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USING ADJUSTMENT TO DEFINE PREFERRED ILLUMINANCES: DO THE RESULTS HAVE ANY VALUE?

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Abstract

The method of adjustment is examined as an approach to determine occupant illuminance preferences. From the results of previous studies using illuminance adjustment and recent studies performed purposely to investigate methodology, it is concluded that the method of adjustment has little value as a means of estimating the mean preferred illuminance. However, there is some evidence that when users are allowed to set their own light level that this enhances their satisfaction with the visual environment. Thus careful selection of the control variables (available range and initial value) offers the opportunity for reduced illuminances, and thus reduced energy consumption, whilst maintaining satisfaction.

Keywords: occupant control, illuminance preference, adjustment method

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1. Introduction

Previous studies have attempted to determine user preference for illuminance in the workplace by providing subjects with a variable light level and asking them to adjust it to their preference; this is the method of adjustment. The results of such studies have been used to draw two contrasting conclusions regarding preferred illuminances relative to typical design standards for offices: some suggest that the preferred illuminance is greater than 500 lux and hence that design standards should be increased, while others suggest that preferred illuminances are lower than 500 lux and hence that design standards could be reduced.

However, investigation of the adjustment methodology reveals a centering bias in which the mean preferred illuminance lies near the centre of the range of available illuminances, and thus that tests using different ranges will lead to different estimates of preferred illuminance. This proposal was examined in three studies, one in Sheffield and two in Copenhagen. What these studies did was to instruct test subjects to set their preferred level (or colour) of light in a space using a rotary control dial, not dissimilar to a typical dimming control dial. Without informing test subjects of the fact, the range of illuminances (or CCT) available using the control dial was changed in successive trials.

These data suggest that the method of adjustment is of little value as a means of estimating the mean preferred illuminance. It is not intended to suggest, however, that there is no value in giving occupants control over their workplace lighting. Control over one's personal environment has been found to improve environmental satisfaction, and if this is combined with careful selection of illuminance range then energy savings may be available.

2. Estimating mean preferred illuminance

2.1 Previous work

Several studies have included illuminance adjustment as a means of giving occupants control over the lighting. These studies have tended to use different stimulus ranges and hence report different mean preferences for illuminance, these tending to suggest a central tendency.

Juslén et al investigated task lighting in an industrial setting (luminaire assembly) [Juslén et al, 2005]. The general lighting gave 100 to 380 lux, depending on location, and test participants were able to add task lighting of 100 to 3000 lux. This was done hourly, with the task lighting being automatically switched off. The mean preferred illuminance was 1752 lux, which is in the middle of the available stimulus range.

Begemann et al recorded preferred illuminances in offices with windows where the horizontal illuminances from artificial lighting were adjustable over a range of 200-2000 lux [Begemann et al, 1995]. Their results show illuminances from daylight and artificial light separately. Whilst it is evident that the illuminances set by occupants respond in some cases to the time of day, the mean illuminance from artificial light is within the range of approximately 700 to 1100 lux, which is near the middle of the available stimulus range.

Boyce et al report preferred illuminances in a windowless office from 18 test participants [Boyce et al, 2000]. Two stimulus ranges were available, 7 to 680 lux and 12 to 1240 lux. Mean preferred illuminances are reported for four office tasks: the mean of these is 398 lux for the lower stimulus range and 518 lux for the higher stimulus range, so again the higher stimulus range yields the higher estimate of preferred illuminance. Veitch and Newsham recorded preferred illuminances set by 94 people in a windowless office; the maximum illuminance available on the desktop was 725 lux and the mean was 423 lux [Veitch & Newsham, 2000].

Boyce et al used an office in which desks were illuminated by a direct/indirect luminaire [Boyce et al, 2006a]. In their dimming control data the indirect lighting was fixed and occupants had control over the illuminance from the direct lighting; 0% to 100% dimming provided mean desktop illuminances in the range of 280 to 1070 lux. They were free to use this control at any time and started at the 50% dimming position. The mean desktop illuminance was 458 lux. This is not in the middle of the variable range (280 to 1070 lux) but is near the middle of the overall range of illuminances (0 to 1070 lux).

Scholz et al investigated the optimum illuminances set by 50 anaesthetists to visualise the larynx during laryngoscopy, and was examined using a manikin [Scholz et al, 2007]. Clearly this is not an investigation of interior lighting but provides an excellent example of stimulus range bias. The test was carried out using three different types of battery powered lamp, labelled Xenon, Vacuum and Halogen these providing maximum available illuminances of 2583, 327 and 2557 lux respectively - the maximum illuminance with the vacuum lamp was much smaller than for the other two lamps. Scholz et al report the median optimum illuminances under each lamp when starting from the high and low ends of the stimulus range. Using the mean of these two values to provide an estimate of optimum illuminance suggests that the Xenon, Vacuum and Halogen lamps required 1069, 182 and 1101 lux respectively. The optimum illuminances are located near the middle of the stimulus range for each of the three lamps and is thus a much lower value for the vacuum lamp than for the other two lamps.

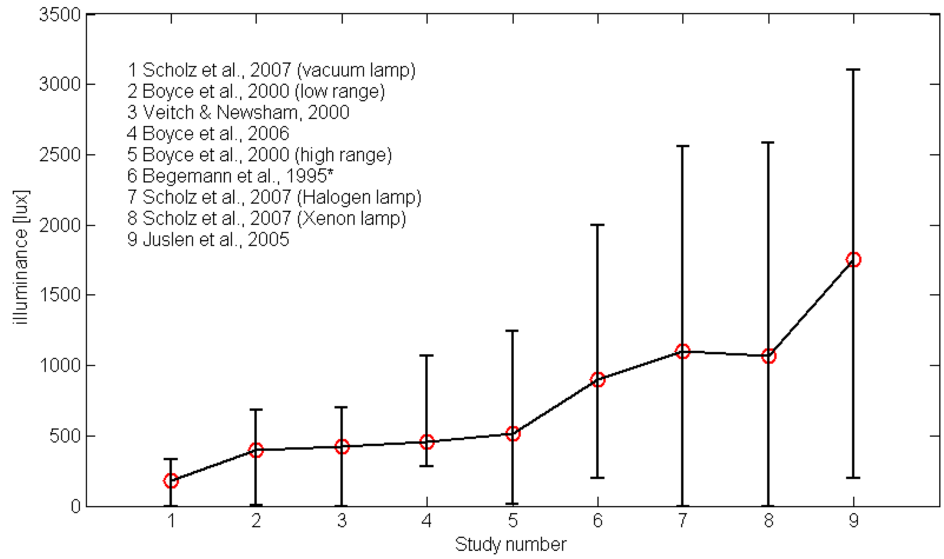

Figure 1. Comparison of stimulus range (vertical lines) and preferred illuminances (data points) reported in previous work. The preferred illuminances are either mean or median values, as reported in the original studies. The data are arranged in order of increasing maximum available illuminance. (* Estimate of central tendency.)

Figure 1 shows the stimulus ranges used in these trials and the estimate of population tendency. The trend is for the estimate of preferred (self-selected or optimum) illuminance to increase as the upper limit of the available stimulus range increases, tending to fall near the middle of the stimulus range.

Further evidence of a centering bias can be seen in results reported by Newsham et al [Newsham et al, 2005]. In the first experiment the test subjects were allowed to use dimming control after lunch in the one-day test period. There were two groups of subjects, one with a task lamp in addition to general lighting (ambient + task) and one without (ambient only). Newsham et al reported mean dimmer settings in addition to mean illuminances. There was no significant difference in dimmer setting between two groups, these being mean settings of 46.7% (std dev 26.1%) for the ambient only group and 47.0% (std dev 23.4%) for the ambient + task group. In both cases, the mean dimmer setting is very close to the centre of the available range. While adding a task light increased the illuminance of settings recorded with the ambient + task group this did not change the settings made using control over the ambient lighting, suggesting that subjects were responding to the illuminance range rather than absolute illuminance.

2.2 New studies

2.2.1 Method

Three studies have been carried out to investigate stimulus range bias in adjustment tasks. The initial study in Sheffield sought preferred illuminances in a scale model decorated to represent a desk top [Fotios & Cheal, 2010]. This was repeated in the first Copenhagen study using a full sized non-daylit room rather than a scale model, and also investigated the effects of anchors (initial illuminance immediately prior to each adjustment trial), CCT and adaptation [Logadottir et al, in press]. The second Copenhagen study [Logadottir et al, submitted] investigated adjustments along a different dimension, CCT, a difference being that while variation in illuminance has an obvious change in magnitude from zero to large a change in CCT is noticeable in form of cooler or warmer colours rather than variation in magnitude. The CCT study used a scale model illuminated using a tuneable array of LEDs. The main features of these studies are reported in Table 1.

Table 1. Ranges and study setup within the three different studies.

Study	Target variable	Setup	Repeated measures	Number of participants	Stimulus range		
						minimum	maximum
Fotios & Cheal, 2010	Illuminance	Scale model	3 ranges x 2 anchors	21	R1	48 lux	1037 lux
					R2	83	1950
					R3	165	2550
Logadóttir, Christoffersen & Fotios, in press	Illuminance	Full size room	3 ranges x 3 anchors x 3 CCT	36	R1	21 lux	482 lux
					R2	38	906
					R3	72	1307
Logadóttir, Fotios et al, submitted	CCT	Scale model	3 ranges x 3 anchors x 2 control devices	36	R1	2736 K	3530 K
					R2	3284	4014
					R3	2736	4014

Complete details of the apparatus and procedure used in these studies can be found elsewhere [Fotios and Cheal, 2010; Logadóttir et al., in press; Logadóttir et al., submitted]. All studies intended to simulate an office environment; the Sheffield study and the CCT study were performed using scale models, and the Copenhagen illuminance study was performed in a non-daylit room. The same basic procedure was used in all three studies. The task was to set the preferred level of light, or colour appearance, using a rotary dial, and this task was repeated by test participants for:

- variations in the range of illuminances (or CCT) available through the control dial. This was achieved using electrical circuitry [Fotios and Cheal, 2010; Logadóttir et al., submitted] or by changing the number of lamps being used [Logadóttir et al., in press].
- variations in the anchor preceding the adjustment trial. In these studies, an anchor was the illuminance or CCT set by the experimenter at the start of each trial. Anchors near the top and bottom of each range were used, and the two Copenhagen studies additionally used middle anchors.
- the Copenhagen illuminance study examined the effect of CCT on settings of preferred illuminance by employing different types of fluorescent lamps [Logadóttir et al., in press].
- the Copenhagen CCT study examined the effect of control type on settings of preferred colour appearance by using two different types of control device, analogue and digital [Logadóttir et al., submitted]. The analogue control dial was a one turn potentiometer with physical limits at each end of the control action so test participants were aware that they were not able to adjust beyond the maximum and minimum points. The digital control dial was an incremental encoder, an open ended control that gave no indication of the stimulus end points, i.e. it could be turned indefinitely, and was set to cover the full variation of a stimulus range in three turns of the rotary dial.

These variations were examined using a repeated measures design in which the orders of the variables were counterbalanced. The Copenhagen studies also examined the effect of adaptation time on preference settings: one half of the test subjects were instructed to wait for five minutes before carrying out each adjustment trial while the other half of subjects made immediate adjustments.

2.2.2 Results

This article is concerned with primarily the effect of stimulus range on preference adjustment. It was found that the anchors affected preference settings, with high anchors leading to higher preferences for illuminance and CCT than low anchors. To give a best estimate of preferred illuminance or CCT in a particular range, the mean of settings made from the low and high anchors was established for each test participant. The data suggested that the middle anchor would give a similar estimate of preference if the control mechanism exhibits a linear relationship between control action and resulting illuminance or CCT. Lamp CCT did not affect settings of preferred illuminance, and thus a mean estimate of preferred illuminance was established across the three levels of CCT. The type of control dial did not affect settings of preferred colour appearance and thus a mean estimate of preference was taken across the two devices.

Table 2 presents the results for the three studies, this being the mean preferred illuminance (or CCT) in each of the three ranges. For the two Copenhagen studies these data include both the adapted and non-adapted subjects. It can be seen that each range lead to a different estimate of mean preference, and these differences were found to be statistically significant. An example of the results is shown in Figure 2, these being results of the Sheffield study of preferred illuminance but the same trend was found in the other two studies. Figure 2 shows a clear stimulus range bias – each of the three ranges of illuminance leads to a different estimate of mean preferred illuminance. The mean preferred illuminances (and similarly CCT) are found near the centre of the range of available illuminance.

Table 2. Results of preference adjustment tasks showing mean value of preferred variable in each range.

Study	**Target variable**	**N**	**Stimulus range**				**Preferred value (mean)**
				minimum	**maximum**	**midpoint**	
Fotios & Cheal, 2010	Illuminance	21	R1	48 lux	1037 lux	542 lux	591 lux
			R2	83	1950	1016	902
			R3	165	2550	1358	1011
Logadóttir, Christoffersen & Fotios, in press	Illuminance	36	R1	21 lux	482 lux	270 lux	337 lux
			R2	38	906	477	523
			R3	72	1307	680	645
Logadóttir, Fotios et al, submitted	CCT	36	R1	2736 K	3530 K	3157 K	3288 K
			R2	3284	4014	3654	3671
			R3	2736	4014	3394	3490

It is possible that the repeated measures procedure may have influenced the responses given by test participants. Consider for example illuminance adjustment using initially the higher range of illuminances (R3); test participants might consider the illuminances available in subsequently observed low and middle ranges to be insufficient, and would set these to the maximum levels possible. Empirical evidence for such order effects can be found in the loudness judgements of Ward and Lockhead [Ward & Lockhead, 1970]. A potential order effect was countered in trials by balancing the stimulus range order between subjects. It is therefore possible that responses gained from participants who experienced only one stimulus range would differ from responses obtained from participants who experienced a series of stimulus ranges. Therefore, Figure 2 also shows the mean results of the first stimulus range experienced by each test participant, as this would not be affected by exposure to the other ranges. It can be seen that the mean preferred illuminances increase as the stimulus range increases, again tending toward the middle of the response range. These data again suggest a significant stimulus range bias on settings of preferred illuminance.

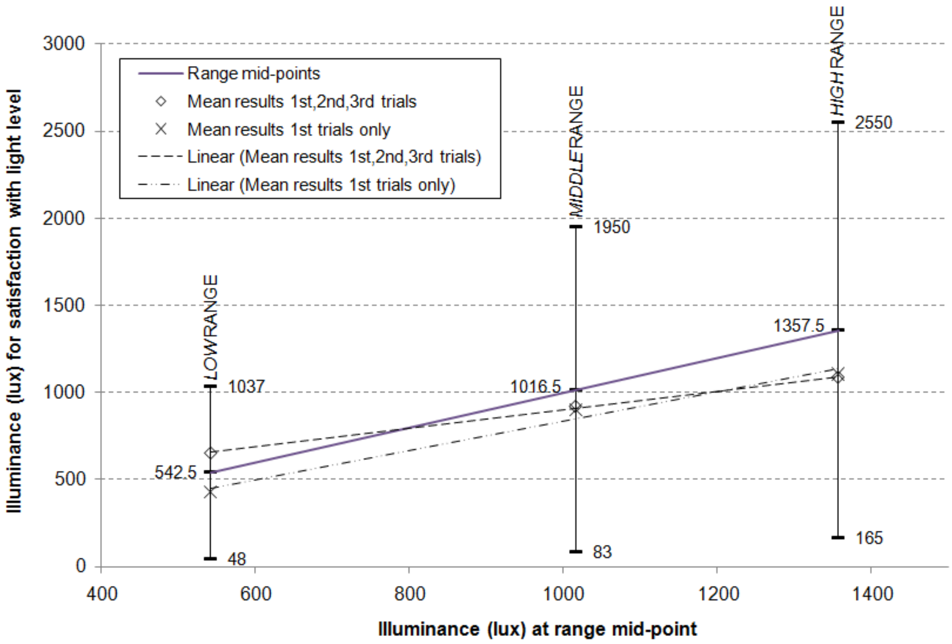

Figure 2. Results of preference adjustments: mean illuminance of preferred illuminance for the three stimulus ranges [Fotios & Cheal, 2010].

Figure 3 shows results from the Copenhagen preferred illuminance trials: these are the frequency by which each region of the control range were set [Logadóttir et al., in press]. Using per cent range of the control setting rather than illuminance range enables the different ranges to be compared, effectively normalising the three ranges. Other than for a slight bias to the 90-100% region in the lowest of the three illuminance ranges (R1: 21 to 482 lux), all regions of the control setting appear to have been used with a reasonable even frequency. Further investigation of this peak suggested it to result from those trials carried out subsequent to higher ranges of illuminance (i.e. R2 and R3), a ceiling effect that is not expected if only one range of illuminances were used. A similar distribution of control settings was found in the preferred colour appearance trials [Logadóttir et al., submitted].

2.3 Summary

Previous work has reported different preferences for illuminance in studies where test participants are instructed to set their preferred illuminance using an adjustment task. These data suggested a stimulus range bias, with different stimulus ranges leading to different estimates of preference, and this was confirmed in three studies [Fotios and Cheal, 2010; Logadóttir et al., in press; Logadóttir et al., submitted]. Test participants tend to use the whole of the available stimulus range: if a test allows high illuminances to be set, some test subjects in the sample will use this region and raise the mean illuminance.

This suggests that the method of adjustment has little value as a means of estimating the mean preferred illuminance. It is not intended to suggest, however, that there is no value in giving occupants control over their workplace lighting. If control over ones personal environment increases satisfaction, and if this is combined with a careful selection of illuminance range (i.e. a range where the majority of settings would be for an illuminance lower than the current standard) then energy savings may be available.

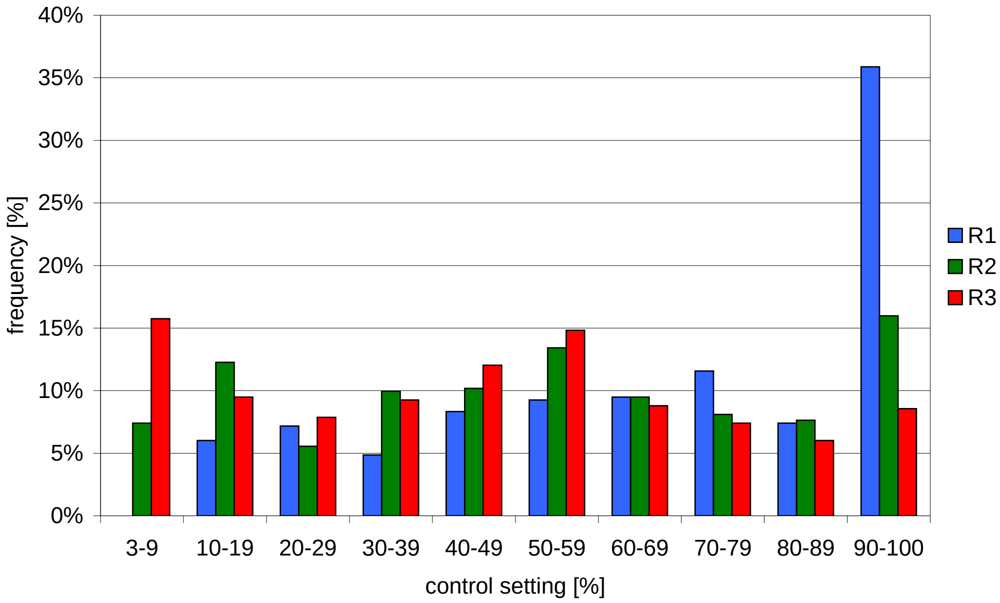

Figure 3. Frequency of control setting at preferred illuminance for the three stimulus ranges (R1: 21 to 482 lux, R2: 38 to 906 lux, and R3: 72 to 1307 lux). [Logadóttir et al., in press].

3. Satisfaction with light level

3.1 Previous Work

There is some evidence that the provision of lighting control can improve satisfaction. Boyce et al [Boyce et al, 2006b] report on ratings of satisfaction in their study of four lighting systems, two offering no control, one offering switching control and one with dimming control. The independent samples data, being experience of only one of these control options, did not tend to suggest any significant differences in ratings of perception and feelings, but results from their repeated measures subjects suggested that lighting with dimming control was rated better than lighting with no control (*base case 1*) for lighting quality and environmental satisfaction.

It appears that the lighting was initially rated at a particular level of satisfaction because it was largely acceptable, whether or not personal control was available, and it was only following the provision of control that occupants realised satisfaction could be improved. This can be seen in the results of two further studies. The first study confirms that giving control to people who did not previously have control increases their ratings of satisfaction. Newsham et al [Newsham et al., 2004] gained subjective ratings before and after test subjects were allowed to control their lighting, using dimming control with a range of 15% to 99% of full light output. They found higher ratings of environmental satisfaction ($p<0.01$) and lighting satisfaction ($p<0.01$) after control was allowed. The second study confirms that people with and without control give the same ratings of satisfaction. This was a study by Veitch & Newsham [Veitch & Newsham, 2000] where one person in each pair in the sample was able to use lighting control to set conditions at the start of the day (LC) and the second person was not (NC), there were no significant difference in ratings of lighting quality or environmental satisfaction between the LC and NC groups when rating lighting as set by the LC group.

3.2 Satisfaction with a low illuminance range

The Logadóttir et al [Logadóttir et al, in press] study of preferred illuminance included three illuminance ranges. The lowest of these ranges (R1; mean desktop illuminances of 21 to 482 lux) was chosen to examine whether such a low illuminance would be acceptable to occupants if it was one they had personally set. Each of the 36 subjects set preferred illuminances in all combinations of the three different CCT conditions, three different stimulus ranges, with four trials per range (three anchors and one repeat). For practical reasons, all trials were completed for one level of CCT before moving to the next level. At the end of each CCT session the test subject was presented with a fixed light level and asked to report their satisfaction, thus giving 36x3 judgements of satisfaction. This illuminance was the mean illuminance they had set in trials with R1. The results of a further study [Newsham et al, 2008], where judgements of satisfaction were recorded following a setting of preferred illuminance, suggest a higher level of satisfaction than was found in the current work. This suggests a clear difference between self-selected illuminance and imposed illuminance†, and that may have implications for personal dimming control in multi-occupancy rooms. Therefore, one half of the test subjects were informed that this was derived from their settings (informed subjects), the other half were not (not-informed subjects), to determine whether this awareness affected ratings of satisfaction. Satisfaction with light level was reported using a three category response scale: (1) they would prefer less light, (2) they were satisfied with the light level, or (3) they would prefer more light. Table 3 and Figure 4 show these illuminances and the ratings.

Table 3. Mean (and standard deviation) satisfaction ratings under the three different CCT and for all three CCT combined and the mean (and standard deviation) illuminances at which these satisfaction ratings were given.

	3000K		4000K		6500K		Overall	
	Mean illum. (lux)	Mean rating	Mean illum. (lux)	Mean rating	Mean illum. (lux)	Mean rating	Mean illum. (lux)	Mean rating
All subjects (n=36)	355 (76.0)	2.4 (0.71)	366 (68.2)	2.5 (0.55)	375 (68.9)	2.5 (0.60)	362 (71.91)	2.43 (0.63)
Informed subjects (n=18)	342 (67.5)	2.3 (0.67)	364 (65.3)	2.6 (0.50)	350 (64.6)	2.4 (0.68)	352 (67.01)	2.43 (0.63)
Not-informed subjects (n=18)	367 (81.7)	2.4 (0.76)	370 (71.0)	2.4 (0.59)	399 (64.0)	2.7 (0.47)	379 (74.72)	2.48 (0.64)

Table 3 suggests little difference in satisfaction rating between the informed and not-informed subjects and does not suggest any consistent changes in satisfaction with CCT. One half of the subjects (N=18) were informed that the presented illuminance was the mean of their settings, and for this group the mean satisfaction rating was 2.43. The remaining half were not informed of their input to the light level, and for this group the mean rating was 2.48. Differences between the two groups are not statistically significant, suggesting that satisfaction was not influenced by knowledge of personal influence on the light setting presented to them. For both groups it appears that there was a preference for more light, despite the illuminance presented being derived from their personal settings of preferred illuminance, and for all but two of the 36 subjects it was possible for them to have set a higher mean illuminance.

† Note also that daylight was present in the Newsham study but was excluded in the Logadóttir et al study.

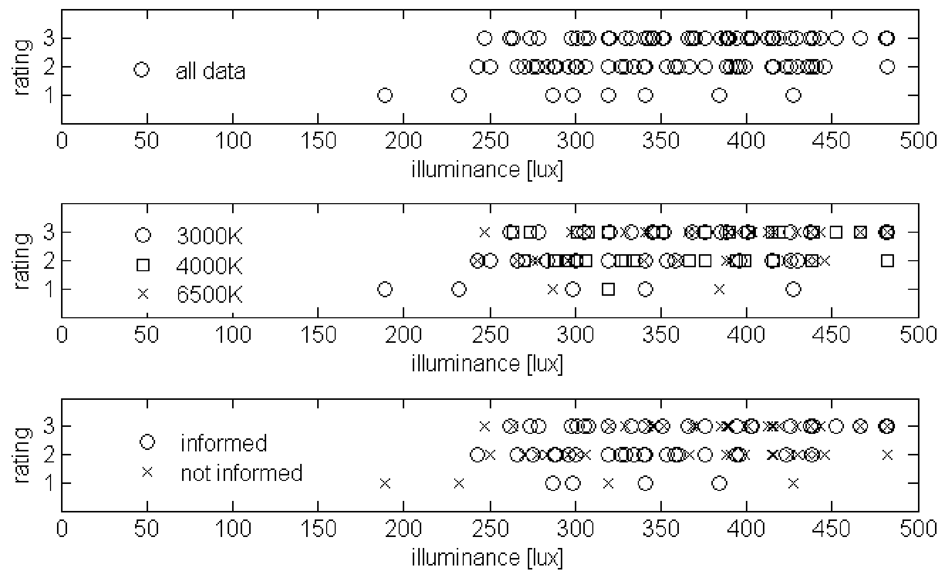

Figure 4. Satisfaction ratings plotted against illuminance. (a) overall data, (b) data categorised by lamp CCT, (c) data categorised by whether or not subjects were informed of their input to the illuminance setting.

Figure 4 shows satisfaction ratings plotted against illuminance. It can be seen that the spread of illuminances considered to be satisfactory is almost identical to the range of illuminances for which more light would be preferred. Figure 4 also suggests that the satisfaction rating is not affected by the lamp CCT or by whether the test subjects were informed of their contribution to the mean illuminance prior to giving the satisfaction rating.

These data suggest that the test subjects would have preferred more light than that with which they were presented, which may be considered a dissatisfaction with the illuminance provided. Why was satisfaction with light level not greater since these were light levels the subjects had set? Possibly the test procedure induced an anchor. Table 4 shows the data broken down according to the stimulus range experienced immediately before the experimenter set the illuminance for which the satisfaction rating was sought, and this was from tests with range R1, the lowest of the three ranges.

Figure 5 shows the satisfaction ratings broken down to range to which subjects were exposed prior to making the satisfaction rating. It can be seen that there is a higher degree of satisfaction with the light level when this rating was made immediately after trials with range R1 than when satisfaction was rated after trials with the ranges of higher illuminance, R2 and R3, these tending to indicate a preference for more light. These data were not considered to be drawn from a normally distributed population. According to the Kruskal Wallis test, ratings of satisfaction given following different stimulus ranges are significantly different ($p<0.05$). The Mann-Whitney tests suggests that the difference between R1 and R2 is significant ($p<0.05$), as is that between R1 and R3 ($p<0.05$) but it does not suggest a difference between R2 and R3 ($p=0.818$). Thus a higher rating of satisfaction is gained if the test subject is not making this rating immediately after exposure to a higher range of illuminances, and this is likely to be the case for judgements of satisfaction in real spaces where a single illuminance range is available.

Table 4. Ratings of satisfaction broken down according to the stimulus range experienced immediately before the experimenter set the illuminance for which the satisfaction rating was sought

Illuminance range prior to satisfaction rating	Mean rating	Std. dev.	Median	% of people giving each rating		
				1	2	3
R1	2.22	0.72	2.00	16.7%	44.4%	38.9%
R2	2.56	0.56	3.00	2.8%	38.9%	58.3%
R3	2.58	0.54	3.00	2.8%	36.1%	61.1%
Across all three ranges	2.45	0.38	2.33	7.4%	39.8%	52.8%

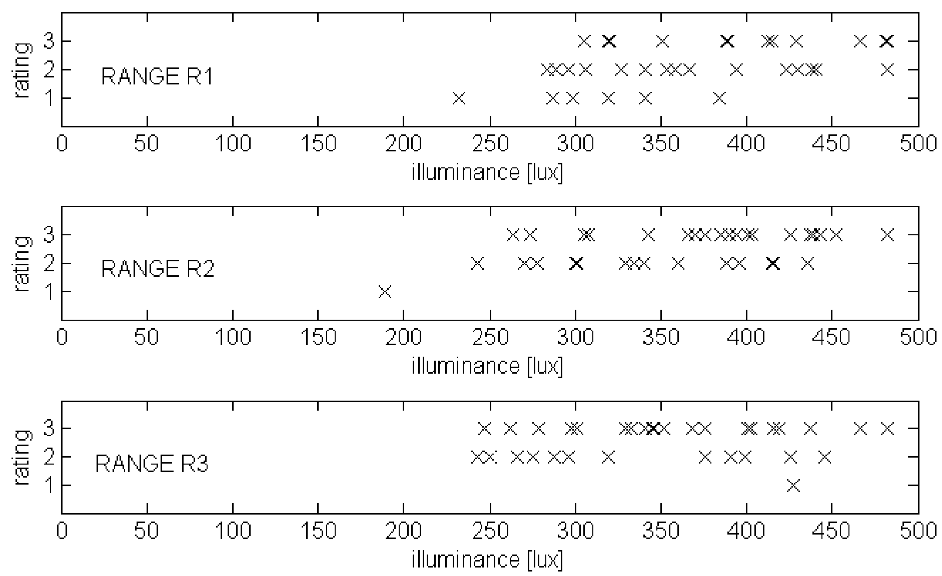

Figure 5 Satisfaction ratings broken down according to range seen immediately prior to satisfaction rating. (a) range R1 (21-482 lux), (b) range R2 (38-906 lux), (c) range R3 (72-1307 lux).

4. Conclusion

This study makes two suggestions regarding illuminance adjustment, firstly that it is not an appropriate method for determining preference, and secondly that it may provide a means for maintaining satisfaction and lower illuminances.

The illuminance adjustment task is vulnerable to stimulus range bias, with different stimulus ranges leading to different estimates of mean preference. The results display a centering bias; this appears to arise because test participants make use of the whole range of available illuminances and the determination of mean preference is thus directed to the centre of the range. When the method of adjustment is used, it is proposed that two or more stimulus ranges are used and that the limits of these ranges are reported, that the anchors are reported, and that these are fully balanced within or between subjects as appropriate.

Illuminance adjustment can, however, be gainfully employed. If users are allowed to set their own light level this can improve their satisfaction with the light level. By choosing a low range of illuminances available through the adjustment control, and by commencing the adjustment from a low anchor, the set illuminances will tend to be lower than the standard fixed illuminance, thus reducing energy consumption (assuming suitable control gear) and maintaining satisfaction with the visual environment.

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