
The Efficacy of Biofeedback-Integrated Ambient Lighting in Stress and Anxiety Reduction

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Published online: December 2024

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Abstract

Background: Stress and mental health issues are prevalent concerns in Pakistan, particularly among women. Traditional biofeedback methods require focused attention, which can be impractical in clinical settings. Ambient lighting provides a non-invasive and innovative approach to biofeedback, enhancing both aesthetic and therapeutic experiences. This study examines the integration of biofeedback with ambient lighting to aid in stress management and relaxation.

Methodology: Twelve participants (six females and six males, aged 25 to 35 years) from research-related university positions at Malir University of Science and Technology, were exposed to a biofeedback-driven lighting system during a timed arithmetic task. The participants completed the task under three conditions: (1) no biofeedback (control), (2) warm-toned lighting biofeedback, and (3) cool-toned lighting biofeedback. The system was connected to the Alive GMP8 biofeedback device, which monitored heart rate variability (HRV) to adjust lighting parameters in real time. Stress levels were measured using the Perceived Stress Scale (PSS), and anxiety levels were assessed using the State-Trait Anxiety Inventory (STAI). The experiment followed a within-subject design with counterbalancing to avoid carry-over effects. Paired t-tests were used to analyze changes in PSS and STAI scores, with a significance level set at $p < 0.01$.

Results: The biofeedback-driven lighting system demonstrated significant improvements in stress and anxiety measures. For the warm-toned lighting condition, the mean PSS score decreased from 29.3 (SD = 2.13) to 21.1 (SD = 2.81), and the STAI score decreased from 57.2 (SD = 3.10) to 45.0 (SD = 3.21), with mean differences of 8.2 and 12.2, respectively ($p < 0.01$). Under the cool-toned lighting condition, the mean PSS score decreased from 28.8 (SD = 2.17) to 20.8 (SD = 2.39), and the STAI score decreased from 56.3 (SD = 3.00) to 44.3 (SD = 3.04), with mean differences of 8.0 and 12.0, respectively ($p < 0.01$). Participants reported enhanced stress awareness, improved relaxation, and a preference for the biofeedback lighting conditions over the control condition.

Conclusion: The biofeedback-driven lighting approach shows promise as a tool for stress management and relaxation in Pakistani healthcare and research settings. Its non-invasive and user-friendly design provides a valuable addition to mental health support strategies. Further research with larger, more diverse samples is recommended to validate these findings.

Keywords: Biofeedback, Ambient Lighting, Stress Management, Anxiety Reduction, Perceived Stress Scale (PSS), State-Trait Anxiety Inventory (STAI), Heart Rate Variability (HRV)

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Introduction

Stress and anxiety are among the most pressing global health concerns, affecting individuals across diverse demographics¹. In Pakistan, the burden of mental health challenges is particularly pronounced, with women facing heightened vulnerabilities due to sociocultural expectations, economic instability, and limited access to mental health resources². These issues not only impact individual well-being but also impose significant social and economic costs. Consequently, the need for accessible, effective, and scalable stress management strategies has become increasingly urgent³.

Traditional biofeedback techniques, while proven to be effective, require considerable time and focused attention⁴. Such methods often demand specialized equipment and trained personnel, making them less feasible in resource-limited healthcare environments⁵. This gap necessitates innovative solutions that are both cost-effective and user-friendly. In this context, biofeedback-integrated ambient lighting has emerged as a promising alternative. Ambient lighting's ability to influence mood, stress, and physiological states through subtle environmental adjustments offers an appealing, non-invasive approach to enhancing mental well-being⁶.

Research suggests that heart rate variability (HRV), a reliable indicator of stress and relaxation states, can be effectively used as a biofeedback parameter⁷. By integrating HRV monitoring with ambient lighting systems, real-time adjustments to lighting parameters can create environments conducive to stress reduction⁸. Warm-toned lighting, often associated with comfort and relaxation, has been shown to lower perceived stress levels, while cool-toned lighting may provide a calming and focused atmosphere. These lighting conditions, when dynamically adjusted based on physiological feedback, have the potential to amplify relaxation responses without requiring active participation from the user⁹.

This study investigates the efficacy of biofeedback-driven ambient lighting systems in reducing stress and anxiety among university professionals. By leveraging a controlled experimental design, it aims to evaluate changes in perceived stress and anxiety levels under different lighting conditions. The findings of this research have the potential to inform the development of innovative, scalable interventions for mental health support, particularly in settings with limited access to traditional biofeedback resources. Furthermore, the integration of aesthetic and therapeutic elements in stress management strategies could enhance user engagement and adherence, paving the way for broader applications in healthcare and beyond.

Methodology

Participants

Twelve participants (six females and six males, aged 25 to 35 years) were recruited from research-related university positions at Malir University of Science and Technology. Inclusion criteria required participants to have no prior clinical diagnosis of stress-related disorders and no visual impairments.

Procedure

Participants performed a timed arithmetic task under three experimental conditions:

1. **Control:** No biofeedback or lighting modulation.
2. **Warm-Toned Lighting Biofeedback:** Ambient lighting adjusted in real-time based on HRV measurements to warmer tones.

3. **Cool-Toned Lighting Biofeedback:** Ambient lighting adjusted in real-time based on HRV measurements to cooler tones.

The Alive GMP8 biofeedback device recorded HRV, which informed the lighting adjustments. Stress and anxiety levels were assessed before and after each condition using the Perceived Stress Scale (PSS)¹⁰ and State-Trait Anxiety Inventory (STAI)¹¹, respectively. The experiment employed a within-subject design, with counterbalancing to mitigate potential carry-over effects.

Statistical Analysis

Paired t-tests were conducted using SPSS version 22.0, to compare pre- and post-condition PSS and STAI scores, with a significance threshold set at $p < 0.01$.

Results

The study examined the impact of biofeedback-driven ambient lighting on stress and anxiety levels, as measured by the Perceived Stress Scale (PSS) and the State-Trait Anxiety Inventory (STAI). The findings are summarized in Table 1 below.

Table 1: Changes in PSS and STAI Scores Across Conditions

Condition	Measure	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean Difference	p-value
Warm-Toned Lighting	PSS	29.3 (2.13)	21.1 (2.81)	8.2	<0.01
	STAI	57.2 (3.10)	45.0 (3.21)	12.2	<0.01
Cool-Toned Lighting	PSS	28.8 (2.17)	20.8 (2.39)	8.0	<0.01
	STAI	56.3 (3.00)	44.3 (3.04)	12.0	<0.01
Control (No Biofeedback)	PSS	29.0 (2.21)	28.7 (2.25)	0.3	N.S.
	STAI	57.0 (3.12)	56.8 (3.20)	0.2	N.S.

Participants reported greater relaxation, improved awareness of their stress levels, and a preference for the warm- and cool-toned biofeedback lighting conditions compared to the control condition. They noted that the dynamic adjustment of lighting enhanced the calming effects of the environment, contributing to a more engaging and therapeutic experience.

Discussion

The findings highlight the potential of biofeedback-integrated ambient lighting as a viable stress management tool. Both warm-toned and cool-toned lighting conditions demonstrated significant reductions in perceived stress and anxiety, as evidenced by PSS and STAI scores. These effects are likely attributable to the physiological and psychological impacts of real-time HRV-based feedback, which dynamically adjusts environmental factors to optimize relaxation^{12,13}.

Warm-toned lighting exhibited slightly greater efficacy in reducing stress and anxiety, consistent with prior research linking warmer hues to comfort and tranquility¹⁴. Cool-toned lighting, while also effective, may provide additional benefits in enhancing focus and mental clarity. This distinction underscores the importance of tailoring biofeedback-driven lighting interventions to specific therapeutic contexts¹⁵.

Participants' subjective feedback further supports the feasibility and acceptability of this approach. The integration of biofeedback with ambient lighting offers a passive, non-invasive means of fostering relaxation, making it particularly suitable for resource-limited or high-stress environments^{16,17}. Unlike traditional biofeedback methods that require active engagement, this system facilitates stress reduction without placing additional cognitive demands on users¹⁸.

Nevertheless, the study is not without limitations. The small, homogeneous sample restricts the generalizability of the findings. Additionally, the short duration of the intervention precludes assessment of long-term efficacy. Future research should address these limitations by incorporating larger, more diverse populations and extended study periods. Exploring variations in lighting intensity, color temperature, and task difficulty could further refine the application of biofeedback-driven ambient lighting¹⁹.

In conclusion, this study demonstrates the promise of biofeedback-integrated ambient lighting as an innovative tool for stress and anxiety management. Its non-invasive, user-friendly design provides a valuable addition to mental health strategies, particularly in settings with limited access to traditional biofeedback resources. Continued investigation into its mechanisms and applications is essential to unlocking its full potential.

Conclusion

This study demonstrates the efficacy of biofeedback-integrated ambient lighting in reducing stress and anxiety. The non-invasive, user-friendly nature of this approach makes it a promising addition to mental health strategies in Pakistani healthcare and research settings. Further investigations with larger samples and diverse contexts are warranted to expand its application.

References

1. Yu B, Hu J, Funk M, Feijs L. DeLight: biofeedback through ambient light for stress intervention and relaxation assistance. *Personal and Ubiquitous Computing*. 2018 Aug; 22:787-805.
2. Consolvo S, Roessler P, Shelton BE. The CareNet display: lessons learned from an in-home evaluation of an ambient display. In *International conference on ubiquitous computing 2004 Sep 7* (pp. 1-17). Berlin, Heidelberg: Springer Berlin Heidelberg.
3. Eggen B, Van Mensvoort K. Making sense of what is going on 'around': designing environmental awareness information displays. *Awareness systems: Advances in theory, methodology and design*. 2009:99-124.
4. Bakker S, van den Hoven E, Eggen B. Peripheral interaction: characteristics and considerations. *Personal and Ubiquitous Computing*. 2015 Jan;19(1):239-54.
5. Occhialini V, Van Essen H, Eggen B. Design and evaluation of an ambient display to support time management during meetings. In *Human-Computer Interaction—INTERACT 2011: 13th IFIP TC 13 International Conference, Lisbon, Portugal, September 5-9, 2011, Proceedings, Part II 13 2011* (pp. 263-280). Springer Berlin Heidelberg.
6. Al Osman H, Eid M, El Saddik A. U-biofeedback: a multimedia-based reference model for ubiquitous biofeedback systems. *Multimedia tools and applications*. 2014 Oct; 72:3143-68.
7. Reiner R. Integrating a portable biofeedback device into clinical practice for patients with anxiety disorders: Results of a pilot study. *Applied Psychophysiology and Biofeedback*. 2008 Mar;33(1):55-61.

8. Lande RG, Williams LB, Francis JL, Gragnani C, Morin ML. Efficacy of biofeedback for post-traumatic stress disorder. *Complementary therapies in medicine*. 2010 Dec 1;18(6):256-9.
9. Moraveji N, Olson B, Nguyen T, Saadat M, Khalighi Y, Pea R, Heer J. Peripheral paced respiration: influencing user physiology during information work. In *Proceedings of the 24th annual ACM symposium on User interface software and technology* 2011 Oct 16 (pp. 423-428).
10. Reis RS, Hino AA, Añez CR. Perceived stress scale. *J. health Psychol.* 2010;15(1):107-14.
11. Knowles KA, Olatunji BO. Specificity of trait anxiety in anxiety and depression: Meta-analysis of the State-Trait Anxiety Inventory. *Clinical psychology review*. 2020 Dec 1; 82:101928.
12. Vidyarthi J, Riecke BE, Gromala D. Sonic Cradle: designing for an immersive experience of meditation by connecting respiration to music. In *Proceedings of the designing interactive systems conference* 2012 Jun 11 (pp. 408-417).
13. Müller H, Kazakova A, Pielot M, Heuten W, Boll S. Ambient timer—unobtrusively reminding users of upcoming tasks with ambient light. In *Human-Computer Interaction—INTERACT 2013: 14th IFIP TC 13 International Conference, Cape Town, South Africa, September 2-6, 2013, Proceedings, Part I* 14 2013 (pp. 211-228). Springer Berlin Heidelberg.
14. Schnädelbach H, Irune A, Kirk D, Glover K, Brundell P. ExoBuilding: physiologically driven adaptive architecture. *ACM Transactions on Computer-Human Interaction (TOCHI)*. 2012 Dec 1;19(4):1-22.
15. Fortmann J, Stratmann TC, Boll S, Poppinga B, Heuten W. Make me move at work! An ambient light display to increase physical activity. In *2013 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops* 2013 May 5 (pp. 274-277). IEEE.
16. Jones BR, Benko H, Ofek E, Wilson AD. IllumiRoom: immersive experiences beyond the TV screen. *Communications of the ACM*. 2015 May 21;58(6):93-100.
17. Ståhl A, Jonsson M, Mercurio J, Karlsson A, Höök K, Banka Johnson EC. The soma mat and breathing light. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* 2016 May 7 (pp. 305-308).
18. Snyder J, Matthews M, Chien J, Chang PF, Sun E, Abdullah S, Gay G. Moodlight: Exploring personal and social implications of ambient display of biosensor data. In *Proceedings of the 18th ACM conference on computer supported cooperative work & social computing* 2015 Feb 28 (pp. 143-153).
19. McDuff DJ, Hernandez J, Gontarek S, Picard RW (2016) Cogcam: contact-free measurement of cognitive stress during computer tasks with a digital camera. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, ACM*, pp 4000–4004.