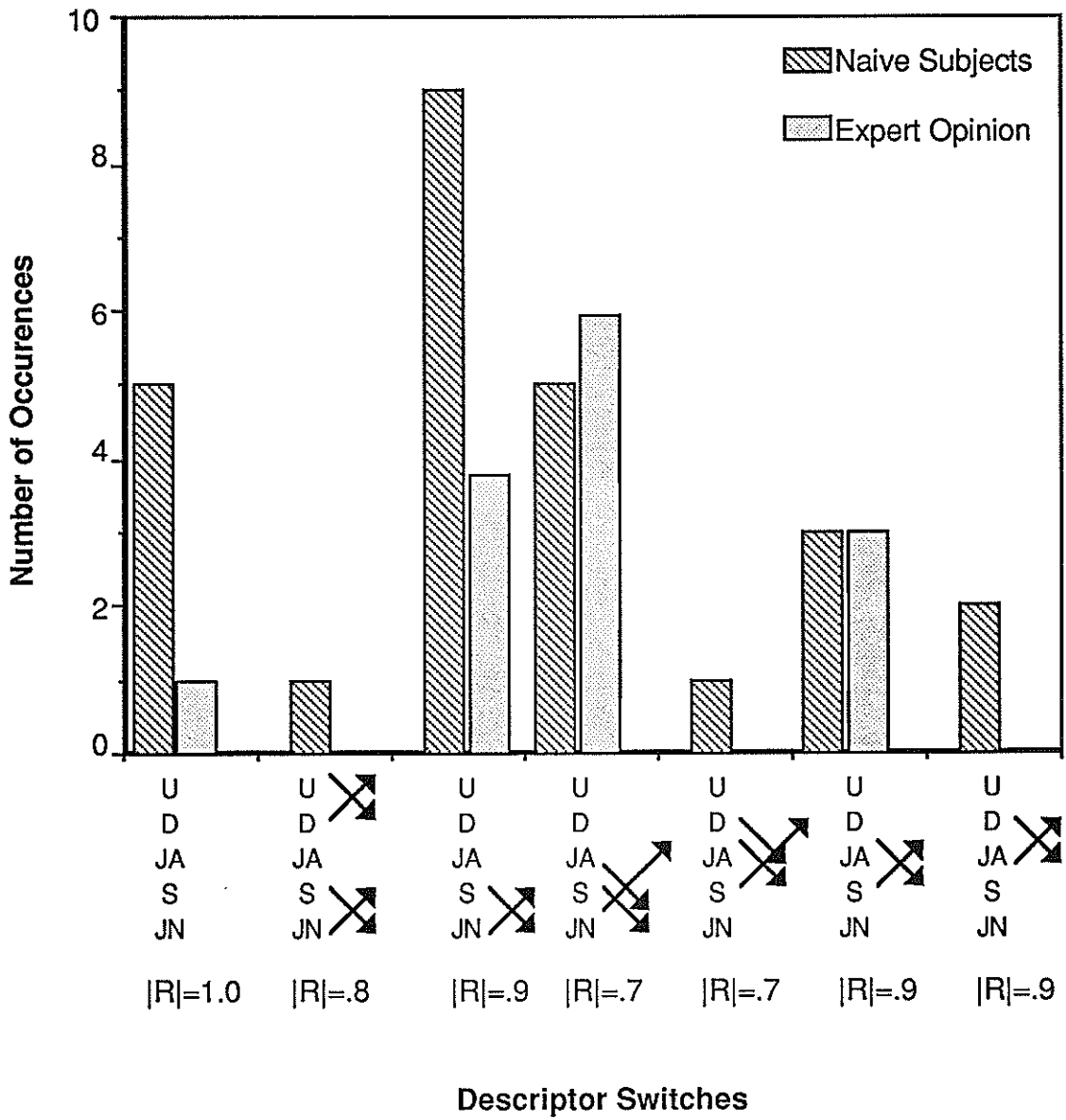


Figure 7. Descriptor switches in Main Experiment and Supplementary Experiment.

DISCUSSION

All subjects were from the U.S., and it is highly likely that the translation of descriptors into different languages, and the natural assignment of numbers to descriptors to represent more (and less) discomfort by other nationalities, will alter user preferences. The de Boer scale was originally developed by Dutch researchers.

The data support two major themes. First, given the particular elements--descriptors and numbers--that comprise the de Boer scale, U.S. subjects construct discomfort scales that reveal strong cross-subject consistencies and interesting patterns of inconsistencies. The preferences of experts tend to reinforce the patterns shown by naive users. Second, and rather surprisingly, not one subject, expert or naive user, exactly matched the modified de Boer scale (Bhise et al., 1975). The large majority of respondents, 75% (30/40), preferred a reverse numerical assignment, i.e., larger numbers representing greater discomfort, while 85% (34/40) reconfigured the descriptors in a sequence that differed from the de Boer sequence. The de Boer scale is a highly useful tool in assessing the discomfort from headlamp glare, widely known and frequently used (by UMTRI as well). Improving the tools of the trade is of value beyond the local laboratory. The data interpretations and suggestions to follow are intended not as criticisms, but as beginning steps toward improving the precision in measuring discomfort glare.

There are at least two U.S. population stereotypes associated with assigning numerals to a psychological scale of measurement. Increasing numerical values are associated with: (1) increasing level (amount) of what is measured, (2) increasing degree of positive value (goodness, desirability) of what is measured. School performance combines both aspects. In U.S. colleges a 3.0 grade point is a "B average," while a 4.0 is a "straight A average." Thus, higher numbers signify a higher level of academic performance, as well as a more desirable grade point as is true in many countries (including The Netherlands). However, discomfort glare from headlamps pits one meaning against the other. Since a higher level of discomfort is less desirable, the numerical assignment might become ambiguous. One proposal is to add zero (0) to the discomfort scale whose associated descriptor is *No Discomfort*. The idea is to anchor the scale at the low end, which strongly implies that larger numbers must mean a greater level (amount) of discomfort, thereby reducing user ambiguity. In practice, this would do violence to the de Boer scale. First, it would reverse the de Boer numerical assignment. Second, only odd levels (every other number) have descriptors, but a descriptor at zero (0) would add an adjacent descriptor.

The data at hand are not adequate for the task of evaluating the suitability of descriptors. The de Boer descriptors were not often reconfigured to match the sequence of the actual

scale (see Figure 7). The descriptor *Satisfactory* is most often displaced, and if *Satisfactory* is omitted (perhaps exchanged for a benign substitute) most of the sequence displacements would disappear. In Figure 7, two low-frequency displacements--a U/D switch and a D/JA switch--will remain, and one high frequency (both naive and expert) displacement--JA/S/JN--will also remain, where one might infer that a benign replacement for S would stay put and a JA/JN switch would still occur. Therefore, *Just Noticeable* might be the trigger for this displacement, and it is also involved in the majority of displacement switches. Any change in sequence requires that at least two descriptors be displaced. These data cannot establish cause, which one(s) of a set of terms triggers the displacement. (Interactions must not be ruled out.) In sum, if substitute terms are to be considered, the data implicate replacing *Satisfactory* and *Just Noticeable*, because they are often displaced. In addition, during subject debriefing it was often reported that *Satisfactory* discomfort is an ambiguous phrase.

Finally, additional considerations not addressed by the data are worth discussing. The first is the spacing of descriptors. An equal-interval psychological scale is clearly desirable. The numbered descriptors imply equal intervals, but subjects commented that descriptors did not seem equally spaced along the discomfort continuum. However, an overriding requirement is that descriptor sequences be the same for virtually all subjects (only interval lengths are then at issue), which is not the case for the data reported.

One logical explanation of the instability of descriptor sequences across subjects is that the descriptors have psychological meaning beyond location along a discomfort continuum. *Just Noticeable* signifies a small amount of discomfort; *Unbearable* signifies a large amount of discomfort. How much discomfort is *Satisfactory* discomfort? *Satisfactory* and *Just Acceptable*, may imply a value judgment about glare, how bad or objectionable it is. Objectionability (value) and level of discomfort may lie on different (but correlated) psychological dimensions. (The two scales must be related monotonically.)

To close, aside from human performance under different glare levels, which can be measured objectively, many other variables important to the glare researcher are subjective. One of these is the level of glare discomfort caused by a given headlamp. The second subjective variable is value related (objectionability or acceptability), which may or may not lie on the same psychological continuum. The researcher may not need to obtain quantitative information about how objectionable the glare from a given headlamp is, but merely to determine whether the glare exceeds the criterion marking the boundary between acceptable and unacceptable. For that objectionability boundary there must be an equivalent criterion on the discomfort scale. It is suggested that the descriptors of the de Boer scale may be referring not only to level of discomfort, but also to value (objectionability or

acceptability). However, a highly desirable characteristic of a rating scale for discomfort glare is that descriptors lie on a unidimensional continuum, evenly spaced (Pitrella & K ppler, 1988).

Our suggested strategy for the improvement of rating scales for discomfort glare is first, to endeavor to refine the de Boer scale so that equally spaced descriptors refer only to levels of discomfort. Second, at the end of any experiment involving discomfort-glare ratings, when all glare sources have been viewed and evaluated, the subject could be asked to choose a point on the discomfort continuum beyond which the level of discomfort is unacceptable. Indeed, subject inconsistencies in this experiment may be artifacts. Suppose that subjects may agree on the discomfort level (magnitude) of a glare source, but at the same time might disagree about the value (acceptability) of that level of discomfort. If *Satisfactory* is a value descriptor among glare-magnitude descriptors, different subjects might insert *Satisfactory* at different places in the descriptor sequence. Finally, consider adding a *No Discomfort* descriptor to try to lock down the numerical assignment across users.

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