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General

Emotional responses of college students to filtered fluorescent lighting in a classroom (v3)

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Background

Classroom lighting, usually bright fluorescent light, can significantly influence the learning environment and emotions of students.

Objective

To assess the emotional impact of classroom lighting on students during an academic year.

Methods

This study used an ABAB withdrawal research design in the following manner: in phase A, the baseline condition, classroom lighting was provided by conventional overhead white fluorescent classroom lights; in phase B, the intervention condition, the conventional overhead white fluorescent classroom lights were covered with fabric filters (thin, translucent, creamy-colored plastic sheets) that were attached to the lighting fixture frame with magnetic discs. The filters produced softer light in the classroom than the fluorescent lights. Each phase lasted for at least 2 weeks. During each phase, students rated 18 pairs of words from the Mehrabian and Russell pleasure, arousal, and dominance semantic differential scale at least four times to assess the emotional impact of the lighting conditions.

Results

For all three emotional behaviors, the mean score of the filtered fluorescent light phase was significantly greater than the mean score of the baseline unfiltered fluorescent lighting phase, indicating more positive emotional responses. Students also noted they experienced fewer headaches and found it easier to see the whiteboard at the front of the classroom when the light filters were in place.

Conclusion

The light filters exerted a positive impact on the students' emotions. Students preferred the filtered lighting to fluorescent lighting. This study supports the installation of filters over fluorescent lights in a college classroom.

Different factors, including lighting, sound, smells, ventilation, humidity, and temperature, inside the classroom can significantly affect students' comfort, mood, and ability to concentrate on learning.[1] Therefore, students' visual comfort is an important aspect of the classroom environment.[2] Factors that need to be considered in visual comfort include the availability of natural daylight and the amount and steadiness of artificial lighting and glare.[3] Fluorescent lighting is widely used due to its low cost, but it has some disadvantages, such as emitting flickering light.[4] The color spectrum of fluorescent light is normally in the blue green region.[5] Since fluorescent lighting does not produce the full-spectrum light of natural daylight, it can potentially trigger headaches, especially when exposure is prolonged.[6]

In classrooms, light emitting diode (LED) light bulbs and fixtures, which mimic the light spectrum of natural

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daylight, have been shown to improve the learning environment, which leads to improvement in student engagement behaviors,[7] attention[8] and emotions (e.g., comfort and alertness).[9,10] However, LED lighting is more expensive than fluorescent lighting and may be beyond the budget of some schools especially in developing countries.[11]

Mimicking the effects of LED lighting by using light filters over fluorescent classroom lighting may be a low-cost alternative to more costly light products.[12] A light filter is a sheet of thin, translucent, heat-resistant acrylic or fabric that covers the fluorescent lighting fixture frame, where it can block glare and produce full-spectrum light.[12] Using light filters in the classrooms may improve students' focus, create a more productive learning environment, and decrease students' stress and frequency of their headaches[12]; there is no empirical evidence, however, to support this claim.

While studies have examined methods to optimize learning environments through improved classroom lighting,[13,14] there is a lack of information on how installing low-cost filters over fluorescent lights may affect students. More specifically, there has been no research on how fluorescent lights covered with a filter affect the students' emotional state in the classroom as measured by the pleasure, arousal, and dominance (PAD) model. Therefore, the purpose of this study is to evaluate the impact of installing filters over fluorescent ceiling lights in a university classroom on the emotions of a group of occupational therapy graduate students.

METHODS

STUDY DESIGN

This study used an ABAB withdrawal research design in the following manner: in phase A, the baseline condition, classroom lighting was provided by conventional overhead white fluorescent classroom lights; in phase B, the intervention condition, the conventional overhead white fluorescent classroom lights were covered with fabric filters (thin, translucent, creamy-colored plastic sheets) that were attached to the lighting fixture frames with magnetic discs.

ETHICAL APPROVAL

The Institutional Review Board of the University of Alabama at Birmingham (Birmingham, Alabama, USA) approved the study protocol (IRB-300003557).

SETTING

This study was conducted in a university classroom with a standard configuration. The classroom had no windows and was in the basement of a university building that was built in 2002. The size of this rectangular classroom was 8.5 m x 13.3 m = 113 m^2. There were 13 sets of fluorescent lighting fixture frames installed on the classroom ceiling. The luminous flux recorded at each of the classroom table under the fluorescent lighting varied from 52.9 to 120.6 lumens. The overall mean and standard deviation (SD) luminous flux of the classroom was 89.2 ± 18 lumens.

PARTICIPANTS

The participants were 58 first-year occupational therapy graduate students who had been newly admitted to the academic program in the 2019 fall semester. During semester, this student cohort spent most of the day (9 am to 5 pm) on Mondays and Tuesdays in this classroom to receive didactic instructions.

PROCEDURES

The study began on September 2, 2019, which was the first day this student cohort spent in the classroom. During the first day of the class, students were informed about the study and invited to participate. The study involved changing the regular classroom ceiling lighting by covering the conventional white fluorescent lights with thin, translucent, "whisper white" fabric sheets (i.e., light filters, https://www.amazon.com/gp/product/B001YT7DFQ/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&th=1) that were secured to the lighting fixture frames with magnetic discs. The light filters are designed to block glare and reduce the amount of flicker produced by fluorescent lights and to potentially transform fluorescent lighting to full-spectrum lighting that is similar to LED lights and natural lighting.[12]

Phase A was the baseline condition, in which the classroom ceiling lighting was conventional white fluorescent lighting, and phase B was the intervention condition, in which the conventional white fluorescent lighting was covered with fabric filters. The study began with the classroom lighting in the phase A_1 condition (no filters), alternated to phase B_1 (fabric filters placed over fluorescent lights), returned to phase A_2, and then alternated a final time to phase B_2. Each phase lasted 2 to 3 weeks. After the initial baseline phase (i.e., A_1) was completed, filters were installed and removed on Wednesdays and data was collected on the following Mondays and Tuesdays. With the installation of the fabric light filters, the overall mean and SD luminous flux of the classroom was 55.3 ± 14.2 lumens. The luminous flux recorded at each of the classroom table under the fluorescent lighting varied from 33.4 to 82.6 lumens.

DATA SOURCES AND MEASUREMENT

Students were asked to complete a survey on their emotions via SurveyMonkey twice a week during the study period. The students completed the surveys in the classroom on Mondays and Tuesdays during a class break that took place sometime between from 9 am to noon. In the survey, they were asked to rate 18 pairs of words, such as "happy" and "unhappy," from the Mehrabian and Russell PAD semantic differential scale,[15] which measures three basic dimensions of human emotional behavior: pleasure (P), arousal (A), and dominance (D). Each word pair is rated on a 7-point scale, e.g., 3 = happy, 0 = neutral, -3 = unhappy. Students completed the PAD scale 20 times between September 3, 2019, and November 19, 2019 (see Table 1 for the research design schedule). A reminder email with an URL link to the survey was sent to students 1 hour before the time designated

Table 1. Schedule of the ABAB research design

Day number	Phase	Date	Day	Number of students
1	Baseline 1	9/3/2019	Tue	57
2	Baseline 1	9/9/2019	Mon	55
3	Baseline 1	9/10/2019	Tue	44
4	Baseline 1	9/17/2019	Tue	51
5	Filtered Light 1	9/23/2019	Mon	46
6	Filtered Light 1	9/24/2019	Tue	33
7	Filtered Light 1	10/1/2019	Tue	43
8	Filtered Light 1	10/7/2019	Mon	26
9	Filtered Light 1	10/8/2019	Tue	19
10	Baseline 2	10/14/2019	Mon	29
11	Baseline 2	10/15/2019	Tue	49
12	Baseline 2	10/21/2019	Mon	16
13	Baseline 2	10/22/2019	Tue	25
14	Filtered Light 2	10/28/2019	Mon	23
15	Filtered Light 2	10/29/2019	Tue	55
16	Filtered Light 2	11/5/2019	Tue	23
17	Filtered Light 2	11/11/2019	Mon	29
18	Filtered Light 2	11/12/2019	Tue	24
19	Filtered Light 2	11/18/2019	Mon	32
20	Filtered Light 2	11/19/2019	Tue	48

for completing the PAD scale. Students completed the PAD scale using the same URL link each time. The online survey took an average of 75 seconds (median = 64 seconds) to complete each time. There were 727 responses across the four study phases (i.e., $A_1B_1A_2B_2$).

Individual interviews with students were conducted at the completion of the study to solicit their opinions about their experiences with the two lighting conditions in the classroom during the study period. An interview schedule, including pre-determined open-ended questions, was used to conduct the interviews. Key questions from the interview schedule are shown in Table 2. Forty-eight students completed individual interviews. The interviews lasted an average of 8.5 ± 4.2 min (range, 3–22 min) and were audio-recorded and transcribed verbatim for analysis. The total number of tests, quizzes, and academic course assignments in each phase was as follows: four each in A_1, B_1 and A_2 and six in B_2.

QUANTITATIVE DATA ANALYSIS

There are three sets of word pairs in the PAD scale with six pairs of words in each set. Each set of word pairs constitutes one of three emotional dimensions (pleasure, arousal, and dominance). Ratings from each set of the six pairs of words were averaged to form the score of each PAD dimension. There were 4 data points (data collection days) in the first baseline phase (fluorescent light, A_1), 5 data points in the first filtered light phase (B_1), 4 data points in the second baseline phase (A_2), and 7 data points in the second filtered light phase (B_2), for a total of 20 data collection time points (see Table 1). The number of students who completed the PAD scale at each time point varied from 19 to 57 across the 20 data collection days. To reduce the errors inherent in any imputation procedure and facilitate comparison between adjacent study phases, we averaged the students' scores of each PAD dimension across the data collection time points within each study phase, resulting in four summation data points ($A_1B_1A_2B_2$). In addition, to evaluate the impact of filtered light on students' emotions, we aggregated data of the PAD dimensions of the two baseline phases (A_1 and A_2) by taking the mean of the scores and performed the same calculation with the two filtered light phases (B_1 and B_2).

Descriptive statistics, such as means and standard deviations, were obtained for the PAD scores for each study phase and for the aggregated baseline and filtered light phases. Distributions of PAD scores were assessed for normality of distribution using box, stem-and-leaf, and normal probability plots separately for each dimension (pleasure, arousal, and dominance). Each of these PAD scores was determined to be normally distributed. Mixed models repeated measures analysis, assuming an unstructured covariance matrix, was used to compare the mean scores (separately for pleasure, arousal, and dominance) across the four study phases. The Tukey-Kramer multiple comparisons test was then used to determine which specific pairwise means were significantly different. The paired t-test was used to compare the mean PAD scores of the aggregated baseline and filtered light phases. Statistical tests were two-sided and performed using a significance level of 5%. Statistical analyses were conducted using SAS software (version 9.4; SAS Institute, Cary, NC).

Table 2. Guiding questions in the interview schedule

1. What do you like most about the classroom lighting with the light/optical filter installed?
2. What do you dislike most about the classroom lighting with the light/optical filter installed?
3. How does the classroom lighting with the light/optical filter installed affect your attention when listening to lectures?
4. How does the classroom lighting with the light/optical filter installed affect your attention when working on a small group project with other classmates in class?
5. How does the classroom lighting with the light/optical filter installed affect your attention when working on an individual project (i.e., assignment or test) in class?
6. How does the classroom lighting with the light/optical filter installed affect your mood in class?
7. How does the classroom lighting with the light/optical filter installed affect your academic performance in class?
8. How does the classroom lighting with the light/optical filter installed affect you as a whole?
9. What additional features would you like to see for the classroom lighting to better meet your learning needs?
10. What could be changed or improved about the classroom lighting?
11. Is there anything else you would like to add before we end this interview? or Do you have anything further to add?

QUALITATIVE DATA ANALYSIS

Transcripts were analyzed using content analysis to identify themes that described the students' experience with the filtered light. Two authors (ALW and JEK) independently read all transcripts multiple times to gain familiarity with the content. They recorded notes about key points (i.e., open coding) while reading each transcript, focusing on content, context, and language use. The two authors continued this process, comparing sections of text across all the interview transcripts. As analysis progressed, codes expressing related concepts were grouped to form themes that captured the shared experiences of the students. To reduce bias in the analysis and enhance credibility, the two authors reviewed each other's theme categorization and compared and contrasted their findings. When there were disagreements, the authors reviewed transcripts and then discussed and resolved the disagreements. To enhance the trustworthiness of interpretation of the transcripts, an independent arbiter (HKY) with substantial experience in qualitative research and familiarity with the study served as an auditor to verify the coding and subsequent interpretation across transcripts.

RESULTS

FINDINGS FROM QUANTITATIVE ANALYSIS

The mean and SD scores of each PAD dimensions in each phase and results for the comparisons between the PAD scores across the four study phases are presented in Table 3. The number of students who completed the survey in at least one data collection days within each study phase varied from 58 in A_1, the first baseline phase (baseline 1) to 50 in A_2, the second baseline phase (baseline 2).

There were statistically significant differences among the mean scores for each PAD dimension. For pleasure, the mean score for A_2 (baseline 2) was significantly less than the mean scores of each of the other three phases; there were no other significant differences. For arousal, the mean score of B_2 (filtered light 2) was significantly greater than the mean scores of A_2 (baseline 2); there were no other significant differences. For dominance, the mean score of B_1 (filtered light 1) was significantly greater than that of A_1 (baseline 1) and A_2 (baseline 2), and the mean rating of B_2 (filtered light 2) was significantly greater than that of A_1 (baseline 1) and A_2 (baseline 2); there were no other significant differences.

Results for the comparisons between the PAD scores for the aggregated baseline and filtered light phases are presented in Table 4. For all three emotional behaviors, the mean score of the filtered light phases was significantly greater than the mean score of the baseline phases (p-values < .01).

FINDINGS FROM QUALITATIVE ANALYSIS

Based on the qualitative analysis of the interview transcripts, students expressed that regular white fluorescent lights triggered headaches during their time in the classroom, whereas, when the filters were in place, they noted their headache frequency decreased. Students also said the filters allowed them to view the whiteboard at the front of the classroom more easily than they could in unfiltered light. A noticeable theme was that the light filters increased and sustained students' attention during class. As indicated by a student's response, "[the filtered lighting] made a huge positive difference" and "I think it put me in a state, which allow[ed] me to hear and engage with my group."

DISCUSSION

Within each emotional behavior dimension, students perceived having more pleasure, arousal, and dominance when

Table 3. Comparisons between PAD scores across four study phases

	Florescent Light 1 (A_1) (n = 58)	Filtered Light 1 (B_1) (n = 54)	Florescent Light 2 (A_2) (n = 50)	Filtered Light 2 (B_2) (n = 57)	p-value
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Pleasure	1.13 (0.87) [b]	1.16 (1.15) [b]	0.24 (1.23) [a]	1.35 (0.88) [b]	< 0.001
Arousal	0.20 (0.74) [a,b]	0.35 (0.92) [a,b]	-0.10 (1.04) [a]	0.44 (0.97) [b]	0.031
Dominance	0.25 (0.69) [a]	0.11 (0.91) [a]	0.58 (0.81) [b]	0.64 (0.88) [b]	<0.001

Note: Means with different superscripts are significantly different at $p < 0.05$.
Abbreviation: PAD, pleasure, arousal, and dominance

Table 4. Comparisons between PAD scores for aggregated florescent light and filtered light phases

	Florescent Light (Phase A)	Filtered Light (Phase B)	
	Mean (SD)	Mean (SD)	p-value
Pleasure	0.85 (0.80)	1.26 (0.81)	< 0.001
Arousal	0.11 (0.69)	0.41 (0.76)	0.006
Dominance	0.21 (0.65)	0.62 (0.68)	< 0.001

Abbreviation: PAD, pleasure, arousal, and dominance

filters were installed over fluorescent lighting in the classroom. Comparisons of PAD scores between two adjacent study phases indicated students experienced significant reductions in pleasure and dominance when the filters were removed in the A_2 phase, and a significant increase in positive responses on all three emotions between the second baseline (i.e., A_2, when the filters were removed) phase and the second intervention phase (i.e., B_2, when the filters were re-installed). It seems the second baseline (A_2) and second filtered light (B_2) phases reflected a better match of the students' emotions toward the fluorescent and filtered lighting. Of the three emotions, the light filters exerted the largest impact on the students' pleasure, followed by dominance and arousal. Overall, findings from the individual interviews were congruent with the students' responses on the change in emotional behaviors when the filtered light was in place. Findings from the interview revealed the reduction in pleasure observed in the baseline phases was due mainly to fluorescent lighting, which caused students to develop headaches and made it difficult for them to see the whiteboard at the front of the classroom, both of which can affect concentration.

Given that the filters dimmed the luminous flux of the classroom by 38%, it is unclear why students still rated their arousal significantly higher when the filter was in place. One possible explanation is the interrelationship between pleasure and arousal, in that an increase in pleasure may indirectly increase arousal.[16]

LIMITATIONS AND RECOMMENDATIONS

It is unclear whether the positive impact of the filtered light on students' emotions is due mainly to the dimmer lighting condition (e.g., a reduction in glare) or to the inclusion of a full spectrum of light, as the light filters dimmed the luminous flux by 38%. Future studies should compare the same luminous flux of filtered light with dimmer fluorescent light bulbs to control for the effect of illumination and glare on students' emotions. In addition, the current study design of this study did not involve randomization of students into two conditions (filtered light vs fluorescent light), therefore, personal or academic related factors could have affected the students' emotions during different phases of the study. Future investigations should include similar studies involving randomization to verify the effect of filtered light on students' emotions.

Moving forward, researchers should address not only the impact of filtered lights on students' emotions, but also on students' engagement and concentration in class, incidents of headache, intensity of perceived flickering and glare, and short- and long-term academic performance. This study employed creamy-colored light filters, but blue and green colored filters may provide calming effects,[17,18] and it is unclear whether filter colors have additional effects on students' emotions and learning. Future studies should compare the impact of different colored light filters over fluorescent lights on students' emotions and learning.

CONCLUSION

Overall, filtered lighting was shown to improve student participants' pleasure, arousal, and dominance, all of which play an important role in a student's ability to be attentive in class. The results of the study indicate that students preferred filtered lighting to conventional white fluorescent lighting in classroom environments. This study supports the modification of existing white fluorescent lights with low cost, easy-to-install fabric filters in college classrooms.

DISCLOSURES ABOUT POTENTIAL CONFLICT OF INTERESTS

None.

AUTHORS' CONTRIBUTIONS

- Substantial contributions to the conception or design of the work: HKY, ADC, GRJ
- Substantial contributions to the acquisition: HKY, ADC, GRJ
- Substantial contributions to the analysis or interpretation of data for the work: HKY, ACW, JEK, RAO
- Drafting the work or revising it critically for important intellectual content: HKY, ACW, JEK, RAO, ADC, GRJ
- Final approval of the version to be published: HKY, ACW, JEK, RAO, ADC, GRJ

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