UMTRI-90-35

CONTEXT EFFECTS ON DISCOMFORT GLARE: TASK AND STIMULUS FACTORS

Michael J. Flannagan
Daniel J. Weintraub
Michael Sivak

November 1990

CONTEXT EFFECTS ON DISCOMFORT GLARE: TASK AND STIMULUS FACTORS

Michael J. Flannagan
Daniel J. Weintraub
Michael Sivak

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

Report No. UMTRI-90-35
November 1990

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-90-35		

4. Title and Subtitle	5. Report Date
CONTEXT EFFECTS ON DISCOMFORT GLARE: TASK AND STIMULUS FACTORS	November 1990
	6. Performing Organization Code: 302753
7. Author(s)	8. Performing Organization Report No.
Michael J. Flannagan, Daniel J. Weintraub, & Michael Sivak	UMTRI-90-35
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
The University of Michigan Transportation Research Institute Ann Arbor, Michigan 48109-2150 U.S.A.	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	
The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety	14. Sponsoring Agency Code

15. Supplementary Notes

The Affiliation Program currently includes Bosch, Donnelly, Ford (Plastic Products Engineering), GE Lighting, GM (Inland Fisher Guide), GTE Products, Ichikoh Industries, Koito Manufacturing, Philips Lighting, Stanley Electric, 3M, and Valeo Automotive.

16. Abstract

Our previous research has shown that the difficulty of a concurrent visual task affects reported discomfort glare. Difficulty in that study was manipulated by changing the size of a stimulus in an acuity task. The present study extends that finding by (1) varying whether the concurrent task is required, independently of stimulus factors, and (2) adding a new manipulation of difficulty that may be perceived by subjects as similar to the intrinsic effects of glare: variation of luminance for the stimulus involved in the concurrent task.

Twenty four subjects were tested. Three tasks were performed by each subject. During some blocks of trials all three tasks were performed on each trial; during other blocks only one of them, glare rating, was performed. The three tasks were: (1) a gap-location task, in which subjects indicated whether a gap had appeared on the top or bottom of a briefly projected outline square, (2) confidence rating, in which subjects indicated their confidence in the gap-location decision, and (3) discomfort glare rating, in which subjects gave a numerical rating of the discomfort experienced from a light source which accompanied the presentation of the gap-location stimulus.

The results replicate the finding that gap size affects discomfort ratings, but only when the concurrent task is required. In contrast, stimulus luminance affects discomfort ratings even when the stimulus is irrelevant, although the effect is much greater when the stimulus is made relevant by requiring the concurrent task. The requirement to perform the concurrent task also resulted in greater overall rated discomfort, and a decrease in slope for the function relating discomfort to glare intensity.

These findings indicate that discomfort-glare evaluation is affected by the presence and nature of a concurrent visual task, and to a lesser extent by the luminance of an irrelevant stimulus. These effects call into question the accuracy of attempts to predict discomfort glare in actual driving situations on the basis of mathematical models or laboratory measurements.

17. Key Words	18. Distribution Statement
discomfort glare, disability glare, driving, headlamps, headlighting, rearview mirrors, task difficulty, rating scales, workload	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	28	

ACKNOWLEDGEMENTS

Appreciation is extended to Dennis Battle for assistance with running subjects, and to the current members of The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research:

Bosch
Donnelly
Ford (Plastic Products Engineering)
GE Lighting
GM (Inland Fisher Guide Division)
GTE Products
Ichikoh Industries
Koito Manufacturing
Philips Lighting
Stanley Electric
3M
Valeo Automotive

CONTENTS

ACKNOWLEDGEMENTS ii
INTRODUCTION 1
METHOD 3
RESULTS 7
DISCUSSION 19
SUMMARY 23
REFERENCES 25

INTRODUCTION

Discomfort glare--the subjective impression of discomfort from bright lights--is an important consideration in the design of a variety of automotive lighting/visibility components. For example, the design of headlamps (Bhise et al., 1977), stop lamps (Pasta and Soardo, 1979), and rearview mirrors (Flannagan, Sivak, and Gellatly, 1990), are all affected by the desire to minimize discomfort glare without unduly restricting other aspects of performance. In order for designers to make rational decisions about the tradeoffs involved in such cases, it is crucial to have a model that makes reasonably accurate quantitative predictions for discomfort glare.

The most prominent candidate for such a model is that proposed by Schmidt-Clausen and Bindels (1974). The essence of their model is an equation that expresses discomfort as a function of three parameters: (1) illuminance of the eyepoint caused by a glare source, (2) the angle between the glare source and the point of visual fixation, and (3) the "adaptation luminance" to which the eye has been exposed. Schmidt-Clausen and Bindels based their model on fits to data they obtained in a laboratory experiment in which those three factors were varied. Although the fits achieved in that context were good, the real-world validity of the model depends on whether those three factors capture all of the important influences on discomfort that exist in the real world. If not, decisions based on the Schmidt-Clausen and Bindels model may be less than optimal.

The possibility that discomfort glare behaves in unexpected ways outside the simple world of the laboratory is suggested by the subjective and psychologically complex nature of discomfort. No objective measures for the evaluation of discomfort glare have yet been developed. The usual approach is to rely on *reported* discomfort glare (e.g., Hopkinson, 1940; de Boer, 1967). However, reported discomfort glare is susceptible to several complicating effects. For example, reported discomfort glare from a given stimulus is affected by the range of other stimuli present (Lulla and Bennett, 1981; Olson and Sivak, 1984). The same light stimulus is reported as being more discomforting when it is presented with other glare stimuli that are relatively dim as opposed to relatively bright.

Another complicating aspect is the dependence of reported discomfort glare on the difficulty of the task that is being performed at the time of the glare presentation (Östberg, Stone, and Benson, 1975; Sivak, Flannagan, Ensing, and Simmons, 1989). In general, the same stimulus is reported as being more discomforting if the concurrent task is relatively difficult as opposed to relatively easy. This finding argues for the inclusion of the relevant concurrent task during discomfort-glare evaluation.

The present study is a follow-up on our previous study (Sivak, Flannagan, Ensing, and Simmons, 1989), in which we demonstrated an effect of task difficulty on discomfort glare by varying the size of a gap that subjects had to detect in a stimulus that was presented simultaneously with a glare source. Subjects had to judge the location of the gap and then rate the discomfort caused by the glare source; more discomfort was reported when the gap was smaller and thus harder to locate. In that study, the gap-location task was always required. Thus it was impossible to tell from those results whether, or to what extent, the effect of gap size on discomfort ratings depended on the gap stimuli being made explicitly relevant. In the present study gap size was varied in factorial combination with whether the gap-location task was required. In addition, the present study included a second way of varying task difficulty: changes in the luminance of the gap stimulus. We included this new manipulation with the expectation that it might be even more effective than gap size in influencing discomfort ratings. The gap-size manipulation involved figural rather than brightness changes, and therefore should have been relatively easy for subjects to distinguish from the effects of glare itself. In contrast, reduction of the luminance of the gap stimulus, which was presented as a bright stimulus in a dark field, should have been relatively difficult for subjects to distinguish from the contrast reduction caused by veiling brightness associated with a glare source.

METHOD

Tasks

Three tasks were performed by each subject. During some blocks of trials all three tasks were performed on each trial; during other blocks only one of them, glare rating, was performed. The three tasks were: (1) a gap-location task, in which subjects indicated whether a gap had appeared on the top or bottom of a briefly projected outline square; (2) confidence rating, in which subjects indicated their confidence in the gap-location task as "low," "medium," "high," or "certain;" and (3) discomfort glare rating, in which subjects gave a numerical rating of the discomfort experienced from a light source which accompanied the presentation of the gap-location stimulus.

Subjects

Twenty-four subjects, twelve males and twelve females, participated in this study. Their ages ranged from 20 to 39 years. Subjects were paid for their participation.

Apparatus

Schematic diagrams of the experimental set-up and the subject's view are shown in Figures 1 and 2. The subject was seated facing a rear-projection screen, at a distance of 6.1 m. Black tape (1.9 cm wide) delineated a 28 x 28 cm area bordering the left edge of the screen. A random-access slide projector located behind the screen was used to project a gap-location stimulus (described below) into the center of the taped square. A second random-access slide projector, immediately adjacent to the left edge of the screen, provided the glare source. The center-to-center distance between the glare source and the projected gap-location stimulus was 26.7 cm (a visual angle of 2.5° as viewed by the subject, who sat directly in front of the gap-location stimulus). Neutral density filters mounted in slide holders provided the three levels of glare used: 4.34, 0.94, and 0.20 lx at the position of subjects' eyes. Both slide projectors were equipped with automatic, remotely controlled shutters which were electronically coupled to provide synchronous 1-second presentations of the glare light and the gap-location stimuli.

A large panel with a 9-point rating scale for discomfort glare, printed in black letters on a white background, was posted at a distance of 2.5 m from the subject. The letters were 1.9 cm high and subtended approximately 26 minutes of arc. This chart was offset so that it appeared to the right of the area in which the gap-location stimulus appeared.

Ambient illumination was provided by a small 25 W lamp positioned behind and to the left of the subject's head, making use of the wall nearby as a reflector/diffuser. The resulting low and somewhat non-uniform background luminance was measured with a Pritchard photometer. At the center of the response panel, luminance was 0.06 cd/m^2.

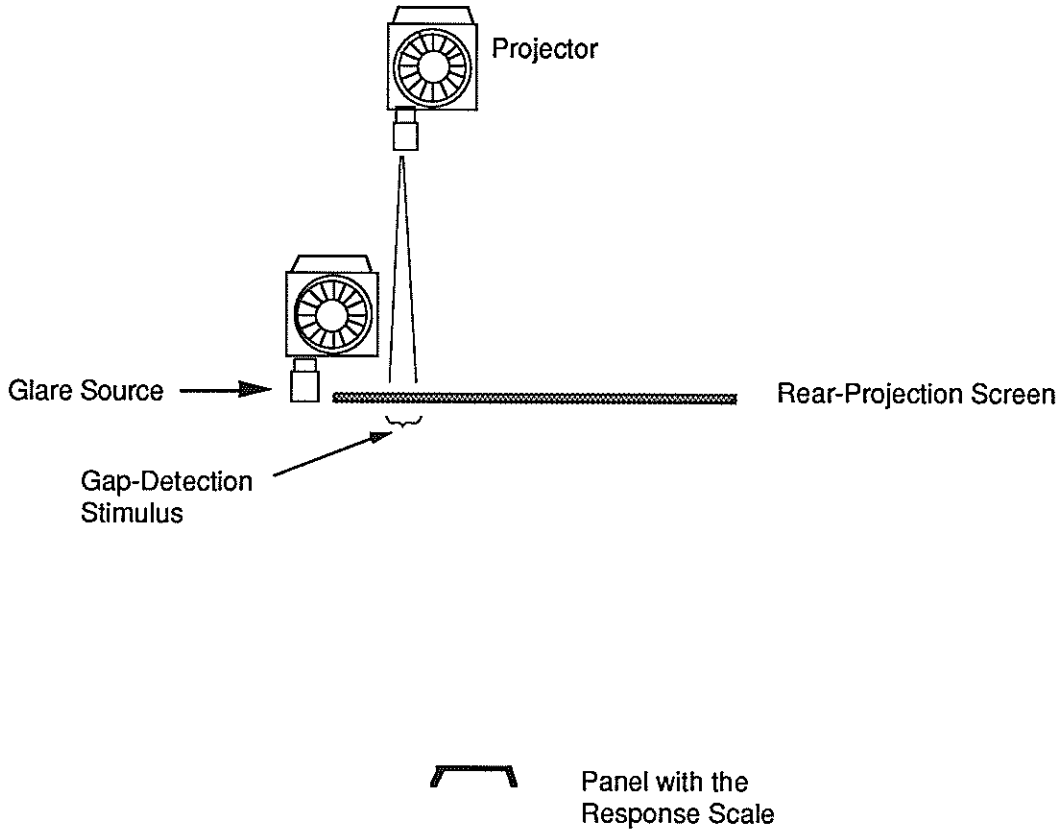

Figure 1. A schematic diagram of the experimental setup.

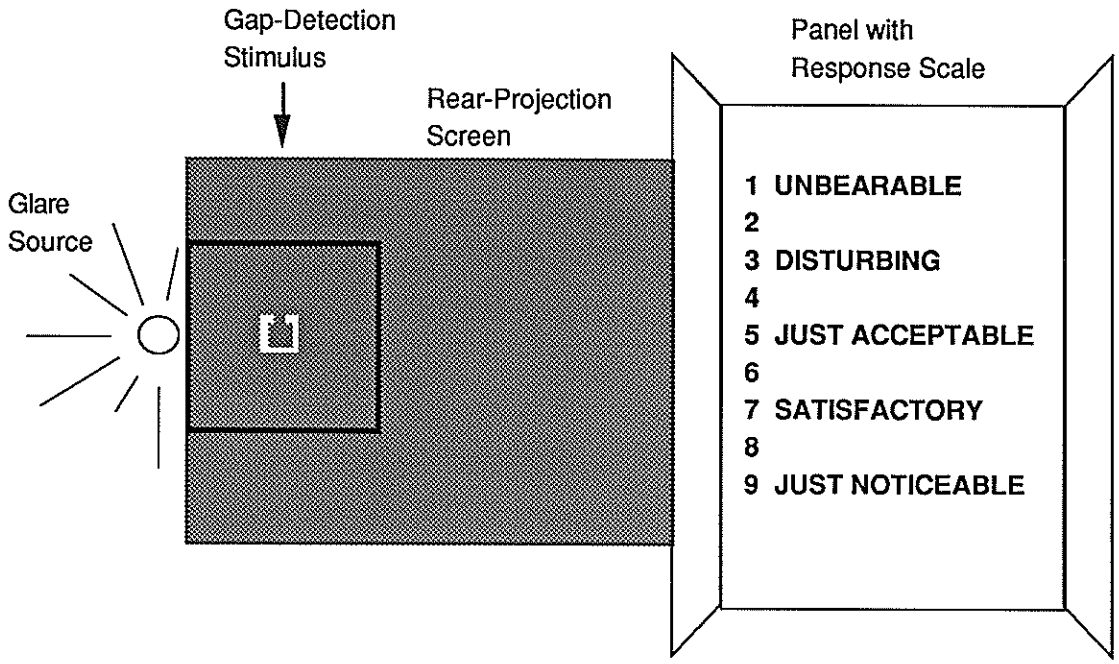

Figure 2. A schematic diagram of the subject's view.

Gap-location stimuli

The stimuli for the gap-location task were outlines of squares subtending 10.2 minutes of visual angle in height and width, with a stroke width of 2.3 minutes. There were two gap sizes (1.74 and 0.53 minutes of visual angle), each of which appeared in both positions (centered in either the top or the bottom edge of the square).

The three gap-location stimuli had the following luminances: 28.9, 9.14, and 2.89 cd/m^2. The luminances of the surround in the immediate vicinity of the stimuli were 0.1025, 0.0405, and 0.0205 cd/m^2 (with the dimmest stimulus having the dimmest surround). (Since the luminances of the surrounds co-varied, to a large degree, with the luminances of the stimuli, contrast would not be a meaningful description of the stimuli.)

Response scale

Subjects were asked to use a 9-point scale (shown in Figure 2) for their assessment of discomfort glare. This scale has been used extensively to evaluate glare in night driving situations (e.g., Bhise, Swigart, and Farber, 1975; de Boer, 1967). It has qualifiers for only the odd points as follows: 1 (unbearable), 2, 3 (disturbing), 4, 5 (just acceptable), 6, 7 (satisfactory), 8, 9 (just noticeable).

Design

Each subject was presented with 5 blocks of trials, each block consisting of an individually randomized ordering of 36 trials representing all combinations of 2 gap sizes, 3 stimulus luminance levels, 2 gap locations (up or down), and 3 glare levels. Task requirements were varied across blocks such that for half the subjects (6 males, 6 females) only glare ratings were required in the first block, and all three tasks (gap location, confidence rating, and glare rating) were required in blocks 2 through 5. For the other half of the subjects, all three tasks were required in blocks 1 through 4, and only glare ratings were required in block 5. Thus all subjects were given a single presentation of each combination of stimulus parameters in the glare-rating-only condition, and 4 repetitions of each combination of stimulus parameters in the condition requiring all three tasks.

Procedure

Subjects were tested individually. They were brought into the experimental room and allowed to adapt to the low ambient lighting conditions used in the experiment for about 8 minutes. During the adaptation period they were given instructions appropriate to the task requirements of the first block (either glare ratings only or all three tasks). They received 18 practice trials that consisted of a full factorial combination of gap size, stimulus luminance level, and glare level. For the practice trials gap location was selected randomly with the constraint that the two gap locations had to occur equally often. When task requirements changed (after either 1 or 4 blocks, depending on the order of task requirements for a particular subject), subjects were given an appropriate new set of instructions and another set of 18 practice trials.

On each trial, a gap-location stimulus and a glare stimulus were presented simultaneously for 1 second. Subjects then responded orally, giving either a glare rating only, or responses for all three tasks, depending on the current condition. When all three tasks were required, subjects gave their judgment about the location of the gap first (by saying "up" or "down"), then their rating of confidence in that judgment (by saying "low," "medium," "high," or "certain"), and finally their rating of discomfort glare (by saying a number from 1 to 9). The interval between stimulus presentations was approximately 15 seconds. Each subject was given a short break between blocks of trials near the halfway point.

RESULTS

Percent correct

Data for percent correct on the gap-location task were submitted to an analysis of variance that included the following factors: gap size, stimulus luminance, gap location, glare level, and order of task requirements (whether blocks of trials in which the gap-location task was required preceded or followed the block of glare-only trials). There were significant main effects of gap size, $F(1,22) = 60.11$, $p < .0001$, stimulus luminance, $F(2,44) = 18.52$, $p < .0001$, and glare level, $F(2,44) = 19.33$, $p < .0001$. The main effects of gap location, $F < 1.0$, and task order, $F < 1.0$, were not significant. The significant main effects of gap size, stimulus luminance, and glare level are shown in Figures 3, 4, and 5. There was a significant two-way interaction of stimulus luminance with glare, $F(4,88) = 11.95$, $p < .0001$, which is shown in Figure 6.

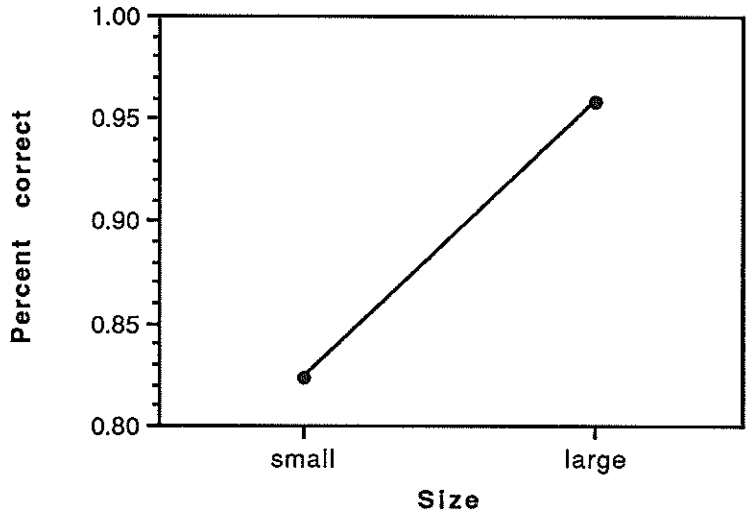

Figure 3. Percent correct on the gap-location task as a function of gap size.

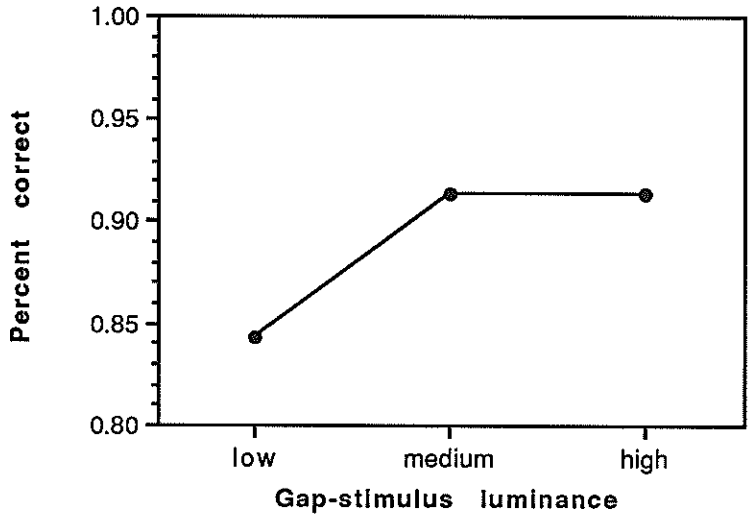

Figure 4. Percent correct on the gap-location task as a function of gap-stimulus luminance.

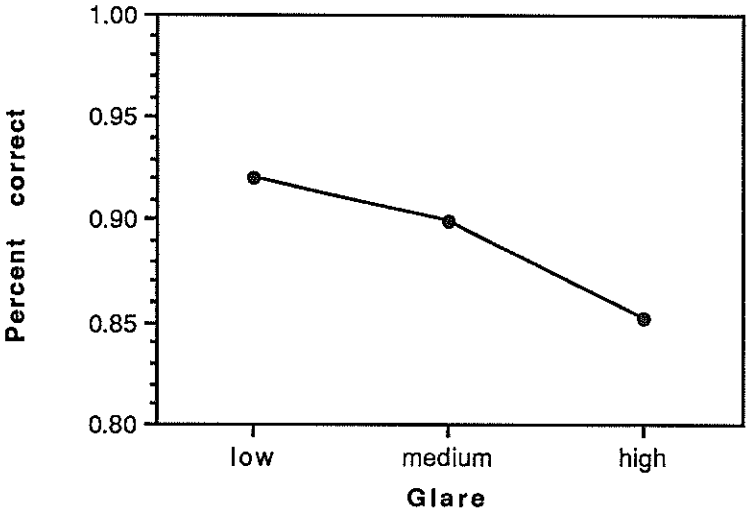

Figure 5. Percent correct on the gap-location task as a function of glare level.

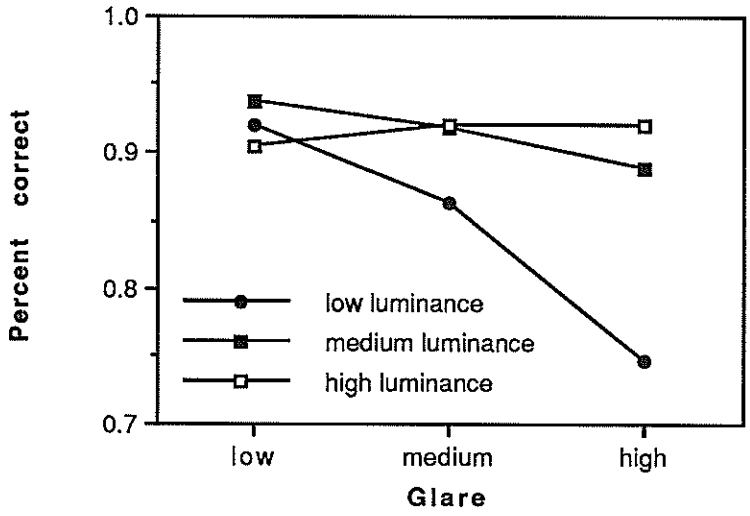

Figure 6. Percent correct on the gap-location task as a function of glare level for the three levels of gap-stimulus luminance.

Confidence ratings

In order to summarize confidence ratings the four responses that subjects could give ("low," "medium," "high," and "certain") were assigned the numerical values 1, 2, 3, and 4, respectively. These numbers were submitted to an analysis of variance with the same structure as that for data on percent correct. There were significant main effects of gap size, $F(1,22) = 156.26$, $p < .0001$, stimulus luminance, $F(2,44) = 57.84$, $p < .0001$, and glare level, $F(2,44) = 56.90$, $p < .0001$. The main effects of gap location, $F < 1.0$, and task order, $F < 1.0$, were not significant. The significant main effects are shown in Figures 7, 8, and 9.

Consistent with the effects on actual performance, there was a significant two-way interaction of stimulus luminance with glare, $F(4,88) = 30.11$, $p < .0001$. In contrast with the effects on performance, there were significant interactions of size and stimulus luminance, $F(2,44) = 57.60$, $p < .0001$, size and glare, $F(2,44) = 42.03$, $p < .0001$, and size, stimulus luminance, and glare, $F(4,88) = 9.86$, $p < .0001$. The two-way interactions are shown in Figures 10, 11, and 12. The three-way interaction of size, stimulus luminance, and glare is shown in Figure 13.

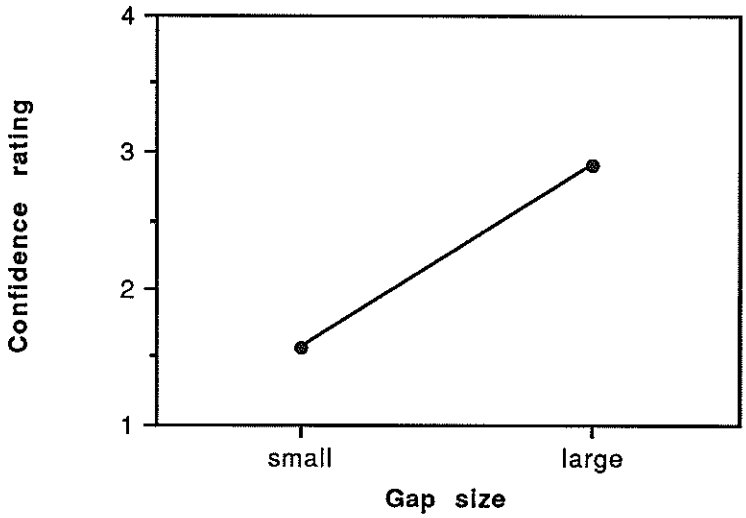

Figure 7. Confidence rating as a function of gap size.

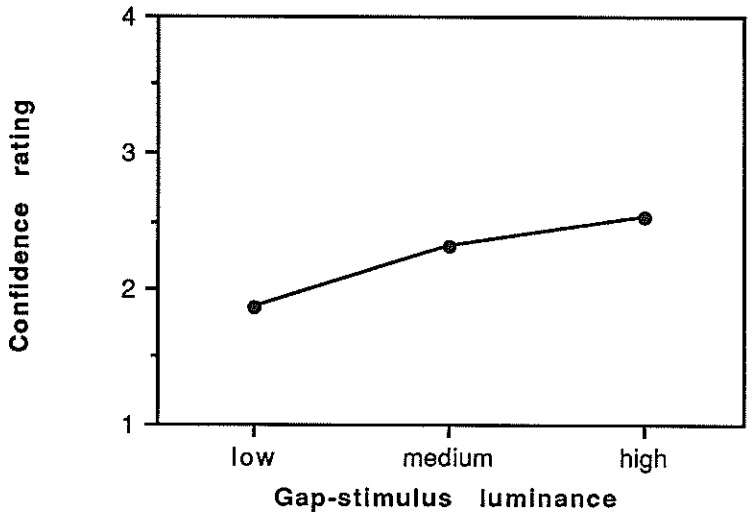

Figure 8. Confidence rating as a function of gap-stimulus luminance.

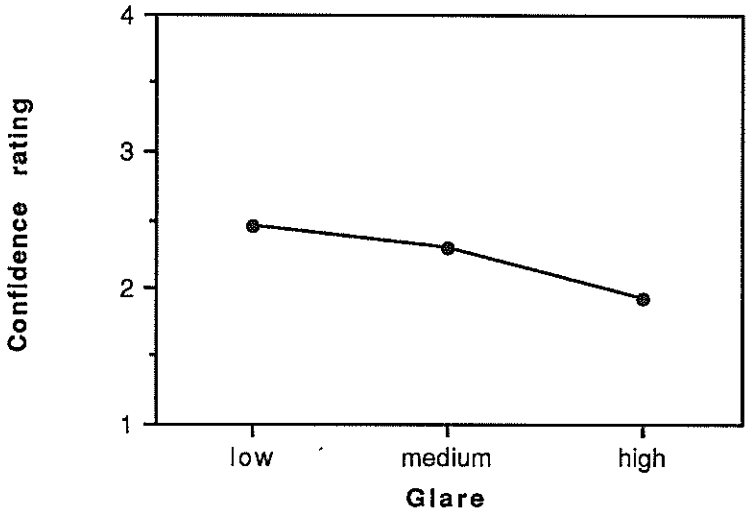

Figure 9. Confidence as a function of glare level.

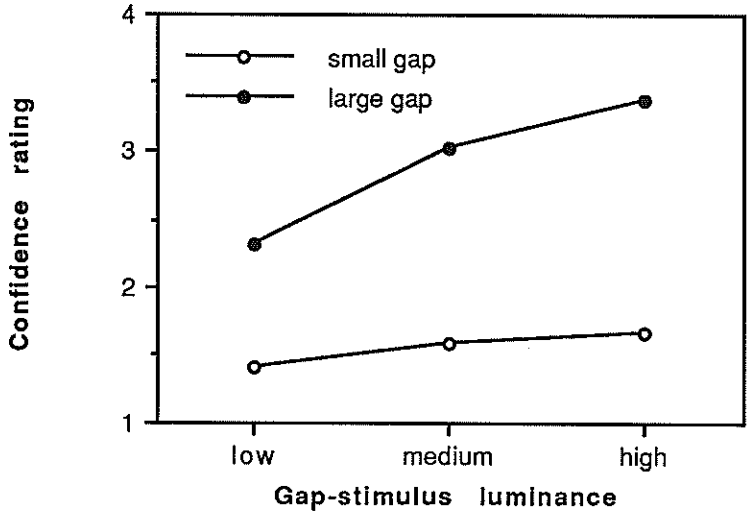

Figure 10. Confidence as a function of gap-stimulus luminance for each gap size.

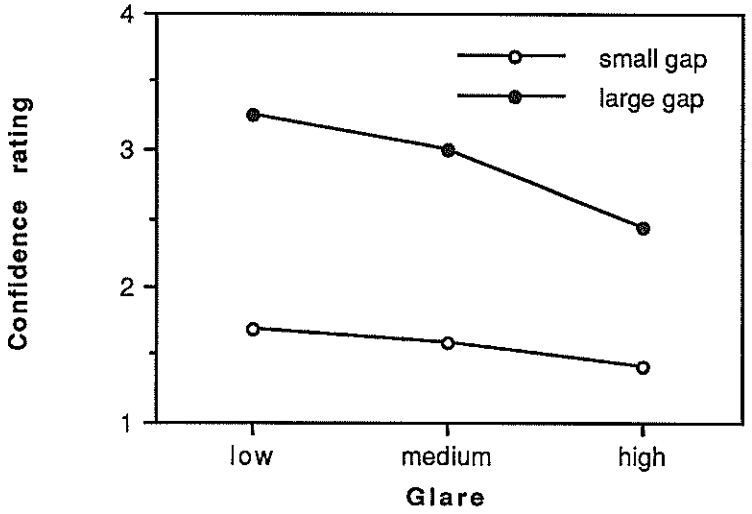

Figure 11. Confidence rating as a function of glare level for each gap size.

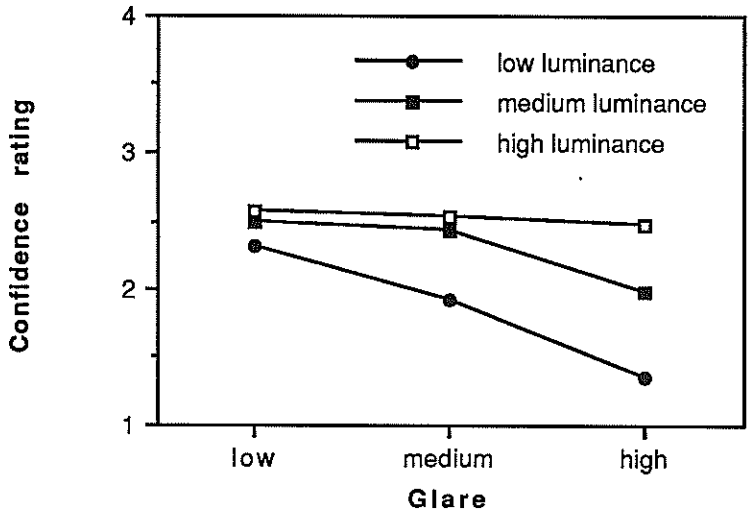

Figure 12. Confidence as a function of glare level for each level of gap-stimulus luminance.

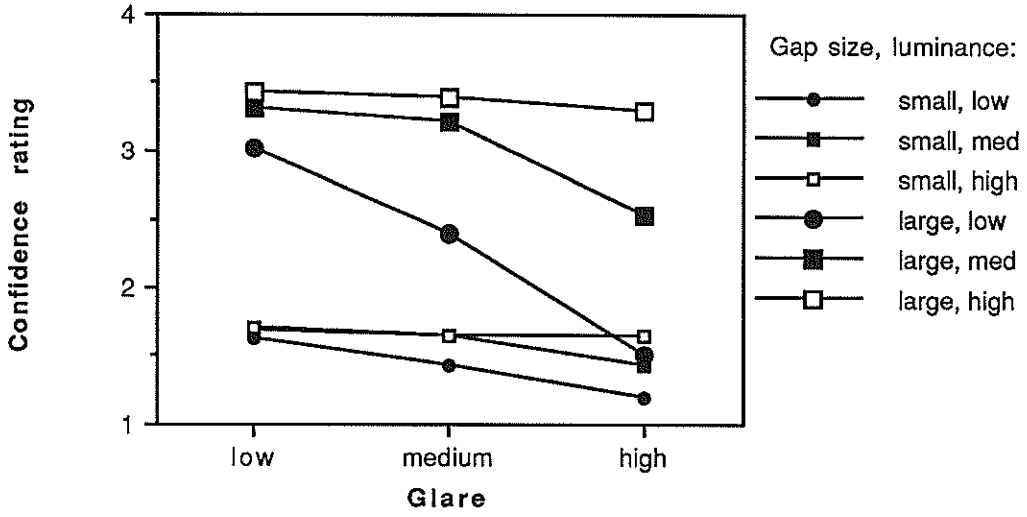

Figure 13. The three-way interaction of gap size, gap-stimulus luminance, and glare level.

Discomfort glare ratings

Discomfort ratings were submitted to an analysis of variance with the following factors: gap size, stimulus luminance, gap location, glare level, order of task requirements (whether blocks of trials in which the gap-location task was required preceded or followed the block of glare-only trials), and context in which the discomfort ratings were made (either alone or while also performing the gap-location task). There were significant main effects of gap size, $F(1,22) = 7.58$, $p < .05$, glare level, $F(2,44) = 499.95$, $p < .0001$, and context, $F(1,22) = 6.11$, $p < .05$. The significant main effects are shown in Figures 14, 15, and 16.

There was a significant two-way interaction of stimulus luminance with glare level, $F(4,88) = 27.79$, $p < .0001$. There were also several significant interactions involving context including: context with size, $F(1,22) = 4.96$, $p < .05$, context with stimulus luminance, $F(2,44) = 3.95$, $p < .05$, context with glare level, $F(2,44) = 58.14$, $p < .0001$, and the three-way interaction of context, stimulus luminance, and glare level, $F(4,88) = 12.80$, $p < .0001$. These effects are shown in Figures 17 through 21.

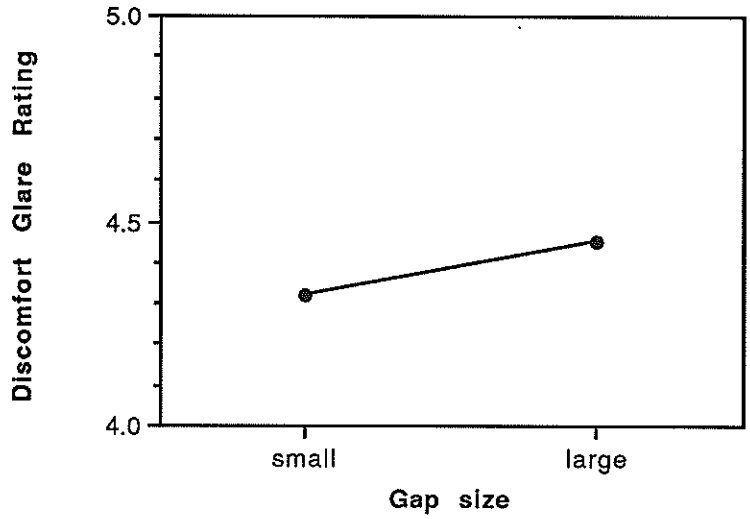

Figure 14. Discomfort glare rating as a function of gap size.

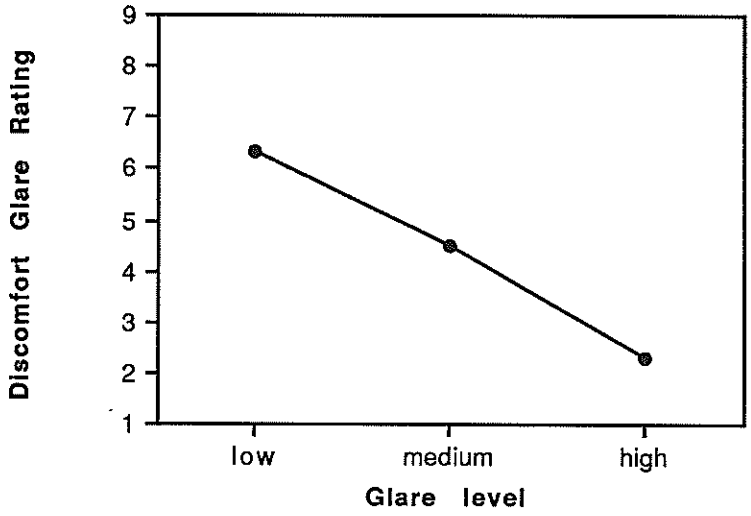

Figure 15. Discomfort glare ratings as a function of glare level.

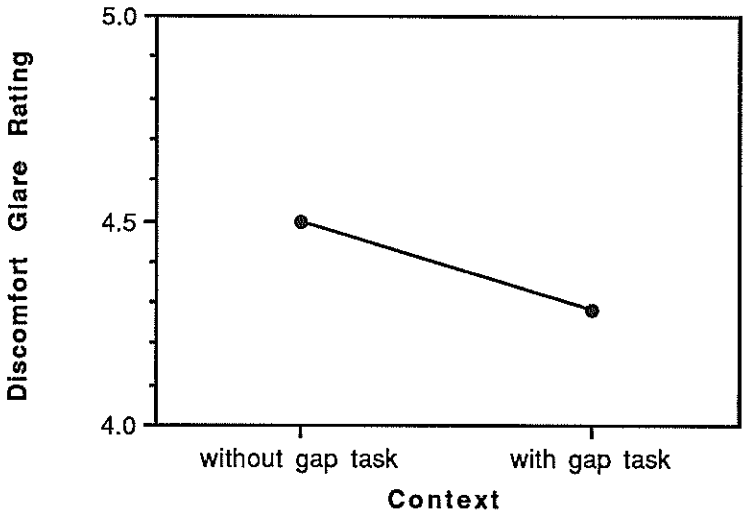

Figure 16. Discomfort glare ratings as a function of whether they are made alone or while also judging the location of the gap.

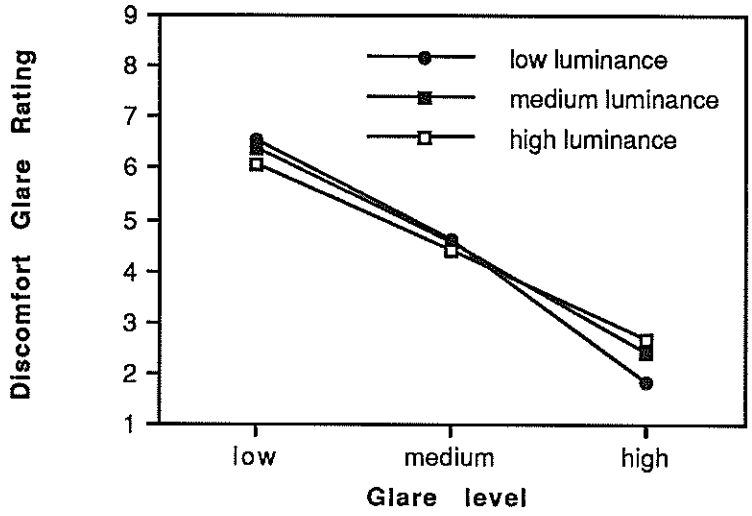

Figure 17. Discomfort glare ratings as a function of glare level for each of the three levels of gap-stimulus luminance.

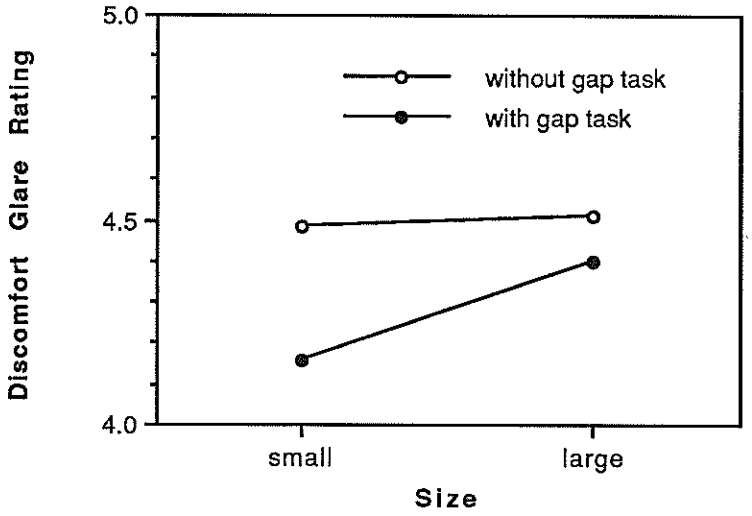

Figure 18. Discomfort glare ratings as a function of gap size for the two task conditions.

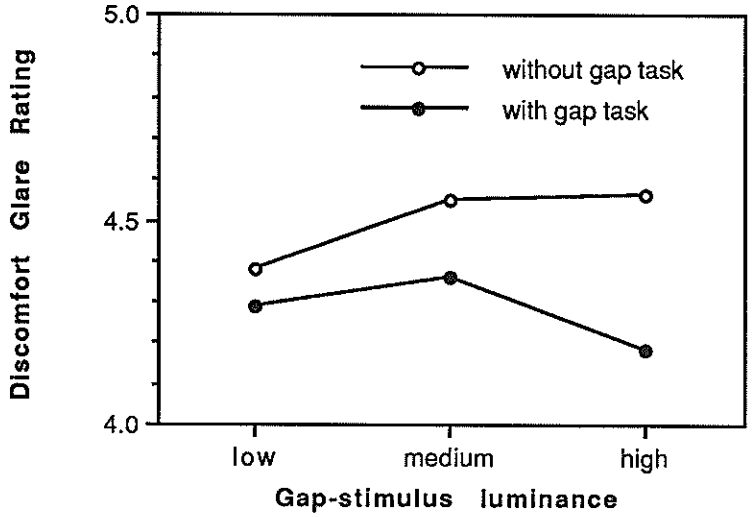

Figure 19. Discomfort glare ratings as a function of gap-stimulus luminance for the two task conditions.

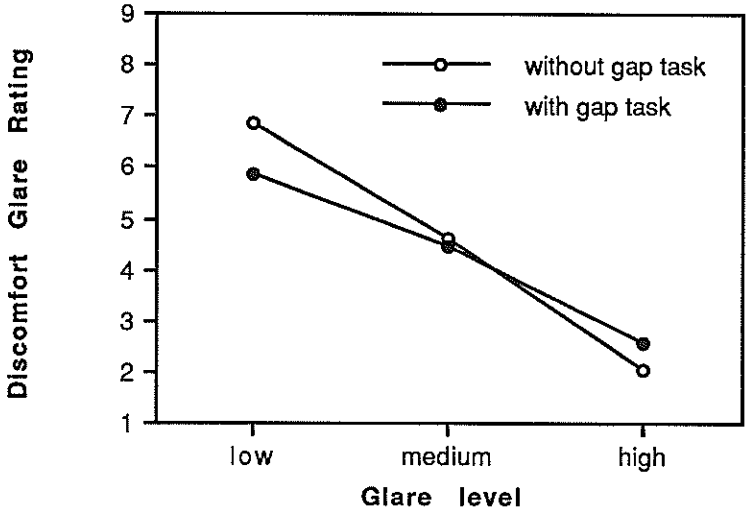

Figure 20. Discomfort glare ratings as a function of glare level for the two task conditions.

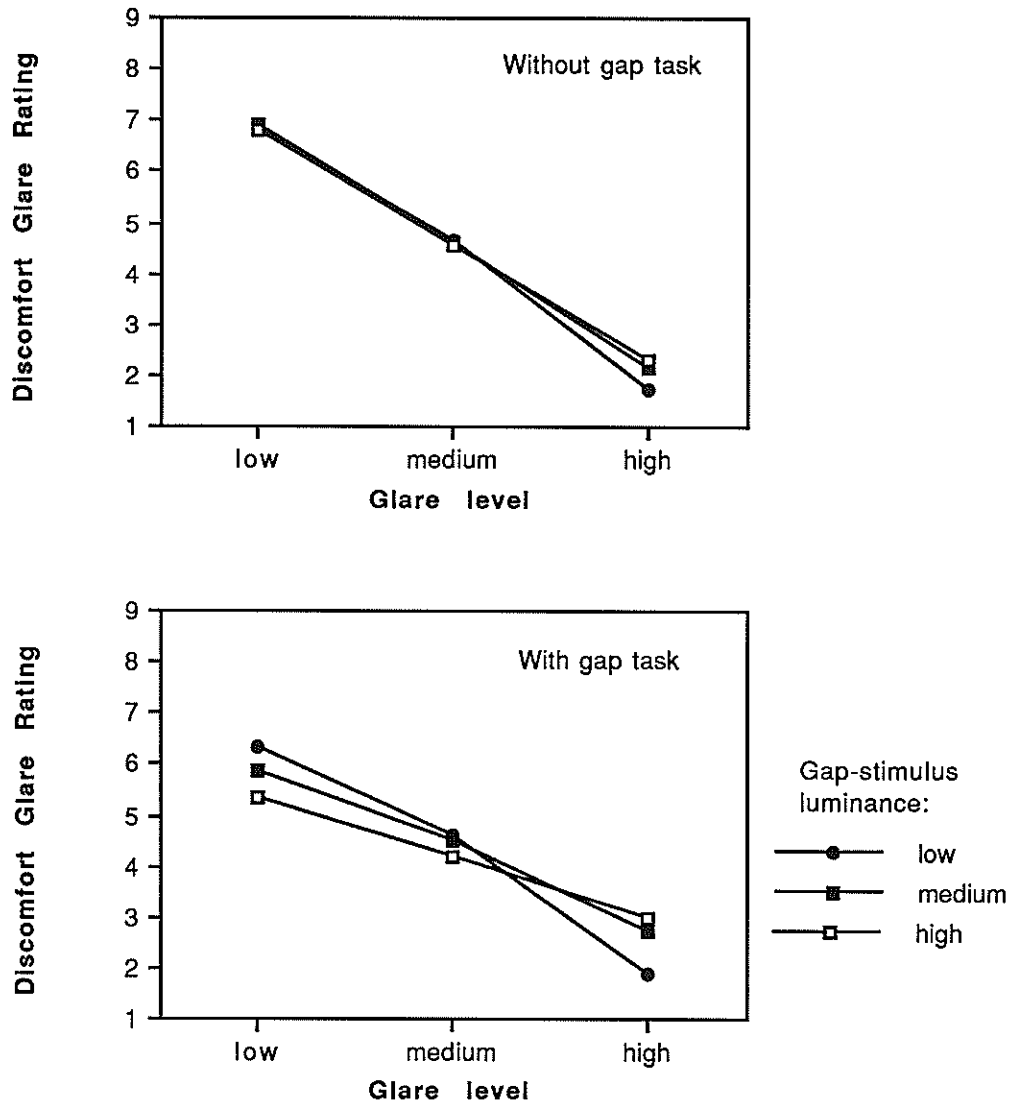

Figure 21. Discomfort glare ratings as a function of glare level for each of the three levels of gap-stimulus luminance, shown separately for trials without the gap task (top panel) and trials with the gap task (lower panel).

DISCUSSION

Percent correct

Performance on the gap task is strongly affected by gap size, stimulus luminance, and glare level in the expected directions: percent correct decreases with a decrease in gap size (Figure 3), a decrease in stimulus luminance (Figure 4), and an increase in glare level (Figure 5). However, there is also a strong interaction between stimulus luminance and glare level (Figure 6). Specifically, while at the highest glare level performance improves with an increase in stimulus luminance, at the lowest glare level performance *worsens* with an increase in stimulus luminance. This finding is consistent with earlier results indicating that under certain ambient conditions visual performance is an inverted-U function of stimulus luminance (e.g., van Noreen, 1981), with best performance at intermediate levels of luminance.

Confidence

In general, the effects on percent correct are mirrored by the effects on confidence ratings. However, the negative effect on performance of high stimulus luminance at low glare levels is not reflected in confidence ratings. For all levels of glare, confidence is highest for the highest stimulus luminance (Figure 12). Confidence ratings show interactions of luminance and glare with size (Figures 10, 11, and 13) that are not present in the data for percent correct. These discrepancies in the effects of size are probably best interpreted as floor effects in confidence ratings. The patterns of interaction in Figures 10, 11, and 13 are all primarily due to the range of confidence ratings for small gaps being smaller than the range for large gaps. Rather than reflecting a true difference in the ranges of subjects' confidence, this may be due to the fact that ratings could not be lower than 1 (corresponding to the lowest permissible response of "low" confidence), combined with a tendency for subjects to be pessimistic in rating their performance.

There is no simple way to quantify subjects' optimism or pessimism in this study because the confidence ratings of "low," "medium," "high," and "certain" cannot be simply calibrated against actual performance. But in a recent study (Flannagan, Sivak, & Gellatly, 1990), when we asked subjects to rate their confidence on a very similar task by estimating the actual percentages of correct responses that they were achieving, subjects strongly and consistently underestimated how well they were doing.

Figure 22 gives some indication of the calibration between percent correct and the way in which subjects used the confidence ratings in this study. The data are mean confidence rating and percent correct over all subjects for each combination of gap size, gap stimulus luminance, and glare intensity (yielding the 18 treatment combinations plotted in the figure).

The correspondence between the plotted points and those treatments is not labeled, so that the effects of various factors on confidence and on percent correct (which can be seen in various earlier figures) are not explicit here. What Figure 22 does show is that the overall relationship between performance and confidence ratings is good (i.e. subjects' confidence ratings do convey information about how well they are actually doing), but the calibration between rating and performance is markedly curvilinear. Subjects use the upper half of the confidence scale (above a numerical value of 2.5) to rate performance above 95%, compressing all performance below that into the lower half.

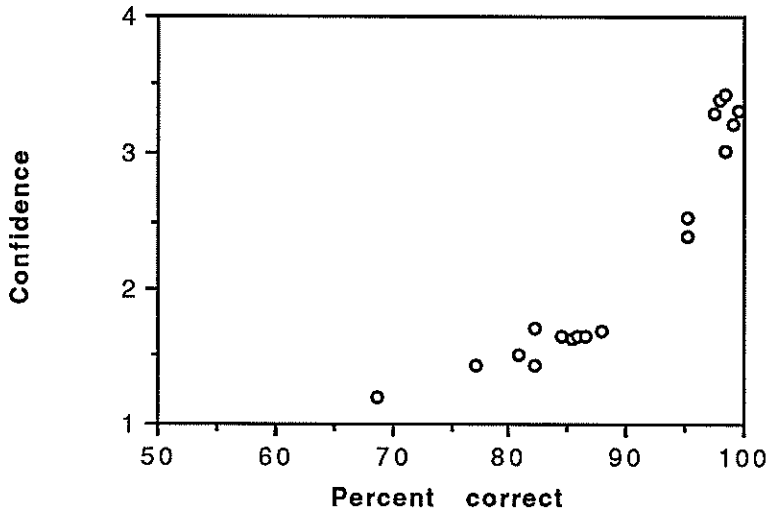

Figure 22. The relationship between mean confidence and mean performance (over all subjects) for the 18 treatments defined by the factorial combination of gap size, gap-stimulus luminance, and glare intensity.

Discomfort

The present effect of gap size on discomfort rating is consistent with the effect obtained in our previous study (Sivak et al., 1989). As shown in Figure 18, the new results indicate that the effect depends on context (whether the gap-location task is required). There is no evidence for an effect of gap size when the task is not required, but small gaps lead to greater rated discomfort when it is. There is also a main effect of context; independent of gap size, the task requirement itself leads to more rated discomfort (Figure 16). This is consistent with the idea that, just as difficulty is lower with large gaps than small, difficulty is even lower if the

task is not required at all. All of these findings are consistent with the previously postulated effect of task difficulty on discomfort glare (Östberg et al., 1975; Sivak et al., 1989).

The effects of the luminance of the gap stimulus on discomfort ratings are more complicated. First, there is actually no *main* effect of luminance on discomfort ratings, even when the gap-location task is required. Inspection of Figure 21 reveals that luminance does have a strong effect, but that it is in combination with glare level. When the task is required (lower panel) there is a perfect crossover interaction, such that at the highest glare level low luminance gap stimuli lead to more discomfort and at the lowest glare level low luminance leads to less discomfort. These effects should be interpreted in light of how glare and luminance affected actual performance.

As shown in Figure 6, when glare is intense luminance differences affect performance (percent correct) in the direction that we had expected (i.e. lower luminance gap stimuli lead to worse performance). At the low glare level, however, the high luminance stimuli actually lead to the worst performance (although the differences in performance at the low glare level are not great). Because of the interaction of glare and luminance in the performance data, the crossover interaction in Figure 21 is actually consistent with the hypothesis that greater difficulty leads to more discomfort. As mentioned above, there is prior evidence that (for light stimuli against a dark background) higher contrast is not always easier to see (e.g., van Noreen, 1981). This makes it somewhat plausible that difficulty does account for all that is going on in the lower panel of Figure 21.

A remaining complication, however, is that the subjective confidence ratings do not reflect the ordering of the performance data for the three levels of luminance at low glare. At all levels of glare, lower luminance leads to lower confidence (Figure 12). It is not logically necessary for effects of difficulty on discomfort to be mediated by differences in subjective confidence, but perhaps the most obvious mechanism for those effects would be for actual performance to affect confidence, which would in turn affect discomfort. However, the fact that confidence and discomfort results are not entirely consistent across combinations of glare and luminance is inconsistent with that hypothesis, at least in its simplest form. Probably the best summary of the effects of gap stimulus luminance on discomfort, when the gap task is required, is that lower luminance does lead to greater discomfort, but only at higher glare levels (which are the only levels with a substantial effect of luminance on percent correct). The reversed effect of luminance on discomfort at the lowest glare level, although highly significant statistically, remains difficult to explain.

In contrast to the effect of gap size on discomfort, the effect of luminance is present even when the gap task is not required (although it is substantially reduced). The upper panel of Figure 21 shows an interaction that appears to be a weakened form of the pattern in the

lower panel. The crossover character is not as evident in the upper panel; luminance has a substantial effect only at the high level of glare. None of the effects in Figure 21 interacts significantly with the order of contexts for individual subjects (whether a subject rated discomfort alone first, or rated discomfort along with the gap task first). Consistent with that pattern, the effect of luminance on discomfort at the high level of glare without the requirement to perform the gap task is significant both for subjects who rated discomfort alone first, $F(2,11) = 3.54$, $p < .05$, and for subjects who rated discomfort along with the gap task first, $F(2,11) = 6.90$, $p < .01$. That means that the effect of luminance on discomfort ratings is present even when the gap stimuli are irrelevant, and even when they have not previously been relevant to the subject's task.

The effect of luminance on discomfort is clearly intensified by the requirement to do the gap task, but luminance also has an effect independent of any explicit task. Lower luminance stimuli probably appear to the subjects to be of lower contrast as well, and subjects may confuse that difference in contrast with the effects of veiling brightness caused by the glare source. According to this hypothesis, the lower luminance gap stimuli influence discomfort ratings because they suggest to the subjects that the glare source is more intense. It is not clear how low luminance gap stimuli could cause subjects any sort of discomfort except by making performance on the gap task more difficult. Therefore, the fact that luminance has an effect on rated discomfort even when there is no task suggests that subjects' discomfort ratings reflect, not purely how much discomfort they feel when exposed to a glare stimulus, but to some degree how intense they believe the stimulus is, independent of whether that intensity leads to actual discomfort.

There is an interesting effect of the concurrent task on discomfort ratings that does not fit the pattern of increased difficulty causing greater discomfort. Figure 20 shows a significant two-way interaction between glare level and context. When the concurrent task is required the slope of the function relating discomfort ratings to actual discomfort is decreased, with relatively little effect on the overall mean rating. This pattern is consistent with a general class of effects in which observations show regression to the mean. One hypothesis for this effect is that the increased demands of having to do the gap-location task make subjects sometimes forget, or not properly select, the discomfort rating that they would normally have selected. Because they are always required to say something, they may then select as a substitute a rating that is only approximately appropriate, or perhaps even random. If that happens on some proportion of trials when the gap task is required, the effect will be to draw the means for sets of those trials closer to the means of the substitute ratings. When the actual discomfort level is very high or very low, the mean of the substitutes will tend to be less extreme, resulting in a regression-to-the-mean pattern such as seen in Figure 20.

SUMMARY

The present study replicates and extends our earlier finding that the difficulty of a concurrent visual task affects discomfort glare ratings (Sivak et al., 1989). As in the previous study, increasing task difficulty by reducing the size of a detail in a visual acuity task led to more rated discomfort. Although the results of manipulating task difficulty by changing the luminance of the acuity stimulus were somewhat more complex, when low luminance caused greater difficulty it also caused more rated discomfort. Although both of these manipulations involve changes in the stimuli to which the subject is exposed, the present results indicate that their effects on discomfort ratings are strongly dependent on the task demands on the subject. Therefore it is task demands rather than stimulus conditions themselves that are responsible for the effects on rated discomfort.

The present results suggest two new effects on discomfort ratings--effects not captured by the generalization that increased difficulty leads to increased discomfort. First, the luminance of an irrelevant stimulus had small but highly reliable effects on discomfort ratings. The mechanism for this effect may involve subjects allowing their perception of the intensity of a glare source, rather than discomfort itself, to influence their discomfort ratings. Second, requiring subjects to rate glare while performing another task caused a decrease in the range of discomfort ratings. This pattern may be due to the second task disrupting performance on the rating task, such that ratings do not reflect experienced discomfort accurately.

These results call into question the accuracy of any model of discomfort glare that does not incorporate some quantification of the difficulty of the task that a subject faces. How these results should be reflected in a theory of discomfort glare is a complicated issue. It could be argued that concurrent-task difficulty affects only the process of rating discomfort, leaving actual glare discomfort unaffected. Subjects might experience a fixed level of glare discomfort as task difficulty is changed, and change their ratings of discomfort glare simply because they allow their ratings to incorporate all sorts of discomfort, without regard for its source. Both a glare source itself and the difficulty they may be having with a concurrent task cause discomfort, and they simply rate the combined effect, ignoring any instructions to focus on discomfort caused by glare. Alternatively, it could be argued that task difficulty affects discomfort glare itself, in a way that subjects could not introspectively distinguish it from an actual change in the intensity of the glare source. From a practical point of view this distinction may not be important. Even if it is possible to isolate a "true" discomfort glare level from the effects of task difficulty, that may not be a useful exercise. For whatever reason, subjects do appear to change the level of glare they are willing to accept as task demands change. The proper goal of a model of discomfort glare perhaps should be simply empirical success in

predicting the acceptable level. Many factors may affect discomfort ratings, and provided only that those ratings reflect actual acceptability, any such effects are important. Someone who has just won a large lottery may be willing to accept higher levels of glare. Arguing about whether the lottery affects any particular theoretical construct is not important if acceptability is the ultimate criterion.

The finding that concurrent-task difficulty has substantial effects on discomfort ratings raises the possibility of incorporating some measure of difficulty into a quantitative model of discomfort glare. For example, the well-established model proposed by Schmidt-Clausen and Bindels (1974) predicts discomfort ratings as a function of three predictors: illuminance from a glare source, visual angle to the source, and adaptation luminance. In principle, manipulation of task difficulty could simply be added to the set of conditions that those authors used to fit the parameters of their model. The structure of the model would have to be modified to incorporate a parameter for difficulty, and a fit to new data would have to be made. The key problem would be quantifying task difficulty in a way that could be applied easily to the range of task demands encountered in the situations of actual concern: various forms of night driving. This problem can be seen as one aspect of the difficult human factors problem of quantifying workload, although it is not clear that a construct such as workload would capture the effects of task demands on an experience as potentially complex as discomfort. Short of a comprehensive quantitative model that incorporates task difficulty, prediction of discomfort glare that is not based on data gathered under actual task conditions should be considered risky.

REFERENCES

Bhise, V.D., Farber, E.I., Saunby, C.S., Troell, G.M., Walunas, J.B., and Bernstein, A. (1977). *Modelling vision with headlights in a systems context* (SAE Technical Paper # 770238). Warrendale, Pennsylvania: Society of Automotive Engineers.

Bhise, V. D., Swigart, T. F., and Farber, E. I. (1975). Development of a headlamp dimming request prediction model. In, *Human Factors in Our Expanding Technology. Proceedings of the Human Factors Society 19th Annual Meeting.* Santa Monica: Human Factors Society.

de Boer, J. B. (1967). Visual perception in road traffic and the field of vision of the motorist. In, J. B. de Boer (Ed.), *Public Lighting* (pp. 11-96). Eindhoven, The Netherlands: Philips Technical Library.

Flannagan, M.J., Sivak, M., and Gellatly, A.W. (1990). *Rearward vision, driver confidence, and discomfort glare using an electrochromic rearview mirror* (Report No. UMTRI-90-27). Ann Arbor: The University of Michigan Transportation Research Institute.

Hopkinson, R.G. (1940). Discomfort glare in lighted streets. *Transactions of the Illuminating Society (London), 5*, 1-24.

Lulla, A.B. and Bennett, C.A. (1981). Discomfort glare: range effects. *Journal of the Illuminating Engineering Society, 10*, 74-80.

Olson, P.L. and Sivak, M. (1984). Discomfort glare from automobile headlights. *Journal of the Illuminating Engineering Society, 13*, 296-303.

Östberg, O., Stone, P.T., and Benson, R.A. (1975). Free magnitude estimation of discomfort glare and working task difficulty. *Göteborg Psychological Reports, 15*, 1-18.

Pasta, M. and Soardo, P. (1979). An optimum visibility design for the stop lamp. In, *Proceedings of the Seventh International Technical Conference on Experimental Safety Vehicles* (pp. 880-883). Washington, D.C.: National Highway Traffic Safety Administration.

Schmidt-Clausen, H.-J., & Bindels, J. Th. H. (1974). Assessment of discomfort glare in motor vehicle lighting. *Lighting Research and Technology, 6*, 79-88.

Sivak, M., Flannagan, M., Ensing, M., and Simmons, C.J. (1989). *Discomfort glare is task dependent* (Report UMTRI-89-27). Ann Arbor: The University of Michigan Transportation Research Institute.

van Noreen, D. (1981). Visual acuity in a condition of traffic sign viewing: the effects of luminance changes. *American Journal of Optometry and Physiological Optics, 58*, 699-705.