This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

Satisfaction and illuminances set with user-controlled lighting

James Uttley, Steve Fotios,† Chris Cheal

University of Sheffield, UK

School of Architecture
University of Sheffield
The Arts Tower
Western Bank,
Sheffield S10 2TN
UK
+441142220371

steve.fotios@sheffield.ac.uk

Recommended Running Head: Satisfaction with user-set illuminance

Keywords: adjustment, energy reduction, illuminance, range bias, satisfaction, user-control.

This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

Abstract

This study was carried out to explore satisfaction with light levels when these are set with user-control over light level. Two ranges of illuminance were used, having maximum illuminances of 500 lux and 700 lux. Previous work has demonstrated that the lower range would lead to lower settings of preferred illuminance: this work was carried out to compare ratings of satisfaction with light levels set using different ranges. Results of the illuminance adjustment task demonstrated that the low range lead to significantly lower illuminances. Results of the ratings of satisfaction with light level did not suggest a difference in satisfaction with the low and high ranges despite the significant difference in illuminance. These results suggest that people would set a lower light level when presented with a lower illuminance range and that they would be equally satisfied with this lower light level than if they had set a higher illuminance under a high illuminance range. This suggests the potential to reduce energy consumption without reducing satisfaction.

Manuscripts are to be submitted in A4, single column, 12-point, double-spaced text (without extra spacing before or after lines).

Indicate the preferred location for each table and figure by at the preferred location between paragraphs in the text.

Headings should not exceed two levels – Main Headings and Secondary Headings – both Caps and lower case, with the title and main headings in Bold Face and secondary headings in Bold Italics. Do not number headings

References

All references are to be in the Harvard/Royal Society/APA in-text format (eg, Gunaratnam, Hyde, Julian & Smith, 2008).

In the list of references, titles of books, journals and published conference proceedings are to be in Capital Italics, not underlined. Include the City: Publisher for all non-journal references.

Cite the date of retrieval for any on-line refereed publications and major government reports, but do not cite ephemeral or non-peer-reviewed website information.

Organisation and length of manuscripts

double-blind refereed journal, organise the manuscript in the following order:

First page with paper Title, authors (no degrees or titles), affiliations for all authors, and international telephone and facsimile numbers and e-mail address for the corresponding author, with the corresponding author identified by a dagger.

The text of the manuscript should begin on the next page with no authors' names, affiliations or self-identifying citations in the remainder of the manuscript, followed by Acknowledgements, References, and finally Tables and Figures each on a separate page.

Number the pages consecutively on the bottom right, but do not insert headers or footers. There is no absolute page or word length, but to increase the flow of papers through the journal without compromising scientific quality and presentation, most manuscripts are 4000-6000 words and 8-10 published pages. Shorter Research Notes of 2000-3000 words are also welcome. Brevity is preferred, with fewer words if there are more tables or figures.

This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

INTRODUCTION

Recent research has reported on users perceptions of interior lighting [Baird and Thompson, 2012]. One problem with measurement of perception is that it is easily biased by the procedure with which it is measured [Poulton, 1989], in fact it is probably almost impossible to avoid bias [Poulton, 1977]. This article presents a strategy where such bias may be used to advantage to meet the objectives of reducing the energy consumed by interior lighting whilst maintaining satisfaction with the lighting.

User-control means that the occupants of a space have control over the amount of light provided by electric lighting, i.e. illuminance adjustment or dimming. Past studies have been carried out to record user preferences for light level by giving them control over their work place lighting, an illuminance adjustment task. Juslén *et al.* investigated task lighting in an industrial setting (luminaire assembly), reporting a mean preferred illuminance of 1752 lux [Juslén et al, 2005]; Scholz *et al.* investigated the optimum illuminances set by anaesthetists to visualise the larynx during laryngoscopy [Scholz et al, 2007]; and others have examined preference in offices [Boyce et al, 2006, Newsham et al, 2004, Newsham et al., 2005, Veitch & Newsham 2000]. These studies often indicate a desire for higher illuminances and some have interpreted these data as evidence for the need to revise standards in lighting guidance, but this has been shown to be an incorrect conclusion.

Fotios & Cheal [Fotios & Cheal, 2010] examined studies using illuminance adjustment to set preferred illuminance and noted that the reported mean preferred illuminance tended to fall near the middle of the available range of illuminances, an apparent centering bias. This is a stimulus range bias because the range made available by the experimenter has a direct influence on the outcome of the test where this is reported as a mean value. The ability to choose preference may also be limited by the range available: if 1000 lux is wanted, but the range does not allow an illuminance as high as 1000 lux, then the test participant may be hindered by a control ceiling or may provide a response that does not truly represent their preference. With either case the range of illuminances available through the dimming control system affects the reported mean preferred illuminance. Fotios and Cheal

[Fotios & Cheal, 2010] therefore carried out an experiment using a scale model to confirm the suspected stimulus range bias: test subjects were instructed to set their preferred illuminance, naïve to the experimenter's ability to change the minimum and maximum illuminances available to them in successive trials. Three ranges of illuminance were used (48 to 1037 lux, 83 to 1950 lux, and 165 to 2550 lux) and in each range the mean preferred illuminance was found near the centre of the range.

Examination of stimulus range bias in the adjustment task was extended by Logadóttir *et al.* [Logadottir et al, 2011a]. This study was carried out in a non-daylit room, furnished as an office, in which test subjects were asked to set their preferred illuminance. This test was designed to examine the influence of anchors (the illuminance set by the experimenter immediately prior to each adjustment) in addition to stimulus range. Three ranges of illuminance were obtained by varying the number of active lamps in each luminaire, and these were desktop illuminances of 21 to 482 lux, 38 to 906 lux and 72 to 1307 lux. The three different stimulus ranges led to significantly different preferred illuminances ($p<0.001$) with the higher stimulus range (i.e. higher maximum value available) leading to higher preferred illuminances. The different anchors also led to significant differences in preferred illuminance within each range, with lower anchors leading to lower preferred illuminances. Logadóttir *et al.* [Logadottir et al, 2011b] also investigated stimulus range bias in the adjustment task within an experiment to determine preferences for correlated colour temperature (CCT). This was done because CCT presents a different type of stimulus dimension to illuminance: variation in illuminance has an obvious direction of magnitude, from zero or low illuminance to a higher illuminance, whereas variation in CCT has no obvious direction in magnitude. Again, a significant stimulus range bias was found, and this demonstrates it is a persistent effect.

It is thus evident that when users are permitted to use a dimming control to adjust the amount of light, their response is biased and constrained by the range of available illuminances and the outcome should not be interpreted as evidence of a mean preferred illuminance. Adjustment provides information regarding response under the particular testing conditions but not an absolute preference.

There is however potential to gain benefit from user control when it is used in real situations. Boyce suggested "*The only honest answer to a demand for rapid and major reductions in the electricity consumed by lighting is a reduction in the illuminances used*" [Boyce, 2010] and this can be achieved with user control. Consider that users are provided with control over the illuminance from electric lighting at their workplace and the available range of illuminances has been carefully chosen, e.g. up to 700 lux for a situation otherwise recommended an illuminance of 500 lux; the results of previous work suggest that users will tend to set illuminances across a broad section of the available range, if not the complete range [Logadottir et al, 2011a], many of which will be lower than 500 lux. In the study reported by Newsham and Veitch [Newsham & Veitch, 2001] and Veitch and Newsham [Veitch & Newsham, 2000] the available range of desktop illuminances had a maximum of 700 lux, from which over 60% of subjects chose illuminance levels lower than 500 lux. User-control with an appropriate range thus provides a possible mechanism for reducing illuminances and thus energy consumption.

When considering such an action there is a need to consider whether an illuminance reduced by user-control would affect visual performance and motivation. The results of Boyce *et al.* [Boyce et al. 2006] demonstrate that for people who have some control over their lighting, the specific illuminances chosen should not affect performance on a variety of tasks. There is some evidence that user-control of lighting can enhance motivation to work. Veitch *et al.* [Veitch et al, 2012] analysed task performance and visual appraisal data obtained from test participants who spent one day in an office research laboratory. A link was found between lighting appraisals, workplace satisfaction and work engagement: people who appraise their lighting as good will also be in a more pleasant mood, be more satisfied with the work environment and more engaged in their work. As was reported by Newsham *et al.* [Newsham et al, 2004] provision of user control leads to higher ratings of environmental satisfaction and lighting satisfaction, and it can therefore be expected that user control of lighting will also lead to improvement in satisfaction with the work environment and engagement with work.

What is not yet known is the appropriate illuminance range, having a maximum sufficiently high to present a wide enough range of light levels to choose from, while sufficiently low to sway settings towards lower light levels and thus target energy reduction. An experiment was carried out to investigate satisfaction with two ranges of illuminance, these having maximum illuminances of 500 lux and 700 lux. These data were used firstly to confirm the effect of range bias on settings of preferred illuminance, the current study using smaller differences between the illuminance ranges than in previous work [Fotios & Cheal, 2010, Logadóttir et al, 2011a], and then to examine satisfaction with light levels set using these illuminance ranges.

METHOD

Apparatus

An experiment was carried out in a simulated work environment in which test participants were instructed to adjust the illuminance to set their preferred level of lighting. This task was repeated for four combinations of illuminance range and anchor, and ratings of satisfaction were sought subsequent to selected adjustments.

During trials participants were seated inside a test room of dimensions 2.4m width, 2.4m length and 2.3m high (Figure 1), a similar size to the room used by Berman *et al.* [Berman et al, 1990] for evaluations of spatial brightness. The walls were made from plywood, the inside surfaces of which were painted with a matt white emulsion, and the floor was dark grey linoleum with low sheen. A desk with matt white surface and a black chair were placed in the room. Overall the interior was neutral and lacking in colour.

[Figure 1]

Six luminaires were suspended above the room in two parallel rows of three (Figure 2). Each luminaire contained four tubular fluorescent lamps, although only two lamps in each luminaire were used for the current study. The lamps were 600mm tubular fluorescent (T8, 18 W, 2940K, R_a 51). A white sailcloth was attached below the luminaires to act as a diffuser and this was the ceiling of the room; in appearance the room was lit by a self-luminous ceiling.

[Figure 2]

The amount of illumination within the room was controlled using electronic control gear that allowed remote lamp dimming via a 0-10volt analogue DC control signal. The control signal came through a voltage-dividing circuit comprising three rotary potentiometers, one of which was adjusted by participants during trials. The range of illuminances available to participants was set by the experimenter using the other two potentiometers to set the upper and lower illuminance limits. The rotary dimmer used by participants required three whole turns to cover the whole of the available range. The dimming control did not provide an *off* command at the bottom of the range, only a minimum light level, and this was set to 40 lux for both ranges.

Two illuminance ranges were used in these trials, desk top illuminances of 40-500 lux (the low stimulus range) and 40-700 lux (the high stimulus range). The 500 lux maximum was chosen to represent typical design standard for offices: with this range, any setting to a lower level would be a potential energy reduction but there is a risk that 500 lux may not be sufficient for some test participants. The 700 lux maximum was determined following Boyce *et al.* [Boyce et al, 2006] who suggested that 90-99% of people should be able to achieve their preferred illuminance with a range of up to 700 lux. With this higher range there is increased likelihood that people would be able to set their preferred level of light, but also a risk that some settings would be above 500 lux, therefore leading to an increase in energy consumption relative to lighting designed to provide 500 lux.

Adjustments of illuminance commenced from two starting points (anchors). The low anchor was 86 lux for both ranges. The high anchor was 90% of the range in use, i.e. 454 lux for the low stimulus range and 634 lux for the high stimulus range. With these anchors, test participants were able to make immediate adjustments in both directions - to higher or lower levels. A 2x2 repeated-measures experimental design was used comprising the four combinations of stimulus range and anchor: low range, low anchor (*LL*), low range, high anchor (*LH*), high range, low anchor (*HL*) and high range, high anchor (*HH*).

This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

Procedure

Participants were asked to adjust the amount of light to their preferred level whilst sat inside the test room. This adjustment task was repeated eight times, with the four combinations of anchor and illuminance range each being presented twice. The order in which the trials were presented was randomised, although it was ensured that equal numbers of participants were presented with each of the conditions on their first trial in order to improve the applicability of analysing first-trial data.

Between each trial participants were asked to put on a blindfold whilst lighting conditions were adjusted. This took 1 minute for each trial. Participants were then asked to remove their blindfold and wait 30 seconds (timed by the experimenter) before adjusting the illuminance to their preferred level. In previous work [Logadóttir et al, 2011a] adjustments were sought immediately or after five minutes adaptation: it was reported that adaptation time did not have significant effect on preferred illuminances.

Participants were asked to report their satisfaction with the level of light in the room using a five-point response scale, ranging from 1 (*I would prefer a lot less light*), through 3 (*I am satisfied with this level of light*) to 5 (*I would prefer a lot more light*). This is essentially the *Artificial Light* response scale used in the Building Use Studies questionnaire [Baird and Thompson, 2012] but using a 5-point rather than 7-point response range. Satisfaction was recorded on four occasions: (i) after the first trial; (ii) after one of the LL condition trials; (iii) after one of the HL condition trials; and (iv) at the end of the eight trials, with an illuminance set by the experimenter to match that set by the participant for the LL trial for which a satisfaction rating was recorded (i.e. rating (ii)). Participants were given 30 seconds adaptation time for this final rating, as with the other trials.

Data were collected from 40 naïve participants (53% female; 85% were aged between 18 and 44 years old and the remaining 15% were aged 45 or over) who were paid to attend. Participants were asked to wear any vision-correcting lenses they would normally wear.

This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

RESULTS

Internal Consistency

Preferred illuminances set on the first and second trials for each range and anchor combination were compared to analyse internal consistency. The mean and median differences between preferred illuminances set on the first and second trial for each combination of range and anchor are shown in Table 1. Analyses of the preferred illuminance data did not suggest they were drawn from a normally distributed population and thus non-parametric statistical tests were employed. The Wilcoxon signed-rank test did not suggest differences between the first and second trials to be significant. Furthermore, regression of the second trial data against the first trial data within each combination of range and anchor led to coefficients between $r = 0.72$ and 0.87, and these are suggested to be significant ($p<0.001$) according to Spearman's test.

[Table 1]

It was therefore concluded that there is a high degree of consistency in preferred illuminance settings on repeated trials with identical conditions. Following previous work [Logadóttir et al, 2011a] subsequent analyses use the mean illuminance setting of participants from the first and second trials for each condition.

Preferred illuminance

Table 2 and Figure 3 show the average preferred illuminances for each of the four test conditions. These data were derived from the 40 test participants and for each participant the data were derived from the mean of their two settings for each condition. It can be seen that the high anchors led to higher preferred illuminances than did the low anchors. For the two high anchors, the higher stimulus range led to higher preferred illuminances. For the low anchors, the two stimulus ranges led to similar preferred illuminances. The LL condition produced the lowest illuminance settings amongst participants whilst the HH condition produced the highest settings.

[Table 2]

This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

[Figure 3]

These data were not found to be normally distributed thus analysis was carried out using non-parametric tests. Friedman's test suggests that there was a significant difference in preferred illuminances for some of the conditions ($\chi^2 = 35.63$, $p<0.001$). Further analysis using Wilcoxon signed-rank tests suggests that preferred illuminances in all four conditions differ significantly from each other ($p<0.01$). Note that for the six possible pairs of the four conditions, Bonferonni correction suggests the critical value p=0.0083 for significance at the 5% level, and for all six pairs this threshold was exceeded.

Following the approach used by Logadóttir *et al.* [Logadóttir et al, 2011a] the effect of stimulus range was determined using the mean of illuminances set using the low and high anchors for each participant. Table 3 shows the preferred illuminances in each range. It can be seen that the low stimulus range produced lower preferred illuminances than did the high stimulus range. The Wilcoxon signed-ranks test suggests that this difference is statistically significant ($p<0.001$). It should be noted that the average illuminance set during low stimulus range conditions was well within the upper limit of the range available (500 lux), so it was not the case that the low range resulted in a lower illuminance setting because of a lower available maximum limiting the value that participants could set.

[Table 3]

The lowest illuminance available (40 lux) was not set as the preferred illuminance in any trial. However, the illuminance was set to the maximum possible in 28 (9%) of the 320 trials. Fifteen of these maximum settings are the result of two participants (one participant set to the maximum in all eight trials, the second participant set the maximum in seven of their eight trials). Nine other participants set to the maximum illuminance on one, two or three occasions. Figure 4 shows the frequency of maximum settings of illuminance by range and anchor combination: the maximum illuminance was set from the high anchor more frequently than from the low anchor.

[Figure 4]

Figure 5 shows the correlation between the mean preferred illuminance settings made by participants when presented with the low stimulus range and the high stimulus range. As can be seen this correlation was positive, and Spearman's correlation coefficient suggests it to be significant ($r=0.906$, $p<0.001$). This suggests that a participant who set their preferred illuminance relatively highly on one of the stimulus ranges would tend also to set it relatively highly on the other stimulus range.

[Figure 5]

These results confirm that settings of preferred illuminance made by illuminance adjustment are affected by the stimulus range and the anchor. The low stimulus range (500 lux) led to lower preferred illuminances than did the high stimulus range (700 lux) and the low anchors led to lower illuminances than did the high anchors. According to the Wilcoxon signed-rank test these differences were statistically significant ($p<0.01$).

Initial response

This experiment followed a repeated measures procedure and it is possible that settings were affected by the experience of previous trials. The data gained from the first trial carried out by test participants allows for analysis without potential sequence bias and without a learning/practise effect. The condition to which participants were exposed on their first trial was balanced to ensure each of the four conditions were used with equal frequency.

[Table 4]

Table 4 shows the average preferred illuminance settings during the first trial, for each combination of range and anchor. These first-trial data follow a similar pattern to that shown by all-trial data, i.e. that the LL condition produced the lowest settings of illuminance, followed by the HL condition, the LH condition, with the HH condition producing the highest settings of illuminance.

Data from the first trial were examined using Kruskal-Wallis test. This suggested that differences between conditions on the first trial illuminance were statistically significant ($H(3) = 14.59$, $p<0.01$). Subsequent analysis of the six possible pairs was carried out using the Mann-Whitney test, again using the threshold of p=0.0083 for significance at the 5% level. For two pairs (LL vs HH and LH vs HH) the differences in preferred illuminance are significant ($p<0.0083$). For two pairs (LL vs HL and LH vs HL) the data do not suggest the differences to be significant (p=0.82 and p=0.33 respectively). For the final two pairs (LL vs LH and HL vs HH) the differences are closer to the threshold (p=0.10 and p=0.01 respectively) and in the latter case a difference is strongly hinted. What these data reveal is that the HH condition (high range and high anchor) lead to settings of preferred illuminance on the first trial that were significantly higher than those set using the other three conditions, and that the difference between the LL, LH and HL conditions is not significant. Thus the differences in settings of preferred illuminance are not as strong as those found through analysis of data from all trials, but a significant effect still exists and this is associated with the range and anchor available.

The experiments carried out by Fotios and Cheal [Fotios & Cheal, 2010] and Logadottir et al [Logadottir et al, 2011a] used three illuminance ranges and their analyses of the first trial data using Kruskal-Wallis also suggested a significant effect of illuminance range, with significant differences between each pair of ranges except for between the middle and high ranges. Thus it appears that with a single adjustment a higher illuminance range tends to lead to higher settings of preferred illuminance.

Ratings of Satisfaction

Participants provided ratings of how satisfied they were with the light level in the experimental room using a 5-point scale and these were recorded on four occasions: (i) following the first trial of the experiment; ii) following one of the low stimulus range, low anchor (LL) trials; (iii) following one of the high stimulus range, low anchor (HL) trials; and (iv) at the end of the eight trials, with an illuminance set by the experimenter to match that set by the participant for the LL trial for which a satisfaction rating was recorded (i.e. rating (ii)). For this final rating the participant was unaware the illuminance had been set to a level they had previously set and rated for satisfaction.

Table 5 shows the average satisfaction ratings. For ratings made after an illuminance adjustment it can be seen that participants only used points 3 and 4 of the response scale, suggesting either satisfaction with the light level (3) or the desire for a slightly higher light level (4). These data were not found to be normally distributed. Friedman's test suggested that the ratings recorded on the four occasions are significantly different ($\chi^2 = 35.63$, $p<.001$).

Two comparisons are pertinent to the current discussion. The first is whether ratings of satisfaction made after adjustments using the high and low illuminance ranges were different, i.e. ratings (ii) and (iii). Table 5 shows that ratings were similar for both cases with a median of 3: the Wilcoxon signed-rank test does not suggest the difference to be significant.

The second comparison is whether ratings of satisfaction with light level were different when rating a light level set by the experimenter (iv) or when the same illuminance was set by the test participant (ii). Table 5 shows that ratings made following the experimenter-set illuminance were higher (median = 4) than following the participant-set illuminances (median = 3), indicating a preference for more light even though the illuminances were identical. Analysis using Wilcoxon signed-rank tests suggests that the difference is significant $p<0.001$).

[Table 5]

As shown in Table 5, throughout the entire experiment no participant expressed a preference for less illuminance when using the ratings, i.e. response points 1 and 2 were not used in any trial, which would have indicated the participant would have liked a lower illuminance than was in the room at the time.

This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

Some participants suggested they wanted more light following trials in which they had set the illuminance themselves (i.e. ratings (i), (ii) and (iii)). In four trials this was understandable, as the participant had set the illuminance to the maximum allowed in the range. Here it must be assumed that the participant's preferred light level lay beyond the range available to them. However, there were also a number of trials where participants did not set the illuminance to the maximum of the range but still reported through the satisfaction rating that they would prefer a higher level of lighting. For example, during those LL trials that were followed by a satisfaction rating, eight of the 10 participants who said they wanted more light had set an illuminance during that trial that was below the maximum available to them. Similarly, five of the seven participants who said they wanted more light following the HL trial also did not set an illuminance at the maximum available.

Comments received from test participants during debriefing suggests these seemingly anomalous satisfaction ratings (wanting more light even though the participant had an opportunity to set a higher illuminance) may have been due to adaptation. These participants reported that when they came to complete the satisfaction rating question, a delay of typically 15 seconds following the adjustment, the light in the room seemed darker than the level they had initially set, which led to them wanting more light and answering the satisfaction rating question accordingly.

This raises the question of whether in a real environment these people would have subsequently used control to increase the illuminance. A tendency for upwards adjustment of light level would diminish the potential for energy saving. Field studies suggest that the tendency to change light levels is small, and show that individual lighting controls are rarely used but when they are, they are used to set a preferred light setting and usually this is only done at the beginning of the day. Boyce *et al.* [Boyce et al. 2006] assigned test subjects to a workstation lit by one of four lighting systems, two offering no control, one offering switching control (0, 13, 26 and 37W) and one with dimming control (initially set to the 50% position) which they were free to use at any time during a whole working day. They found that 63% of test subjects adjusted only once: for the dimming control group 82% of the illuminances in the final (fourth) session were those set in the first session (79% for the switching group), 11% did not make any variation, 11% made adjustments on two occasions, and 16% made adjustments on three to five occasions. Boyce *et al.* conclude that people tend to set the light level to what is expected for the day's work at the beginning of the day, and then change it only when essential. Infrequent use of control is also apparent in the results of two further field studies [Moore et al, 2003, Galasiu et al, 2007].

Table 5 shows the satisfaction ratings gained following the first trial carried out by each test participant. The overall satisfaction rating was not significantly different to ratings reported later in the test session following an adjustment response. There were also no significant differences in ratings reported following the four test conditions when used in the first trial.

CONCLUSION

This study was carried out to explore satisfaction with light levels when these are set with user-control. Illuminance adjustment was carried out in a laboratory room constructed to provide a controlled environment for brightness judgments. Two illuminance ranges were used in these trials, having maximum illuminances of 500 lux and 700 lux. The aim was to investigate the proposal that the lower range would lead to lower settings of preferred illuminance but that there would be equal satisfaction with light level set in both ranges. Results of the illuminance adjustment task demonstrate that the low range did lead to significantly lower illuminances. In only a few cases was the control dial set to maximum: at present it is not possible determine whether these maximum settings indicate a real desire for more light or a cantankerous response. Analysis of repeated settings made for the same condition of range and anchor suggests good internal consistency. Analysis of preferred illuminances set using different ranges suggests a consistent setting relative to the range available: a person setting slightly below average for one range would also set slightly below average for a different range.

Results of the ratings of satisfaction with light level do not suggest a difference in satisfaction with the low and high ranges despite the significant differences in illuminance. Note that ratings were recorded only after settings made using the low anchor, and the low anchor was the same for both ranges. A significant difference in ratings of satisfaction was found between light levels set by the user and the experimenter: the light level set by the experimenter was found to be less satisfactory (i.e. a stronger desire for more light) despite the illuminances being identical.

These results demonstrate the tendency for participants to set a lower level of illuminance when presented with a lower stimulus range, but they are no less satisfied with this lower illuminance than if they had set a higher illuminance when using a higher stimulus range. This confirms the potential for a reduction in energy consumption without reducing satisfaction.

References

Baird, G., Thompson, J. (2012). Lighting conditions in sustainable buildings: results of a survey of users' perceptions. *Architectural Science Review*, 55(2), 102-109.

Berman, S.M., Jewett, D.L., Fein, G., Saika, G., Ashford, F. (1990). Photopic luminance does not always predict perceived room brightness. *Lighting Research and Technology*, 22(1), 37-41.

Boyce, P.R. (2010). Editorial comment. *Lighting Research and Technology*, 42, 5-6.

Boyce, P.R., Veitch, J.A., Newsham ,G.R., Jones, C.C., Heerwagen, J., Myer, M., Hunter, C.M. (2006). Occupant use of switching and dimming controls in offices. *Lighting Research and Technology*, 38, 358-378.

Fotios, S.A., Cheal, C. (2010). Stimulus range bias explains the outcome of preferred-illuminance adjustments. *Lighting Research and Technology*, 42(4), 433-447.

Galasiu, A.D., Newsham, G.R., Suvagau, C., Sandler, D.M. (2007). Energy saving lighting control systems for open-plan offices: a field study. *Leukos*, 4, 7-29.

Juslén, H.T., Wouters, M.C.H.M., Tenner, A.D. (2005). Preferred task-lighting levels in an industrial work area without daylight. *Lighting Research and Technology*, 37, 219-233.

Logadóttir, Á., Christoffersen, J., Fotios, S.A. (2011a). Investigating the use of an adjustment task to set preferred illuminance in a workplace environment. *Lighting Research and Technology*, 43(4), 403-422.

Logadottir, A., Fotios, S.A., Christoffersen, J., Hansen, S.S., Corell, D.D., Dam Hansen, C. (2011b) Investigating the use of an adjustment task to set preferred colour appearance. *Color Research and Application*, first published online 15th September 2011. DOI: 10.1002/col.20714.

Moore, T., Carter, D.J., Slater, A.I. (2003). Long-term patterns of use of occupant controlled office lighting. *Lighting Research and Technology*; 35, 43-59.

Newsham, G.R., Veitch, J.A. (2001). Lighting quality recommendations for VDT offices: a new method of derivation. *Lighting Research and Technology*, 33: 97-116.

Newsham, G.R., Veitch, J.A., Arsenault, C., Duval, C. (2004). Effect of dimming control on office worker satisfaction and performance. Proceedings of IESNA Annual Conference, Tampa, Florida. 19-41.

Newsham, G.R., Arsenault, C., Veitch, J., Tosco, A.M., Duval, C. (2005). Task lighting effects on office worker satisfaction and performance, and energy efficiency. *Leukos*, 1, 7-26.

Poulton, E.C. (1977). Quantitative subjective assessments are almost always biased, sometimes completely misleading. *British Journal of Psychology*, 68, 409-425.

Poulton, E.C. (1989). *Bias in quantifying judgements*. Hove: Psychology Press.

Scholz, A., Farnum, N., Wilkes, A.R., Hampson, M.A., Hall, J.E. (2007). Minimum and optimum light output of Macintosh size 3 laryngoscopy blades: a manikin study. *Anaesthesia*, 62, 163-168.

Veitch, J.A., Newsham, G.R. (2000). Preferred luminous conditions in open-plan offices: research and practice recommendations. *Lighting Research and Technology*, 32, 199-212.

Veitch, J.A., Stokkermans, M.G.M., Newsham, G. (2012). Linking lighting appraisals to work behaviours. *Environment and Behavior*, first published online 16 September 2011. DOI: 10.1177/0013916511420560

Stimulus range and anchor	Difference between first and second trials			Difference between ratings*
	Mean difference lux)	Standard deviation (lux)	Median difference (lux)	
LL	44	52	21	n.s.
LH	48	51	24	n.s.
HL	56	84	30	n.s.
HH	80	83	52	n.s.

Table 1. Differences between preferred illuminances set on first and second trials for each range x anchor combination.
LL = Low stimulus range, low anchor; LH = Low stimulus range, high anchor; HL = High stimulus range, low anchor; HH = High stimulus range, high anchor.
*Note: (i) Differences examined using t-test (HH trials) and Wilcoxon test (LL, LH and HL data, non-normally-distributed); (ii) n.s. = not significant.

Stimulus range and anchor	Mean preferred illuminance (lux)	Standard deviation (lux)	Median preferred illuminance (lux)
LL	218	116	184
LH	385	89	391
HL	250	168	194
HH	488	133	491

Table 2. Preferred illuminance found using low stimulus range, low anchor (LL), low stimulus range, high anchor (LH), high stimulus range, low anchor (HL) and high stimulus range, high anchor conditions. Mean and median determined from the mean of two trials carried out by each test participants for each condition.

Condition	Mean preferred illuminance (lux)	Standard deviation (lux)	Median preferred illuminance (lux)
Low stimulus range	301	93	296
High stimulus range	369	138	370

Table 3. Preferred illuminances set using the low (500 lux) and high (700 lux) stimulus ranges. These data are mean of low and high anchor trials taken for each range.

Condition	Mean preferred illuminance (lux)	Standard deviation (lux)	Median preferred illuminance (lux)
LL	271	114	235
LH	340	100	323
HL	288	195	245
HH	510	104	507

Table 4. Preferred illuminances set on the first trial. Note, n = 10 for each condition.

Instance of rating	Median satisfaction rating	Mean satisfaction rating	Standard deviation	Minimum rating	Maximum rating
(i) First trial	3.0	3.23	0.42	3	4
(ii) Following LL adjustment	3.0	3.25	0.44	3	4
iii) Following HL adjustment	3.0	3.18	0.38	3	4
(iv) illuminance set by experimenter	4.0	3.70	0.52	3	5

Table 5. Descriptive data for satisfaction ratings provided at different times during the experiment, using 5-point scale. Note: n = 40 for all ratings.

This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at:
http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

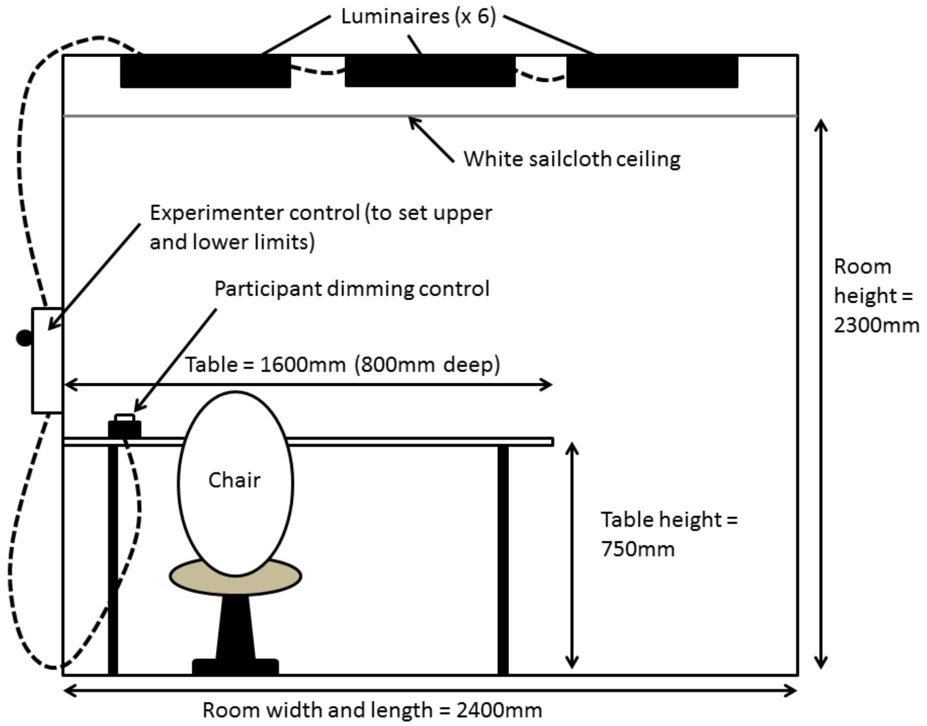

Figure 1. Section through test room.

This is an Author's Original Manuscript of an article whose final and definitive form, the Version of Record, has been published in Architectural Science Review, Vol. 56(4), 2013, pp. 306-314, available online at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.724380#.UtgMr9J_vPo

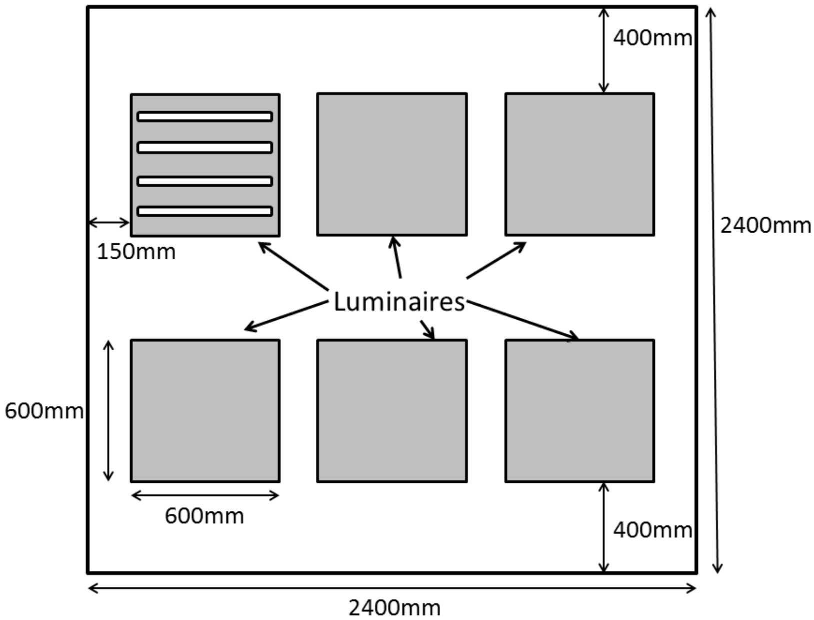

Figure 2. Plan of ceiling to show luminaire array. Each luminaire contains four fluorescent tubes: for this project only two were used and these were arranged symmetrically.

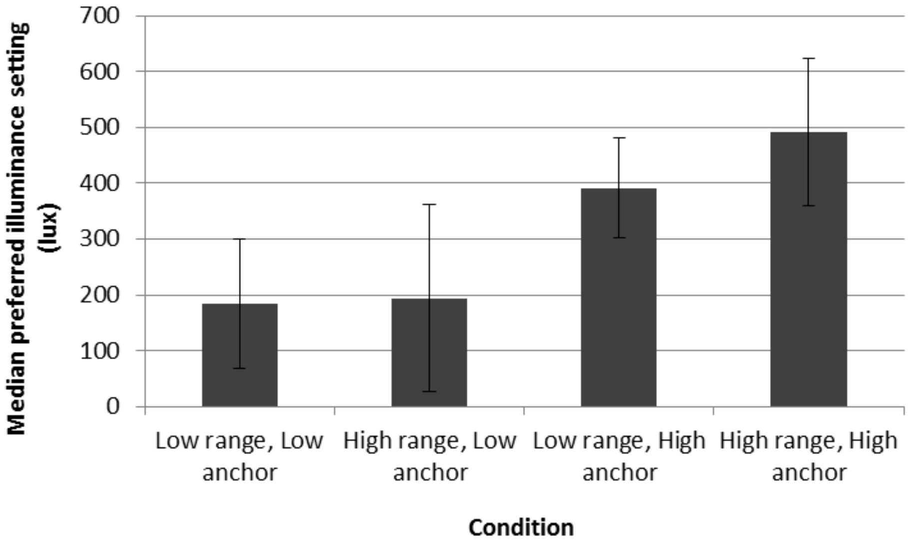

Figure 3. Median preferred illuminance for each combination of range and anchor. Error bars show standard deviation.

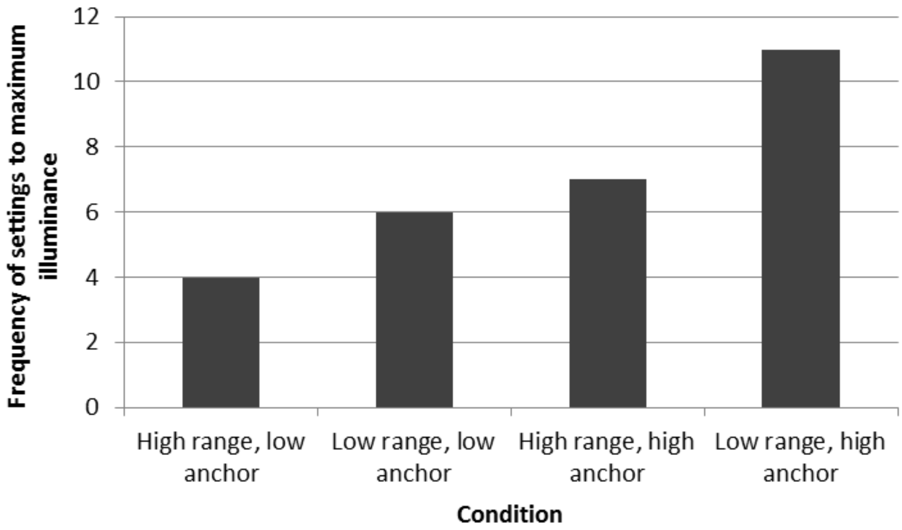

Figure 4. Frequency of trials during which illuminance was set to the maximum available. Of the 320 trials, the maximum setting was used on 28 trials (9%).

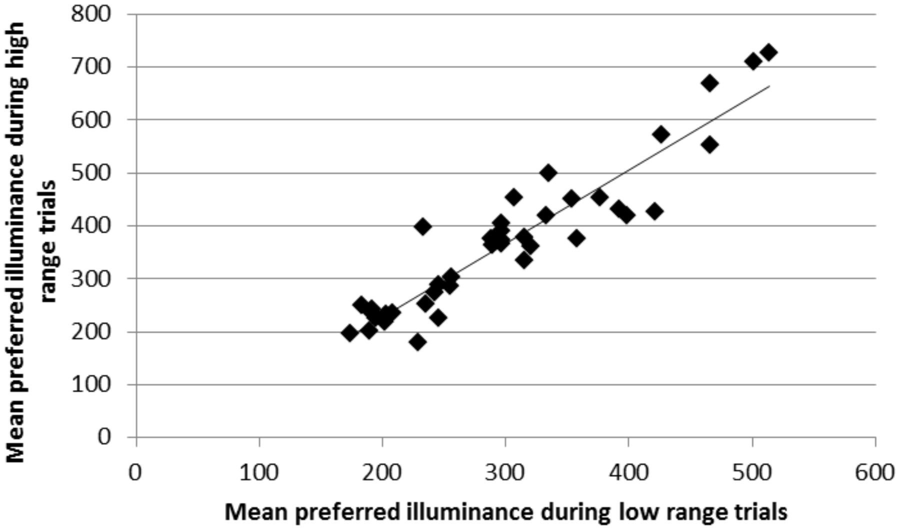

Figure 5. Correlation between mean illuminance settings with low and high stimulus ranges.

.