AIDOL: Augmenting Immersion with Dynamic Optical Lighting for Inducing Behavior Change in Live Concert Viewing

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Figure 1: AIDOL recognizes the accelerometer of the smartphone to dynamically change the intensity and timing of the light.

Abstract

This paper presents AIDOL (Augmenting Immersion with Dynamic Optical Lighting), a smartphone-based system that dynamically adjusts flashlight intensity based on device acceleration to enhance audience engagement during live concerts. We implemented three lighting modes—fast response (MODE A), slow response (MODE B), and binary threshold (MODE C), and conducted a user study with 18 participants. Results suggest that MODE B generated the highest acceleration intensity regardless of user preference. This result indicates that slower-responding lighting more effectively encourages active movement. Our findings indicate the potential of nudge-based dynamic optical feedback to transform concert viewing into a more physically engaging experience.

CCS Concepts

• **Human-centered computing** → **Ubiquitous and mobile computing**; • **Hardware** → Sensor applications and deployments.

Keywords

Live viewing, behavior change, smartphone, ubiquitous computing

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1 Introduction

Live music concerts have established themselves as a significant sector within the entertainment industry, generating substantial economic effects and contributing to the subjective well-being and happiness of audiences [9, 19]. A critical factor in the success of these events is "immersion", the degree to which an audience feels absorbed in the experience. Traditionally, immersion is achieved through high-quality audio, stage production, and collective audience participation [13, 17]. Beyond the psychological benefits, active participation in live concerts, often characterized by rhythmic movement and waving penlights, may offer physical health benefits [3, 14, 19]. By maintaining a physical engagement, concert viewing can serve as moderate exercise, contributing to health promotion through increased energy expenditure [16].

To enhance this sense of immersion, researchers have explored various technological interventions. Previous studies have utilized

synchronized lighting systems [18], haptic feedback devices [2], realtime music generation [11, 12], and virtual reality (VR) environments to augment the concert experience [7, 8]. While these technologies successfully enhance visual and auditory immersion, they often face a specific limitation: they tend to treat the audience as passive recipients rather than active contributors. For instance, centralized control of audience penlights, while visually cohesive, may reduce the individual's sense of agency and physical engagement. There remains a lack of systems for high immersion with the encouragement of active, voluntary physical movement.

To address the passivity observed in conventional augmentation methods, this research turns to the field of behavioral change and "Nudge" theory. A nudge is a subtle intervention that alters people's behavior predictably without forbidding any options or significantly changing their economic incentives [1, 15, 20]. In the context of a live concert, applying a nudge, such as dynamic optical feedback that rewards vigorous movement, could effectively motivate the audience to move more actively. By designing a system that links physical effort to visual rewards, we aim to enhance physical activity, thereby transforming the concert experience into a health-promoting activity.

In this paper, we propose AIDOL (Augmenting Immersion with Dynamic Optical Lighting), a system designed to induce behavior change and enhance immersion during live concert viewing. Figure 1 shows the concept vision of AIDOL. The core concept of AIDOL is to detect the user's smartphone's acceleration to dynamically adjust the intensity and timing of the device's light. By using the smartphone's built-in accelerometer and flashlight, the system creates a direct feedback loop in which the lighting extends the user's physical motion. This approach aims to provide a "Sense of control," ensuring that the light changes in sync with the user's movements, while also providing "Exercise motivation" to encourage users to shake their smartphones more actively. Through this mechanism, AIDOL seeks not only to heighten the entertainment value and enjoyment of the concert but also to serve as a tool for "Fatigue mitigation", ultimately promoting healthier behavior in entertainment settings. Our research questions are as follows:

- RQ1 How do different acceleration-to-light mappings affect users' movement?
- RQ2 What kind of lighting control mode is most effective in inducing active movement and enhancing immersion?
- RQ3 Does the preference for lighting control mode impact the overall acceleration intensity?

2 Related Work

Hödl et al. work on large-scale audience participation in live music using smartphones. In their system, each audience member's smartphone screen displays colors synchronized with the music, creating a collective visual experience [5]. Shirzadian et al. uses a GSR sensor to detect audience physical activity and visualize it on the screen, creating a collective visual experience. The technology was used in Jazz live and found that the visual layer could add value to the experience during a live concert, providing a higher level of immersion and a sense of togetherness among the audience [10]. Meng et al. use physiological data (BVP and EDA) to visualize the audience's physical activity and create a collective visual experience in VR. The technology was used in a classical music live and found that physiological data-based reproduction of musical performances in VR can enhance the audience's affective states [6]. Fushimi et al. implements atmoSphere, which provides users with immersive music experiences using spatial audio and haptic feedback. The technology was used at a live concert and found to enhance audience engagement and immersion [4].

Compared to these works, AIDOL is the first to use a smartphone's acceleration to dynamically adjust the intensity and timing of the light, enhancing audience engagement and momentum.

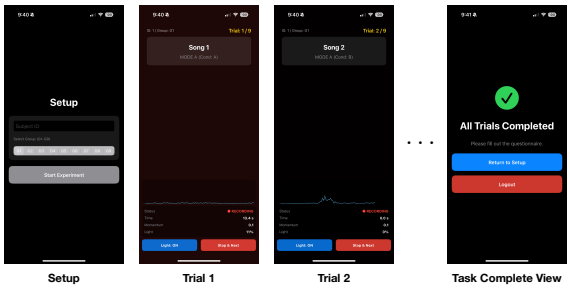


Figure 2: User interface view of the smartphone. User first select their group according to the experiment conductors instructions. Once participants complete nine setting different trials, they are instructed to complete the post-survey.

3 Methodology

3.1 AIDOL Application

Figure 2 shows the user interface view of the AIDOL application installed on the smartphone. The application has two main features: **(1) Group Selection**: Participants can select their group according to the experiment conductor's instructions. According to the selected group, the smartphone will emit light differently depending on its acceleration. **(2) Trials**: Participants participate in nine different trials. Nine different combinations consist of the combination of three lighting modes (MODE A, MODE B, and MODE C) and three music pieces (Music 1, Music 2, and Music 3). Each trial is a two-minute exercise session. Once participants complete nine different settings, they are instructed to complete the post-survey. In each trial, the smartphone's acceleration is stored in the Firebase Realtime Database. The acceleration data is collected at a 20Hz sampling rate. The database will have *user_id*, *group_id*, *mode_id* as the key, and *acceleration*. The *user_id* is a unique participant identifier. The *group_id* is a unique identifier for a group. The *mode_id* is a unique light mode identifier. The *acceleration* is the acceleration of the smartphone in the x, y, and z axes. The database is hosted on the Firebase platform. The application accesses the database using the Firebase SDK. The acceleration is collected and stored to Firebase at a sampling rate of 20Hz. The application is developed using Xcode and Swift and is therefore mainly available on iOS devices.

3.2 Mode Description

The penlight application implements three distinct lighting modes (MODE A, B, and C) that control the flashlight brightness based

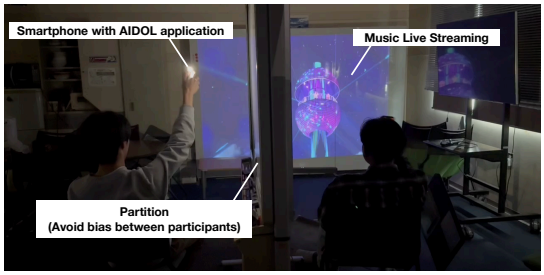


Figure 3: Experiment setup. Participants were asked to hold the smartphone in their hand and perform the exercise according to the experiment conductors' instructions.

on device acceleration. Each mode employs a different response characteristic to translate acceleration data into light intensity.

3.2.1 Acceleration Normalization. For all modes, the raw acceleration magnitude a is first normalized and processed:

$$a_{\text{norm}} = \min\left(\frac{a}{1.5}, 1.0\right) \tag{1}$$

$$I_{\text{target}} = (a_{\text{norm}})^{0.5} \tag{2}$$

where a_{norm} is the normalized acceleration value and I_{target} is the target intensity used for brightness calculation.

3.2.2 MODE A: Fast Response Mode. MODE A implements a fast-responding lighting control with high sensitivity to acceleration changes. The brightness $B(t)$ at time t is updated using an exponential smoothing filter:

$$B(t) = B(t-1) + \alpha \cdot \left(I_{\text{target}}(t) - B(t-1)\right) \tag{3}$$

where $B(t-1)$ is the previous brightness value, $I_{\text{target}}(t)$ is the current target intensity, and $\alpha = 0.7$ is the smoothing coefficient. The high smoothing coefficient ensures rapid adaptation to acceleration changes, resulting in smooth and responsive light transitions.

3.2.3 MODE B: Slow Response Mode. MODE B implements a slow-responding lighting control with low sensitivity to acceleration changes. It uses the same exponential smoothing formula as MODE A, but with a significantly smaller smoothing coefficient $\alpha = 0.002$. The minimal smoothing coefficient creates a gradual, delayed response to acceleration changes, producing slow and smooth light transitions that lag behind the actual motion.

3.2.4 MODE C: Binary Threshold Mode. MODE C implements a binary (on/off) lighting control based on a threshold. Unlike MODE A and B, which provide continuous brightness values, MODE C operates in a discrete manner:

$$B(t) = \begin{cases} 1.0 & \text{if } a > 0.5 \\ 0.0 & \text{otherwise} \end{cases} \tag{4}$$

where a is the raw acceleration magnitude. When the acceleration exceeds the threshold value of 0.5, the flashlight is set to maximum brightness ($B = 1.0$); otherwise, it is turned off ($B = 0.0$). This mode provides immediate, binary responses without intermediate brightness levels.

3.3 User Survey

3.3.1 Pre-Survey. We ask participants to fill in personal information and their experience with the live concert. For personal information, we asked participants to fill in their name, email address, age, gender, and occupation. For the live concert experience, we asked participants to report their frequency and experience with using the penlight during the concert. All of this information was provided to allow participants to opt out at any time upon request.

3.3.2 Post-Survey. We ask participants to provide feedback on the AIDOL application and the live concert. Following the experiment, a post-survey was conducted to evaluate the participants' subjective experience with the application. The questionnaire consisted of items assessing system performance and psychological effects. To evaluate system interaction, we asked about specific metrics. Participants were asked to rate the questions on a 1 to 10 Likert scale. Questions 1 to 6 were the questions asked for each light mode. **Q1:** I felt the light changed as intended, in sync with my movements. **Q2:** The light reacted instantly to my movements without delay. **Q3:** The rhythm of the music and the movement of the light were well-matched. **Q4:** Did using this app make you want to shake your penlight more actively? **Q5:** I felt less fatigue and exhaustion when moving my body than I usually do. **Q6:** Operating and experiencing this under these conditions was purely enjoyable. **Q7:** I think it is helpful to use such an application in a live concert setting. **Q8:** I preferred the mode that emitted light that changed with the music's rhythm. **Q9:** Please fill in your overall opinion about the AIDOL application and the live concert.

4 Data Collection

4.1 Participants

In this experiment, we recruited 18 participants (15 males and 3 females) who expressed interest. The reason for selecting 18 participants is to account for the order effect of the nine experimental combinations, conduct two trials for each pattern, and confirm reproducibility. Participants were recruited from the university, primarily from within the authors' research laboratory. All participants were university students in Japan. The DFKI Ethics Committee has approved the experimental setting.

4.2 Experiment Setup and Procedure

Figure 3 shows the experiment setup. The study has been conducted by recruiting two participants simultaneously. We asked each participant to sit in the chair located in front of the projector. To avoid bias from the other participant's movements, we placed the partition between the two participants. Each participant holds a smartphone with the AIDOL application installed. We used a smartphone with a motion sensor to measure its acceleration. Depending on the selected group, the smartphone will emit light differently in response to its acceleration.

For the procedure, we first ask participants to agree to the study's terms and conditions. Once confirmed, we asked participants to complete a pre-survey, including questions about their demographics and experience with the live concert. Participants then select their group according to the experiment conductor's instructions. In

each trial, the conductor asks the participant to click "start data collection", and then begins playing music. Participants then perform the exercise according to the experiment conductor's instructions. This process is repeated for nine different conditions/trials. Once the exercise is completed, the experiment conductor will ask participants to click stop data collection. Participants then complete the post-survey, including questions about their subjective experience with the AIDOL application and the live concert.

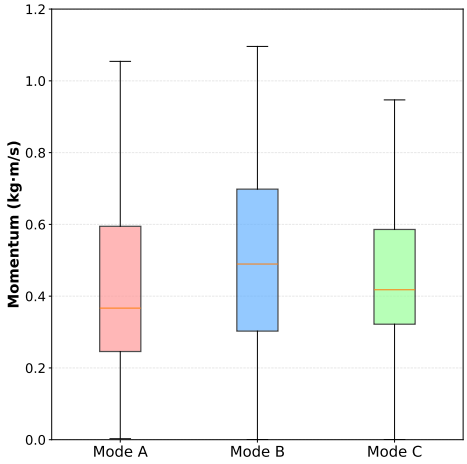
5 Result and Discussion

Figure 4 shows the comparison of the momentum against the general light mode and participants' preference. We found that the momentum (acceleration intensity) was generally higher with *MODE B*, regardless of participants' preferences. In the post-survey, we found that four preferred *MODE A*, two for *MODE B*, and 12 participants preferred *MODE C*. For groups preferring *MODE C*, they still have a momentum highest with *MODE B* condition. This result indicates that user preferences do not directly apply to the activities/momentum participants perform. Hence, against the research question we set, for RQ1, dynamic optical lighting based on a smartphone can alter users' movement. For RQ2, *MODE B* tended to elicit the highest movement in this exploratory study, which requires users to exert greater effort because the lights respond slowly to acceleration. Lastly, for RQ3, the preference for lighting control mode does not affect overall acceleration intensity or movements. This result indicates that participants' immersion does not always correlate with the amount of physical activities they perform.

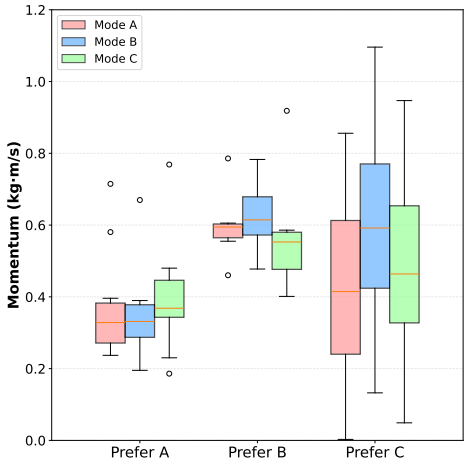
6 Limitation and Future Work

This experiment was conducted in a controlled laboratory setting with simulated live streaming, which may not fully replicate the social atmosphere and emotional dynamics of an actual concert venue. Also, each trial was only two minutes long, making it difficult to assess fatigue effects or sustained engagement over a full concert duration. In this experiment, we attempted to measure "momentum", but it is possible that what was actually measured was the acceleration intensity recognized by the smartphone sensor rather than true physical activity.

To overcome these limitations, future work should include field studies conducted at actual live concert venues with more diverse participant populations, capturing the genuine social atmosphere and audience dynamics. It will also be important to introduce more precise methods for evaluating physical activity, such as estimating calorie expenditure or using wearable devices, to better understand the relationship between lighting control and actual exertion. Long-term, longitudinal experiments are recommended to assess whether the nudging effect of MODE B is sustained over time or wanes as users become accustomed to the interaction style. Furthermore, implementing collective audience experiences—for example, enabling the AIDOL system to synchronize lighting effects across multiple devices among a crowd—may enhance participants' sense of immersion and social connectedness. Exploring personalized lighting modes that automatically adapt to each individual's movement patterns could help align user preferences with physical engagement, ultimately increasing both enjoyment and health benefits.



(a) Comparison of lighting modes vs. momentum.



(b) Comparison of preference vs. momentum.

Figure 4: The comparison of the different participants' momentum of each light modes and preference of the modes.

7 Conclusion

This paper presented AIDOL, a system that uses smartphone acceleration to control flashlight intensity to enhance concert engagement. Our exploratory study suggests that MODE B (slow response) elicited the highest physical activity, regardless of user preference, suggesting a disconnect between subjective preferences and physical engagement. Findings suggest that nudge-based lighting systems requiring greater effort may promote active movement in entertainment settings. Future work should explore long-term effects and integration with collective audience experiences.

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