PosProjector: An Ambient Projection Notification System for Posture Correction During Desk-Based Study

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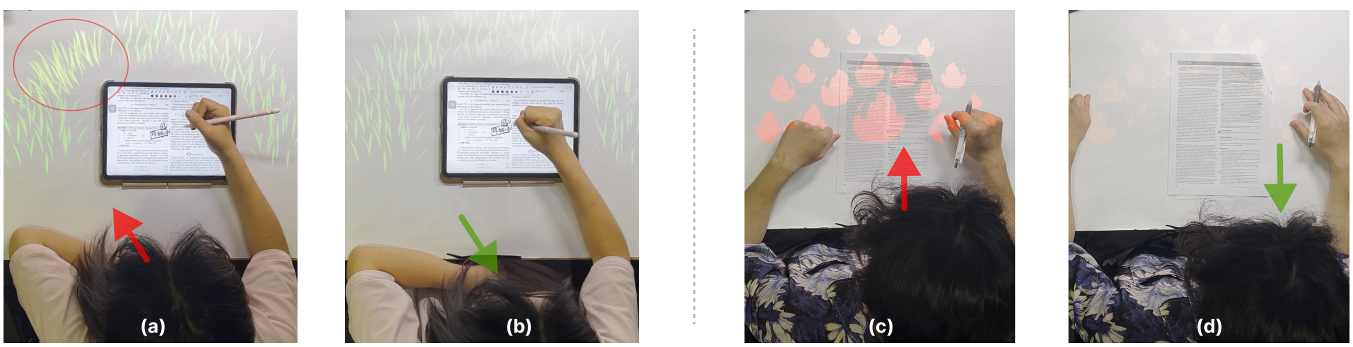

Figure 1: PosProjector presents slow and less intrusive visual notifications on the desk for posture correction through the projector. The system supports multiple notification strategies and various desk-based learning media, including tablets and paper. Drawing on ambient display design and visual-field theory, the system aims to create a notification system that integrates naturally into users' learning environment and nudges users' behavior change. For the grass design, it will wither in the direction the user's head bends down (a)(b). For the flame design, the flame will intrude into the user's central vision gradually when the user's posture goes wrong (c), after the user corrects the posture, the flame will recede (d).

Abstract

Poor posture during desk-based learning activities can lead to many health issues, such as spinal problems, musculoskeletal discomfort, and myopia. While traditional posture correction systems use immediate feedback to notify users of their wrong posture, they often disrupt users' concentration. This study explores an ambient projection notification system for non-intrusive posture correction notifications during desk-based learning scenarios. Through a notification elicitation study and an expert co-design workshop, we investigated users' perception towards basic elements of projection notification and derived a design space for desk-based projection notification. We then implemented and evaluated PosProjector, an ambient projection notification system, by applying two notification strategies that embody the most representative dimensions of the design space. Results showed that PosProjector can improve users' posture with little task interference and support various media, including paper and tablets. We further discussed the implications of how to design the least intrusive projection notification system for posture correction.

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CCS Concepts

• **Human-centered computing** → *HCI design and evaluation methods.*

Keywords

Ambient Design, Posture Correction, Augmented Reality, Projector Camera System

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1 Introduction

Sitting posture is important for students' health during desk-based study. Good posture has many positive effects, while improper posture can cause many negative effects on students' health and study efficiency, including affecting the morphological development of the spine [40] and causing musculoskeletal discomfort [14] and myopia [51, 57]. Traditional methods for posture correction use instant feedback for posture correction, such as light, beeper, or vibrator alerts [1, 70]. However, traditional forms of notification are known to cause distraction from users' current tasks and may interrupt their learning processes.

Unobtrusive methods have emerged in the HCI field as a way to minimize the disruption brought to users. One approach is to guide user posture changes through minor modifications to the user's work medium, such as using monitors with slow robots to guide posture correction through small arm adjustments [58] and making subtle changes to tablet content for unobtrusive correction [65]. However, these correction feedback methods are closely bound to the devices that users are using, making them relatively rigid and difficult to transfer to broader desk-based activities, such as paper-based learning. Another approach is to non-intrusively prompt users about incorrect posture through environmental changes, which is widely known as ambient design. Recent studies have explored ambient displays for posture feedback, such as a cloud-and-moon display that glows for correct posture and flashes red for risky postures [39], anthropomorphic wall projections [68], and monitor-based virtual turtles that bend to indicate errors [36]. However, most of these ambient systems are designed for work scenarios, where the display plane is typically parallel to the monitor plane and perpendicular to the desk. As a result, they cannot be directly applied to desk-based reading and writing scenarios, where activities primarily take place on the horizontal surface of the desk.

To this end, projectors emerge as a feedback display method that can present notifications through flexible visual stimulus change. Using projection as notification has two advantages. First, it can get rid of device restrictions and is capable of presenting notifications across multiple desk-based activities to support a wider range of use scenarios. Second, the flexibility of projection content allows for multi-dimensional content design, supporting interaction strategies that leverage different visual fields (e.g., central, peripheral) and accommodate diverse notification formats (such as text, graphics, and animations). While projection-based notification shows promise for unobtrusive posture correction, there is limited understanding of how users perceive projection notifications in desk-based learning environments and how to design effective notification systems that balance noticeability with minimal disruption.

To explore how users perceive projection notification and how to design the projection notification system, we raised the following research questions (RQs):

RQ1: How do users perceive basic notification design dimensions, such as position and type?

RQ2: How to design a projection-based posture notification system? What aspects should be considered during projection notification design?

RQ3: How effective are different projection notification strategies in improving posture during different learning media?

To answer these RQs, we conducted a mixed-method three-stage study including a notification elicitation study, an expert co-design workshop, and an evaluation study under real learning activities as shown in Figure 2. The three-stage study helped us gain deep insights into how to design a projection notification system for users. Our key contributions were as follows:

(1) Empirical understanding of projection notification perception: We conducted an empirical study to examine how participants perceive basic dimensions of projection notifications (e.g., light change types and notification position) during reading tasks. We measured participants' reaction times to the notifications and collected their subjective attitudes.

(2) Comprehensive design space for projection-based posture notification systems: Through the expert co-design workshop, we developed a five-dimensional design space for designing a projection notification system for posture improvement purposes. We also collected experts' refinement feedback on the probe for prototype iteration.

(3) Projection notification system for posture correction and evaluation: We designed and implemented PosProjector, which contained two projection notification strategies (Grass and Flame) that used representative design dimensions from the design space. The findings showed the system's effectiveness in reducing posture violation duration across both paper and tablet learning activities while causing little interference to participants' primary tasks.

2 Related Work

2.1 Posture Correction System

Posture has long been recognized as a critical factor influencing physical well-being, and recent research highlights a growing prevalence of postural issues among students and desk-bound individuals [13, 34, 41]. Studies in health and ergonomics show that different forms of suboptimal posture are linked to specific health consequences. For example, sedentary behavior is associated with chronic low back pain [5], and forward head posture is related to neck pain [27, 72], etc. To mitigate these risks, prior work has proposed several evidence-informed strategies, such as frequently varying lumbar posture [52], and adopting upright lordotic spinal postures and neutral lumbar postures [37]. Building on these theoretical foundations, HCI researchers have developed posture correction systems to help people regulate their reading or writing postures. These systems adopted different kinds of posture recognition techniques, such as pressure sensors [21, 24], motion sensors in smart garments [6], and vision-based methods that use camera [3, 20]. For the feedback

Figure 2: This figure demonstrates three parts of our study and their connections. Study 1 was the Notification Elicitation Study that investigated participants' perceptions and initial parameter sets for the basic notification types. The result of Study 1 then inspired the probe design of Study 2 - Expert Co-Design Workshop, in which we explored the design space of projection notification for posture correction purposes. In Study 3, we designed and implemented PosProjector, which contains two kinds of notification strategies based on the design space and probe feedback of Study 2, and evaluated it under the learning scenario.

methods, researchers used flash light, beeper, or vibrator [70], LED light and speaker [1] and vibrotactile haptic feedback [71] to remind people's wrong posture. However, many prior systems adopt a notification mechanism that delivers alerts as soon as a wrong posture is detected [1, 6, 70]. To minimize the interruption of notifications, recent research has developed systems that can change users' posture in an unobtrusive manner through actively adjusting users' display media and chairs. For example, several researchers have used motorized computer monitors to guide users' posture change actively [58, 69, 73]. Wang et al. developed a system that uses slow visual stimuli on tablets to unobtrusively amplify the improper posture of children and induce self-correction during handwriting [65]. However, systems that are bound to specific interaction media, such as monitors or tablets, are less directly applicable to tasks like paper-based learning that do not rely on digital displays. Active chairs offer another approach to unobtrusively influence posture through subtle tilt of the seating surface [24]. Although they can accommodate a wider range of activities, such chairs are often bulky and difficult to move. Using projection, our system provides a desk-surface notification mechanism that can flexibly support diverse desk-facing activities while remaining easy to set up.

2.2 Ambient Information System

An ambient information system presents information within the environment in a subtle, non-distracting manner. Weiser used "calm technology" to describe the systems with subtle environmental cues, allowing users to monitor non-critical information while focusing on primary tasks [66]. Pousman characterized them as systems that display important but non-critical information, update content through subtle, non-disruptive changes, and maintain aesthetic appeal appropriate to their surroundings [54]. An ambient system is suitable for providing real-time posture feedback because it can reduce the distraction brought to users and enhance users' posture awareness through metaphor. Current research has used different ambient displays like Flower-Shaped Ambient Avatar [29], an ambient display located on the side of the computer screen that can show weather [39] and anthropomorphic objects' projection on the wall [68] to promote users' reflection on their sitting posture. However, these ambient systems' use scenarios are under working space where the presence of ambient information is vertical with the desk, which means their configurations cannot be directly applied to desk-reading and writing scenarios where users' vision field is on the desk. In addition, prior ambient systems always relied on fixed display positions—such as LED-based cues [60] and decorative ornaments [22, 29]—which limited the design space and restricted dynamic or spatially varied feedback. In our system, we take a first step in exploring how the a dynamic display position can support a richer design space by leveraging different vision fields and enabling dynamic, flexible notification strategies on the desk.

2.3 Central and Peripheral Vision

Central and peripheral vision both play an important role in human visual processing. The central vision is located in the very center of our gaze with an eccentricity of 2.5°, and peripheral vision is outside of the central vision [26, 33, 48]. Paracentral is the ring-shaped region between the central and near-peripheral areas. While there is not a universal visual angle definition of this area [61], many researchers in HCI define paracenter eccentricity between 2.5° and 4°, and the near-peripheral vision is located between eccentricities of 4° and 15°. [33, 38]. Central and peripheral vision have different functional characteristics in many aspects. Central vision is characterized by spatial resolution and color vision with high acuity, while peripheral vision is very sensitive to movement and less to detail and color compared to central vision [16]. Gutwin et al. compared different visual popout effects at different visual areas and found that motion popout maintains accuracy even at low intensities and wide angles from the display center, while other visual variables like shape and color decrease rapidly as the angle from the center increases [26]. Thus, the spatial presence of a notification within the visual field is a critical factor to consider when designing projection notifications. Many researchers have used the peripheral vision field to present information for the purpose of minimizing notifications' interruption to the main tasks, such as employing subtle visual cues in wearable or head-mounted displays and exploring different visual feature combinations for peripheral presentation [15, 16, 44]. While most research has focused on peripheral vision for less intrusive notifications, central vision also holds potential for subtle cues when carefully adjusted in terms of prominence and delivery strategy. However, few studies have examined this possibility. Therefore, our study also incorporates central vision into the design space to explore the full spectrum of subtle notification design.

3 Study1: Notification Elicitation Study

We first conducted a notification elicitation study to investigate participants' perception of basic notification patterns (RQ1). Study 1 had two primary objectives: 1) Investigate participants' perception and preferences towards basic notification dimensions. 2) Collect the parameter set of users' reaction time and notification transition time for controlling the notification presence speed in the following study. The findings from Study 1 were then used to inspire the design of the interactive probe for Study 2 - expert co-design workshop.

3.1 System Design

Based on previous literature, we summarized and defined two fundamental dimensions that structure the primary design space of projection-based notifications, which are **light change types** and **notification position**. Additional details on how the design space was initially defined are provided in the Appendix A.1. For the implementation, the projection light was controlled using an application developed by Unity engine version 2021.3.23f1c1. Based on two design dimensions from the design space, there were four notification conditions (2 notification positions × 2 light change types) as shown in Figure 3:

Condition PC: Peripheral + Color change
Condition CC: Central + Color change
Condition PL: Peripheral + Luminance change
Condition CL: Central + Luminance change

Transition time from the initial state (state 0) to the fully presented notification state (state 1) was used to indicate the changing speed of notification. Longer transition times indicated slower rates of change. For each condition, we established four different transition times, which required a total time of 20, 40, 60, and 80 seconds to change from the initial state 0 to the final state 1.

The experiment was conducted in an indoor environment isolated from external light sources. We mounted a projector on a tripod and calibrated its projection position according to our previously calculated center visual field parameters. A desk lamp provided the primary illumination for the working area, ensuring the average desktop illumination exceeded the recommended minimum of 500 lux for healthy reading and writing activities.

3.2 Experiment Procedure and Participants

We assigned participants an English reading task with multiple-choice questions printed on A4 paper as their primary task and instructed them to press the reaction button when they noticed a notification appearing. The four notification conditions (PC, CC, PL, and CL) were presented using a Latin Square counterbalancing

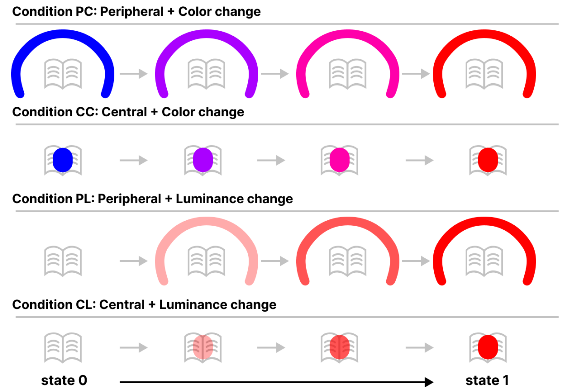

Figure 3: Demonstration of four experiment conditions. State 0 is no notification, while state 1 is the fully displayed notification. Notification transition time is defined by the time it takes to change from state 0 to state 1. To enhance the visual representation, in conditions PL and CL, transparency is utilized in place of the HSV' V(value) component in the figure to depict the brightness changing patterns of the projected content on the desktop surface.

scheme. Within each condition, the notification with four transition times (20, 40, 60, and 80 seconds) appeared in random order. After each condition, participants completed a subjective questionnaire that included the NASA-TLX scale, three notification-specific questions, and a preference rating for each condition along with the reasons they liked or disliked it. We clarified to the participants that the NASA-TLX ratings should be interpreted in relation to the perceived workload imposed by identifying the notifications instead of the reading task. 20 participants (10 male, 10 female, age: M = 21.8 years, SD = 4.38) who were capable of studying for a prolonged time were recruited from a local university campus forum. Participants who were nearsighted wore their glasses or contact lenses.

Across all three studies, all participants were compensated according to local standards and all participants were right-handed and reported no color vision deficiencies or color blindness.

3.3 Data Collection and Analysis

For effect analysis, reaction time was analyzed using a series of repeated-measured ANOVAs. In cases where the normality assumption was violated (Shapiro-Wilk test $p < 0.05$), we applied an Aligned Rank Transform (ART) before performing our analysis [67]. Paired t-tests with Bonferroni correction were performed for pairwise comparisons. To examine the relationship between transition time and reaction time across different notification conditions, we employed a series of simple linear regression analyses. For each notification condition (PC, CC, PL, and CL), we conducted separate Ordinary Least Squares (OLS) regression analyses, where reaction time was regressed on transition time. Questionnaire ratings, including TLX (NASA Task Load Index) and three notification-related questions, were analyzed using Friedman tests and Wilcoxon signed-rank tests for post-hoc analysis when needed.

3.4 Results

3.4.1 Reaction Time. The reaction time of every condition under each notification transition time was shown in Figure 4 (a). An RM-ANOVA test revealed a significant effect of condition on reaction time at 20s, 40s, and 60s, while marginally significant at 80s. In general, CL condition was the most noticeable, while PC was the least noticeable notification. There was also a significant interaction effect between notification transition time and condition ($F_{9,171} = 6.87$, $p < 0.001$), which indicated that the reaction time patterns under different notification conditions varied with changes in transition speed. Through the ordinary least squares (OLS) regression in Figure 4(b), we discovered color change had a steeper coefficients slope than luminance change in peripheral (PC: [0.0148, 0.0236] vs. PL: [0.0128, 0.0179]), while they had overlapping confidence intervals (CC: [0.0158, 0.0207] vs. CL: [0.0154, 0.0207]) in central vision. This indicated that color change notification had higher temporal sensitivity than luminance change in the peripheral area, while they had similar sensitivity in the center. This phenomenon could be interpreted as the center visual field possesses superior discriminative precision for color changes than peripheral vision. Because the cone cells responsible for color discrimination in the human eye are mainly concentrated in the central macular region [56].

The reaction times observed across four conditions provided preliminary parameter sets for controlling light color and luminance variations at different notification positions in desk-projection systems. Moreover, the results revealed perceptual differences in how users respond to different notification patterns, which expanded the understanding of basic visual cues in notification design.

3.4.2 Perspective on Different Notification Conditions.

Notification Perception and Preference: Among all conditions (Figure 5), participants reported higher confidence for recognizing notifications in central vision than peripheral vision, with CC more confident than PC ($p = 0.017$), CL more confident than PL ($p = 0.002$). For noticeability, participants also regarded central vision as more noticeable than peripheral vision, with CC more noticeable than PC ($p = 0.001$), CL more noticeable than PL ($p = 0.012$). CC was the most distracting one among all conditions and was also the least preferred condition in the preference rating. Though CC was the second effective notification strategy according to the reaction time results and scored high in the confidence and noticeability questions, participants reported why they disliked this condition. This was mainly because always having projection light in the center of vision highly distracted users' learning activities. 15 out of 20 participants mentioned that the persistent light distracted their reading activities a lot and made them uncomfortable when viewing the reading materials. Based on the generally negative feedback from users, Center Color change condition was excluded in the following probe design.

Perception of Effort: After each notification condition, participants completed a NASA-TLX effort questionnaire. The result of the questionnaire was shown in Figure 6. Wilcoxon signed-rank tests showed that color changes required more mental demand to identify compared with Luminance changes, both in central vision ($p = 0.040$) and Peripheral vision ($p = 0.021$). Furthermore, color change required more temporal demand($p = 0.010$) and more effort ($p = 0.011$) than Luminance change in peripheral vision, which indicated that the differences between color and luminance were more distinct in peripheral vision. CC caused significantly more frustration than the other three conditions, which was also a reason for its exclusion in the probe design.

4 Study2: Experts Co-design Workshop

The notification elicitation study deepened our understanding of participants' perception of basic notification design dimensions. However, a more comprehensive and creative low-intrusive projection notification design space that integrated aesthetics and innovative interaction methods remained underexplored. To this end, a probe-based expert co-design workshop was conducted to answer RQ2: How to design a projection-based posture notification system? What aspects should be considered during the projection notification design?

4.1 Method

We used a probe-based expert co-design workshop because technology probes can serve as tangible artifacts that enable hands-on exploration and concrete discussions of abstract design concepts [4, 30]. Moreover, we adopted the expert workshop rather than normal users because experts' professional backgrounds enable them to provide a more comprehensive and professional assessment, which are leveraged in co-design processes where specialized domain knowledge is required of the prototype [49, 63, 64]. Such expertise can help generate more innovative design concepts and identify underexplored design dimensions within the projection notification system framework. We conducted an individual design workshop because we wanted to leave longer and more flexible time for experts to experience the probe.

4.2 Probe Design

4.2.1 Interaction Design. We designed the posture correction probe based on three conditions that had a higher preference rating and lower distraction in Study 1 (Figure 5), which were PC, PL, and CL. We also excluded condition CC because it caused the highest level of frustration, as shown in Figure 6 and elicited generally negative qualitative feedback from participants, as reported in Section 3.4.2. For the interaction design, when the system detected participants' wrong posture, it would gradually display a notification after a five-second grace time, aligning with previous posture correction systems [58, 65]. After users changed their posture to the correct position, the system reset the notification to state 0 immediately. For the posture correctness detection, we predefined a safe range based on the users' original posture. Users' correct posture was calibrated before each experiment as an upright sitting position comfortable for studying. A safe range with head left-right tilt less than 10 degrees and head-desk distance larger than -0.025 (relative coordinate defined in our study) was defined in the study, aligning with the setting in [65]. When the user's posture exceeded the safe range, the system classified it as an incorrect posture.

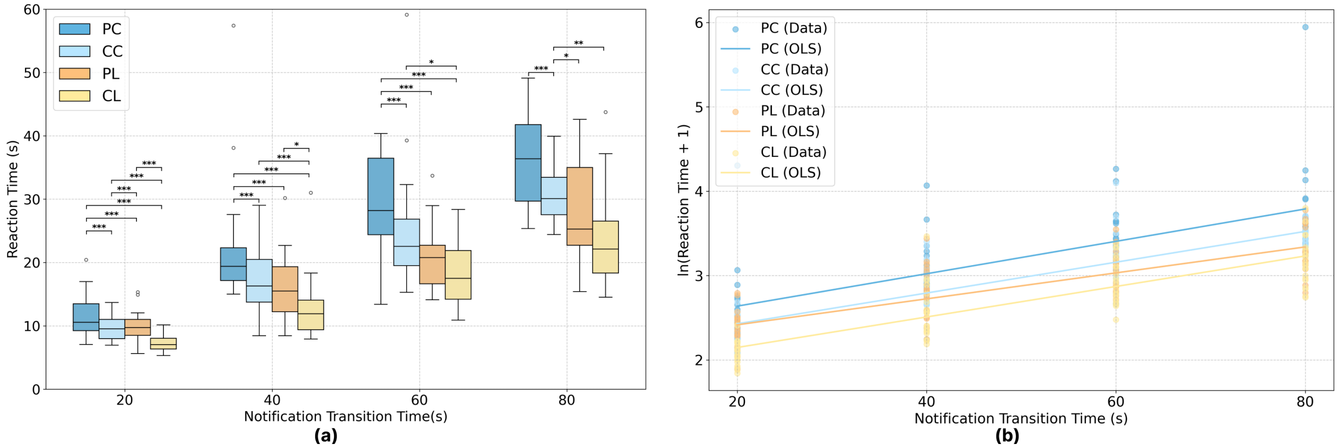

Figure 4: (a). The reaction time of four conditions at four notification transition times. Statistical significance is denoted with * for $p < 0.05$, ** for $p < 0.01$, and * for $p < 0.001$. The reaction time indicated that the CL condition was the most noticeable, while PC was the least noticeable notification. (b).Linear Regression of Reaction Time on Transition Time by Condition. The steeper slope of PC than PL indicated that color change notification had higher temporal sensitivity than luminance change in the peripheral area, while they had similar sensitivity in the center.**

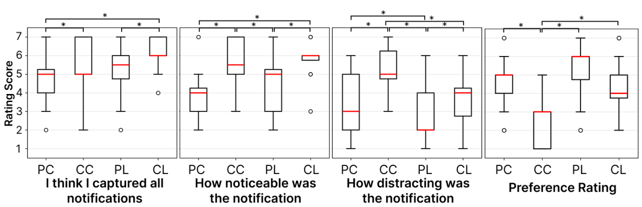

Figure 5: Notification ratings towards four notification conditions (a scale from 1 (low) to 7 (high)). Statistical significance is denoted with * for $p < 0.05$. In general, notifications in central vision were more noticeable than periphery. Among all conditions, CC caused the most distraction and the least preference rating, so it was excluded from Study 2's probe design.

We further encoded users' head tilt direction in five directions (left, left forward, forward, right forward, right) as Figure 7 displayed, because it could better remind people of their wrong posture deviation direction. State 0 was the default state with a healthy posture, while State 1 was the fully displayed notification. For the notification transition time (the duration required to move from state 0 to state 1), we derived the values for each condition from the regression curves in Figure 4 (b) by taking the x-value on the regression curve at which the predicted reaction time on the y-axis equals 20 seconds, since a reaction time of around 20 seconds is considered unobtrusive in previous literature [57, 58]. This yielded transition times of approximately 40 s for Probe PC, 50 s for Probe PL, and 70 s for Probe CL.

4.2.2 Implementation. For the implementation of the system, we used the same configuration of the projection and the lamp as Study 1. For the posture recognition, we added a camera (Xbox kinect v2) placed 1 meter in front of the participant. The detailed configuration was provided in Appendix A.4. The body landmark was detected through Google Mediapipe machine learning algorithm [1]. We used landmarks of the eyes for the calculation of head right tilt and left tilt, and nose height for the calculation of the head-desk distance. Safe range was defined through the absolute value of angle [-10,10] for head left tilt and right tilt. Head forward tilt was indicated by the head-desk distance through the normalised coordinate system output by the posture detection model, and the safe offset range for the head-desk distance was less than 0.025. When participants' posture exceeded the safe range for more than 5 seconds, the system would gradually present the notifications. After the participant returned to the correct position, the notification would become state 0 immediately.

4.3 Experiment Procedure and Participants

The co-design workshop consisted of three parts: 1) introduction of the research background and probe experience session, 2) probe feedback interview, and 3) brainstorming session. For the introduction part, we first introduced the project foundation and design process of our design probes. We then introduced the concept of different vision fields and ambient design. During the probe experience, participants were instructed to intentionally stay in an improper posture to trigger and observe each intervention several times until they fully understood how each intervention worked. After completing the probe experience, we conducted a semi-structured interview to collect the probe feedback on the probe's usability and improvement. After the interview, we introduced the design space that we summarized in Study 1 and encouraged them to think divergently towards more design solutions that could balance noticeability and distraction. 10 experts (4 female, 6 male) were recruited through personal networks and snowball sampling in the

[1]https://ai.google.dev/edge/mediapipe/solutions/vision/pose_landmarker

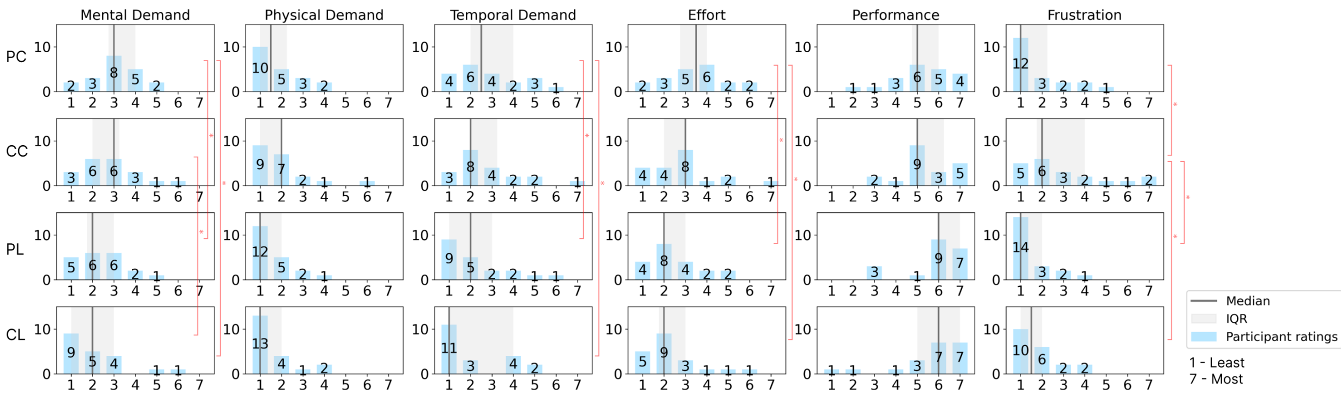

Figure 6: NASA-TLX Questionnaire results towards different notification conditions. Statistical significance is denoted with * for $p < 0.05$. Color change required more mental demand to identify than luminance change in both center and peripheral vision. Color change also caused more temporal demand and required more effort to identify in peripheral vision. The CC condition caused the most frustration, which is the reason for being excluded from Study 2's probe design.

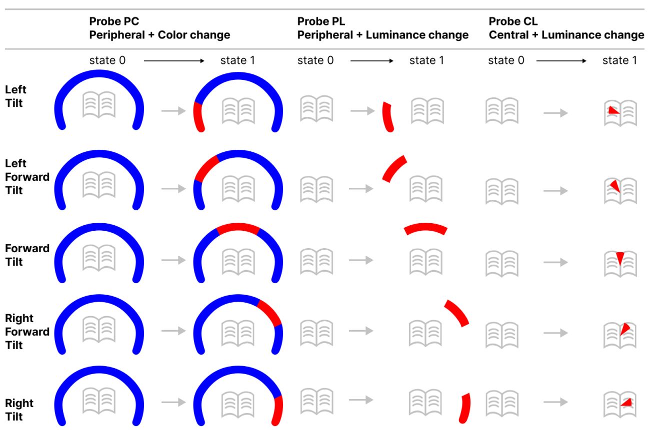

Figure 7: Probe design demonstration. State 0 is the notification state in healthy posture, while State 1 is the fully displayed notification. PC, PL and CL conditions were adopted in the interactive probe and CC was excluded.

workshop. All participants were experienced researchers or designers with established expertise in human-computer interaction or interaction design. Participants' information was detailed in the Appendix A.2.

4.4 Data Collection and Analysis

We first transcribed the audio into a script using an automatic speech recognition system - Feishu. For the design draft analysis, we transferred participants' design drafts from paper to electronic format and linked participants' interpretation scripts with their draft accordingly to help researchers better understand their designs. Then, two researchers analyzed the draft and summarized the design characteristics of the draft through the thematic analysis method [7, 8, 50]. They collaboratively discussed and refined the coding results to identify overarching themes and subthemes that structured our findings. The themes were finally developed into different design dimensions under the design space and probe iteration feedback.

4.5 Results

4.5.1 Design Space for Projection Notification System. To summarize participants' design ideas in the co-design workshop, we created a design space that extracted different themes from the design drafts to structure the design ideation process (Figure 8). The design space served as a preliminary framework for designing projection notifications by systematically outlining its key design dimensions and potential alternatives. It could enable researchers to map out various notifications designed for posture correction purposes and examine how these factors may influence user experience in the future. Next, we'll introduce the design dimensions one by one.

1. Mapping Strategy. Mapping Strategy constitutes the high-level strategic approach that guides design solutions, indicating how the system translates detected posture parameters into user-perceivable feedback mechanisms. **Guidance Notification** represents a direct, instructional approach that employs clear and unambiguous visual cues, such as arrows, patterns with directional cues, or textual instructions, to provide specific guidance for posture adjustment. **Create Interference** strategy utilizes visual interferences to draw on human attention and encourage users to maintain correct posture to minimize disruptions to the primary tasks. The **Consequences of Force** strategy employs a creative approach that integrates postural data with concepts of physical force to generate intuitive interactions. Examples include compressing abstract rings to show deformation, flattening nearby plants, or producing cracks on the desktop surface, each metaphorically illustrating the notifications triggered by posture change. **Trends in Metaphor** employs gradual real-time changes in metaphorical elements to represent posture quality, which maps good posture to positive developments and poor posture to deterioration. Lastly, **Avatar Mapping** uses anthropomorphic digital representations that mirror the user's posture in real time, establishing a direct visual correlation between physical state and virtual embodiment.

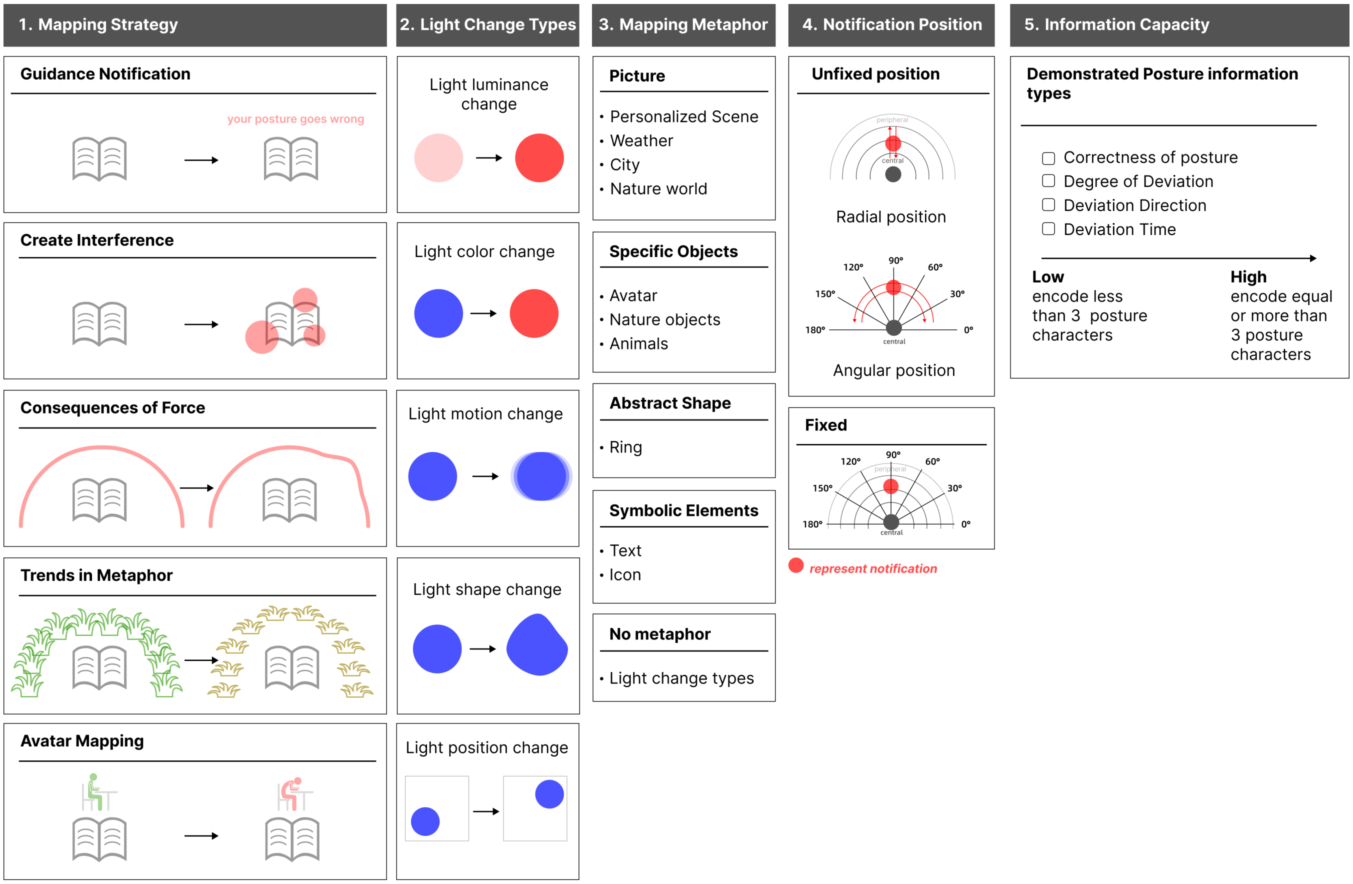

Figure 8: Design space derived from expert co-design workshop. It contains five design dimensions, which can also be comprehended as the theme extracted from the experts' design drafts. 1. Mapping Strategy constitutes the high-level strategic approach that guides the interaction design. 2. Light Change Types are the most fundamental manipulation parameters available for information transmission within the projection's visual elements. 3. Mapping Metaphor describes how posture data is transformed into cognitively accessible visual representations. 4. Notification Position defines how feedback is spatially projected within the user's environment, and is typically described using a polar coordinate system. 5. Information Capacity refers to the quantity of discrete information sources the system can convey.

2. Light Change Types. Light Change Types summarize the most fundamental manipulation parameters available for information transmission within the projection's visual elements. **Luminance change** encodes posture states through light intensity, while **color change** encodes posture states through hue variations. **Motion change** indicates posture state through dynamic visual effects. **Shape change** includes diverse transformations such as scaling, geometric shifts, organic deformations, and aspect ratio adjustments. Finally, **position change** manipulates the spatial coordinates of projected light within the desk environment. In most drafts, position change is described using polar coordinate systems because radial distance from the visual center strongly influences salience and effectiveness of the notification on the desk.

3. Mapping Metaphor. The design dimension of Mapping Metaphor establishes the conceptual framework of how abstract posture data is transformed into cognitively accessible visual representations, with choices ranging from complex, concrete imagery to highly abstract or even non-metaphorical forms, as shown in Figure 8. Different metaphor examples were shown in Figure 9. E8 used the weather change of the peripheral scene to present notification in a vivid way (Figure 9 (a)),*"The city background is dynamic—clouds move and the environment changes. When my reading posture is correct, I see blue skies; when incorrect, the sky gradually turns gray and dark and even starts to rain."* E10 further suggested that the picture could support users' personalized construction to enhance their protection awareness of the self-created scene (Figure 9 (b)), *"People care about their creations, so users can design virtual environments through blocks, plants, etc. Poor posture causes water to flood the environment and crush plants."* E2 used specific objects like the growth of grass to indicate posture (Figure 9 (c)), *"Imagine grass around you—wherever your head tilts, the grass in that direction withers. Normal grass is green and upright, but grass where your head leans turns brown and shrinks."* **Abstract Shape** provide symbolic representations through geometric transformations, such as circles

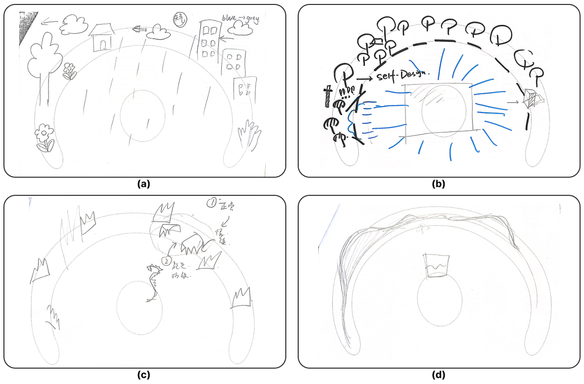

Figure 9: Drafts of expert co-design workshops that indicated different design strategies and metaphors. (a) used weather change, (b) used self-designed surroundings, (c) used plants, and (d) used an abstract ring to indicate posture state.

distorting in the direction of deviation, as P7 proposed in Figure 9 (d), *"I imagine something like dough—if you're leaning on it, wherever your posture tilts, that side would bulge out, like being squeezed and deformed."*

4. Notification Position. The Notification Position dimension defines how feedback is spatially projected within the user's environment, and is typically described using a polar coordinate system. When the position is **unfixed**, notifications appear at varying radial or angular coordinates to convey different urgency or directional information. When the position is **fixed**, notifications consistently appear at predetermined locations, providing stable reference points that reduce the effort required to locate notifications.

5. Information Capacity. Information Capacity refers to the quantity of discrete information sources a projection-based feedback system can convey, aligning with the concept of information capacity in ambient information systems [54]. In the design workshop, participants usually used four kinds of posture characters as information sources, which were the correctness of posture, degree of deviation, deviation direction, and deviation time.

4.5.2 Probe Feedback.

Optimizing Notification Position for Easier Identification. During the workshop and evaluations, participants noted that peripheral notifications near the desk surface drew less attention than those positioned in front of the primary visual field. *E1 mentioned "When my posture deviates, right side notifications become positioned in my blind spot, necessitating head rotation for detection" E4 further suggested "Forward leaning maintains primary visual field detection, but leftward or rightward leaning creates blind spots. Notifications should be consistently positioned either all in front or all behind to avoid mixed detection zones."* Feedback suggested that peripheral notifications should avoid being too near to desk edges to prevent blind spots. In Study 3, we therefore shifted the peripheral area slightly inward, keeping it within the anterior boundary of the macular visual field.

Smooth Recovery and Error-Tolerant Posture Assessment Mechanism. Current probe notifications' instant transition from incorrect state to correct state posed challenges for maintaining smooth and reliable feedback. Experts raised improvement directions from two aspects: First, the recovery should not occur too abruptly, *"Currently, as soon as I return to normal, the system triggers the normal state and the feedback disappears immediately. The transition feels too abrupt."* Thus, we set a gradual notification recovery that lasted 5 seconds in Study 3's evaluation prototype. (E8) Second, there should be an error-tolerant mechanism for the posture assessment. Several experts reflected that sometimes unconscious rapid posture shifts were misclassified as the right posture and caused the system to start recovery, even though they remained in an incorrect posture and were unaware of their mistake. To address this issue, we added a delay of holding correct posture for 2 seconds before recovery initiation to support an error-tolerant posture classification.

Minimizing Projection Salience During Healthy Posture States. Expert feedback revealed concerns about maintaining appropriate feedback visibility during periods of correct posture in the Probe PC condition. Some experts said although in peripheral vision, too bright colors would also cause distraction. *"If I'm just reading and there's a blue ring around me, I find it somewhat distracting. The blue light itself is obtrusive and can interfere with my primary activities"* (E7). E10 also reported, *"Since the projection is very bright, I might unconsciously notice its illumination while reading, potentially affecting my central visual reading experience."* This feedback suggested that when using peripheral light change for notification, the luminance under the correct position should be modified to a dim state to avoid distraction. So in Study 3, we dimmed the system's light luminance when the user's posture was correct.

5 Study3: Evaluation Study

Through the expert co-design workshop in Study 2, we explored a comprehensive design space in which we could map out various design strategies for a low-intrusive projection notification system. We then implemented PosProjector, a projection notification system that adopted two notification strategies (Grass and Flame), which utilized several key dimensions in the design space for non-intrusive posture correction. Through the evaluation study using PosProjector, we sought to explore RQ3: How effective are different projection notification strategies in improving posture during different learning media?

5.1 PosProjector System Design

5.1.1 Interaction Design.

Grass. The Grass prototype implemented the design strategies of **Trends in Metaphors** and **Consequences of Force** in design space. As illustrated in Figure 10, this design used unfixed angular positioning to encode the direction of posture violations. For example, when users adopted an incorrect forward posture, the grass in front of users began to wither, creating a direct spatial correspondence between posture deviation and visual feedback. Other directional violations triggered corresponding regional changes in their respective spatial locations. Despite the notification position

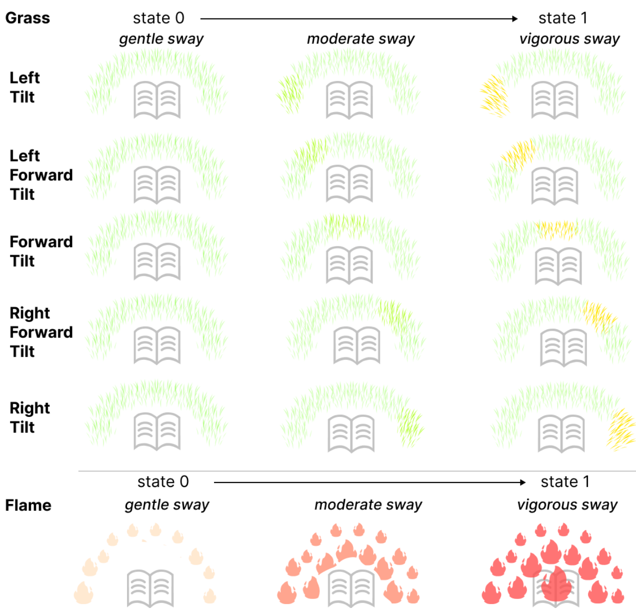

Figure 10: Visual design transitions for Grass and Flame prototypes showing progressive changes from healthy state (state 0) to violation state (state 1). The Grass prototype displays directional withering corresponding to posture deviations, while the Flame prototype shows radial propagation with increasing intensity.

change, the color transitioned from healthy green to warning yellow, while luminance gradually increased to enhance visibility. The motion dynamics shifted from natural, gentle swaying to vigorous movement to capture user attention. Additionally, the shape deformation caused upright grass to bend downward, mimicking the effect of stress on natural vegetation.

Flame. The Flame prototype employed a **Create Interference** strategy, where posture violations triggered flame intrusion from the peripheral to central vision area (Figure 10). The flame utilized unfixed radial positioning to create increasingly salient notifications that drew users' focus toward correcting their posture. Despite the position change, flame color progressed from orange to deep red, while motion characteristics amplified flame sway from gentle to vigorous movements. Luminance increased to enhance visibility, and the shape expanded to show more prominent fire effects that demanded immediate attention.

Interaction Flow. Both prototypes utilized identical posture thresholds as the probe in the co-design workshop. The system monitored head tilt within ±10 degrees for left and right directions, and maintained head-desk distance coordinates above -0.025 to indicate healthy posture. Based on the refinement feedback from Study 2, we implemented a strategic 2-second delay in health state before recovery initiation, as shown in Figure 11, to prevent misclassification of swift posture adjustments. The notification system required 5 seconds to gradually return to the healthy state once the correct posture was detected. The gradual recovery process provided users with clear and smooth feedback about their posture correction progress.

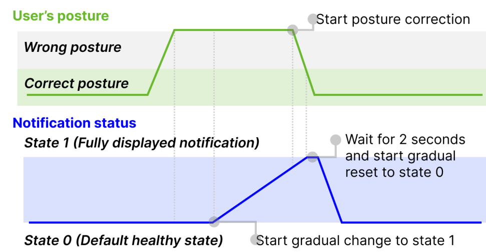

Figure 11: Interaction design for the posture evaluation system. The diagram illustrates the relationship between user posture states and notification status over time. When users transitioned from correct to wrong posture, the system gradually escalated to State 1 (fully displayed notification). Upon detecting posture correction, the system waited 2 seconds before initiating a gradual 5-second recovery to State 0 (default healthy state), preventing false classifications and providing stable feedback.

5.1.2 Implementation. For the implementation, the prototype employed the same approach as the probe used in the co-design workshop, with detailed configuration in the Appendix A.4. The software was developed using Unity engine version 2021.3.23f1c1. Participant's posture was detected using an Xbox Kinect v2 camera, with landmark detection performed through Google MediaPipe's machine learning algorithm. For the system's feedback mechanism, we utilized Unity's Shader Graph to implement the visual effects to achieve consistent and gradual changes in the visual elements. We parameterized the visual transformations and mapped the visual effect states to the posture correctness state valued 0-1. The final output was projected using a projector (XGIMI Z6X). The resulting visual effects of the projection were illustrated in Figure 1.

5.2 Method

5.2.1 Conditions. To explore different devices and design strategies' effects on users' posture, we conducted a two-factor within-subject experiment, with 3 intervention conditions (baseline with no intervention, grass, flame) X 2 learning media (paper, tablet), with 16 students. For the effectiveness measurements, we used violation duration time aligned with previous research [18, 58]. For comparison between different design strategies, we used the Relative Posture Quality Index (RPI) as a individual-specific metric corresponding to the ratio between two violation durations, similar to [65]. RPI could eliminate the impact of participants' different initial posture baselines and accurately reflect participants' posture improvement rates. It was calculated as the individual's intervention violation duration/baseline violation duration.

5.2.2 Tasks. We chose reading and writing as our primary tasks and employed two common desk-based learning media: paper and a tablet, to examine our system's usage across different contexts. The primary learning task was studying through participants' own learning material, which was set to the designated media before the experiment. To minimize the different contents' effect on participants' learning state, we asked them to use similar learning material on paper and tablet. Each learning session lasted 20 minutes.

5.3 Experiment Procedure and Participants

Before the experiments started, we collected participants' learning materials and helped them prepare the materials on different media. The procedure of the experiments was shown in Figure 12. To minimize the fatigue effects, we asked participants to come and learn for one condition with two media each day. Before the experiment began, we asked participants to sit upright and comfortably so as to maintain a neutral posture, which is recommended as a healthy sitting posture in ergonomics [37, 47]. We then calibrated each participant's eye height to 40 cm above the desk by adjusting the chair, following the approximate average seated eye height reported in anthropometric literature [53]. This posture was subsequently recorded as the participant's standard head–desk distance in the system and normalized to a coordinate value of 0. When the normalized coordinate dropped below −0.025, the system classified the posture as "too close" to the desk. Participants were informed that there might be visual changes in the projection to indicate their posture state, but they were not given specific details about the design or purpose of these visual cues. This approach was intended to keep participants aware of the visual interventions for posture correction without explicitly revealing what the interventions were or how they worked. After that, participants started their learning tasks for the following three days. To minimize participants' physical state changes during the day, we let each participant come to learn at approximately the same time each day. We always put a baseline on the first day to avoid the possible learning effects after participants experienced the intervention condition. Participants completed a notification questionnaire after each condition and had a semi-structured interview after each intervention, which could help us understand their learning experience using different devices and conditions. On the last day of the study, we interviewed them about their opinions comparing the two interventions. The order of experiencing media and interventions was counterbalanced using a Latin Square.

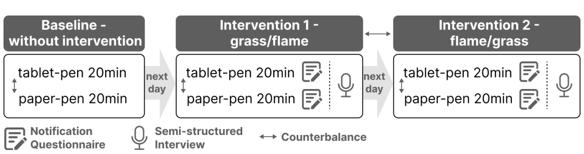

Figure 12: The procedure of study 3. Each participant experienced six sessions of learning on three days, with two sessions on each day.

For the participant recruitment, we recruited from the same school online community in the same way as Study 1. 16 participants were recruited (11 female, 5 male), M = 23.81, SD = 3.73. A survey (details are provided in the Appendix A.3) conducted before the experiment revealed that although participants lacked awareness of maintaining proper posture, they demonstrated strong motivation to improve it, indicating a clear need for an unobtrusive posture correction system.

5.4 Data Collection and Analysis

During the evaluation study, we collected participants' posture data, including head tilt degree and head-desk distance. When participants' posture was out of the predefined threshold, it would be recognized as a violation posture. The state of the system's notification, ranging from state 0 - state 1, was also collected to indicate the notification state. State 0 represented no notification, while state 1 meant a fully presented notification. Participants' subjective feedback, including questionnaires and interviews, was collected to reflect the participants' perception and attitude towards the system.

For the correction effectiveness analysis, the violation duration of participants' posture data was analyzed using a series of repeated-measure ANOVAs. In cases where the normality assumption was violated (Shapiro-Wilk test $p < 0.05$), we applied an Aligned Rank Transform (ART) before performing our analysis [67]. Paired t-tests with Bonferroni correction were performed for pairwise comparisons. Questionnaire ratings were analyzed using Friedman tests and Wilcoxon signed-rank tests for post-hoc analysis when needed.

For the interviews, we first transcribed the interview audio into scripts using an automatic speech recognition system - Feishu. Then, we used thematic analysis to generate participants' opinions and feedback towards the system. Their feedback was then combined with the quantitative data to help us comprehensively understand users' experience while using the system.

5.5 Results

5.5.1 Effectiveness of Posture Regulation. Both the violation duration and RPI value in Figure 13 showed that PosProjector could reduce the violation duration time. For the violation duration in Figure 13 (a), RM-ANOVAs showed significant main effects of condition in both paper and tablet media (paper: $F(2, 30) = 18.27$, $p < .001$; tablet: $F(2, 30) = 16.26$, $p < .001$). The interaction effect between experimental condition and device type was not statistically significant, $F(2, 30) = 0.289$, $p = .751$. When using the paper device, participants exhibited significantly longer violation durations in the baseline condition compared to the flame condition ($t = 6.59$, $p < .001$, Cohen's $d = 1.91$) and the grass condition ($t = 3.83$, $p = .002$, Cohen's $d = 1.17$). No significant difference was found between the flame and grass conditions ($t = -2.01$, $p = .062$, Cohen's $d = -0.45$). When using the tablet device, violation durations were significantly longer in the baseline condition compared to the flame condition ($t = 6.32$, $p < .001$, Cohen's $d = 1.65$) and the grass condition ($t = 3.74$, $p = .002$, Cohen's $d = 1.04$). There was no significant difference between the flame and grass conditions ($t = -1.72$, $p = .107$, Cohen's $d = -0.50$). In Figure 13 (b), most of the RPI value (intervention violation time/baseline violation time) was less than 1.0, indicating that individuals' posture violation duration decreased in the intervention. To conclude, PosProjector significantly reduced participants' violation duration during their study using both paper and tablet devices.

5.5.2 Differences Between Two Design Strategies. For strategy comparison, we compared the RPI value (intervention violation time / baseline violation time) difference of grass and flame strategies under the tablet device and paper device, because RPI was better at reflecting an individual's posture improvement status. The

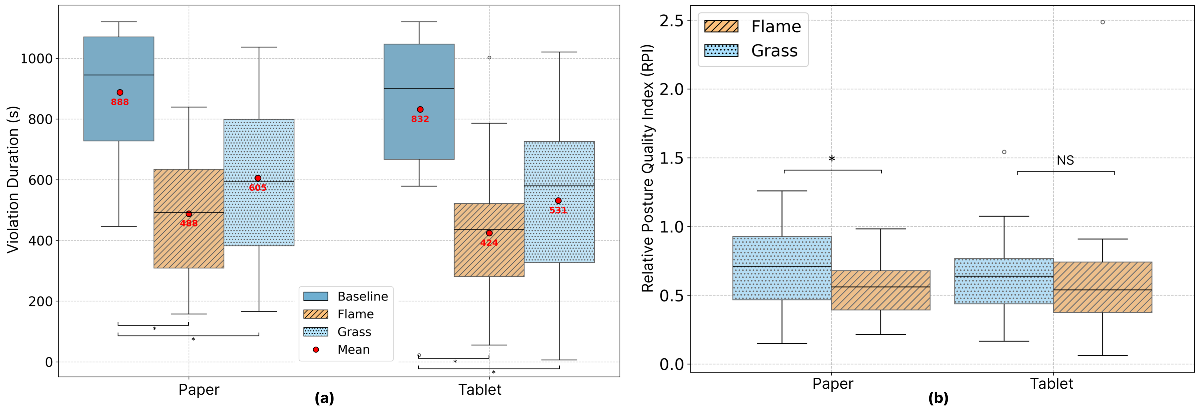

Figure 13: (a). Violation duration of six learning conditions. Statistical significance is denoted with * for $p < 0.05$. Under both learning media, violation duration during intervention was significantly reduced compared to baseline. (b). Relative Posture Quality Index of grass and flame using different devices. Statistical significance is denoted with * for $p < 0.05$. Flame had a lower RPI value than grass when using paper media, indicating flame reduced more proportional violation duration time.

Wilcoxon signed-rank test was used to compare RPI values since they were not normally distributed. As shown in Figure 13 (b), under the paper device, the Wilcoxon signed-rank test revealed a significant difference in RPI between *Grass* and *Flame* conditions ($W = 26$, $p = .029$, $r = .546$), indicating a large effect. The median RPI was higher in the *Grass* condition ($Mdn = 0.711$) compared to the *Flame* condition ($Mdn = 0.561$), suggesting that participants' violation duration decreased more after using the flame than the grass. For the *Tablet* device, no significant difference was found between *Grass* and *Flame* conditions ($W = 48$, $p = .323$, $r = .247$), which might be because the light from the tablet decreased the flame notification salience when the projection light overlapped with the tablet light. The different intervention performances under different media could further be explained through participants' subjective feedback on noticeability.

As shown in Figure 14, overall, the flame had higher notification awareness and salience ratings in both devices, which could explain why the flame brought a lower PPI value than grass in paper media. The salience of the flame condition aligned with the results of Study 1 (Figure 4 (a)), where the Center Luminance (CL) condition required the shortest reaction time for users to identify among all conditions. In the flame prototype, the light intruded into users' central vision, similar to the CL condition, which made it more salient and easier to detect than the grass condition. However, while it was more effective in improving posture, its increased salience also resulted in higher distraction, according to users' qualitative feedback and the ratings shown in Figure 14. The greater salience and distraction of the flame condition could be explained by the distinction between active and passive notification strategies. As S7 mentioned *"For the grass, I need to actively observe whether the grass will change while I'm reading. But if it's flame, I don't need to think so much—I just wait for it to actively spread to the center to remind me."* This feedback indicated that grass and flame employed two distinct notification strategies concerning proactivity. Grass exemplified a passive strategy, requiring users' active attention, whereas flame embodied an active strategy that gradually intruded into central vision. This result also showed that there was a trade-off between noticeability and distraction. Participants suggested flexibly matching use scenarios to manage the trade-off. S8 suggested design choice should match user motivation levels: *"I think it depends on different needs. If you really want to change your posture during this period, then use flame. If you just want it to be optional, changing is better, but it's no big deal if you don't. I think grass is the better choice".*

For the overall preference question in the interview, 6 participants reported they liked grass more, while 6 reported they preferred flame. The rest 4 participants reported they liked both designs. Some participants liked the grass because it could provide more gentle feelings. For example, S6 said: *"I prefer the grass element because I think grass is green, and it feels more gentle. Fire makes me feel a bit anxious and restless."* S10 identified complementary benefits of both designs: *"Actually, both have advantages. For the flame, when my posture is wrong, the reminder is more obvious because it spreads to the center. For the grass, it's not as obvious, but I can know which direction my posture is deviating toward".* While different participants held different preferences towards two strategies, the three user experience-related questions in Figure 14 showed that there were overall high ratings in both strategies in usability, overall preference, and willingness to use.

For the direction encoding of the system that only existed in the grass design, some participants said they needed more direct feedback on how to adjust the posture, while some said they didn't. S2 expressed a preference for direction hint: *"I actually prefer the grass's directional guidance. Because flame lacks directionality—I don't know which way I'm deviating. I can only return to a posture I feel is comfortable and correct, but sometimes my comfortable posture isn't the correct posture."* (S2). Some participants expressed that they do not need the directional notifications. *"Since I generally know what correct posture should be like, detailed positional information may not always be essential."* (S6) The qualitative feedback showed that violation direction encoding was more aligned with individual user preferences rather than universal usability principles.

5.5.3 Comparison Between Different Devices. For the devices, some participants thought that when using paper learning, it was overall easier to identify the notification in both grass and flame conditions, because paper was on the same surface as the desk and did not have self-luminance. Even when notifications only appeared in the peripheral area in the grass condition, the screen light would also decrease the sensitivity in identifying the notification. S6 provided insight into how different media affected light sensitivity: *"Paper doesn't emit light, but iPad does. When it emits light, my sensitivity to light changes might be slightly reduced because the device itself has significant light variation. But with paper, I'm more sensitive to changes in the projected light."* Participants also reported that they were more likely to trigger violation posture in the paper scenario because it was easier to adjust their posture when reading content at different places on the paper. Instead, when using a tablet, they adjusted their posture less frequently because the content on the screen was always at the center. S5 noted *"With paper, I might have several sheets at once, so looking left and right becomes a bit biased, but with a tablet, I can adjust its size and position right there."*

5.5.4 Participants' Perception of Basic Light Elements. To understand participants' perception of more detailed elements that composed the metaphor in the PosProjector. We also investigated participants' perception of the basic five light change types, as shown in Figure 15. For grass notifications, participants exhibited heightened sensitivity to the light shape change in notification capture confidence and noticeability. Light motion change also elicited strong participant responses, suggesting that the grass metaphor effectively utilized participants' natural sensitivity to movement-based visual cues in the peripheral vision field to create notifications. The overall ratings between different media - paper and tablet, were approximately the same in the grass condition. Flame notifications revealed a different sensitivity profile with light position change and light color change, demonstrating slightly higher sensitivity scores. Notably, flame-tablet conditions consistently showed less capture confidence and noticeability than flame-paper conditions in most design elements, which indicated flame was less salient under tablet media. This might be due to the overlap of the tablet light and the projection light, which diminished the noticeability of the projection in central vision.

Notably, in all intervention conditions, color change had the highest distracting ratings among all dimensions. Furthermore, there was a decrease in color change when comparing notification noticeability and participants' capture confidence. In other words, participants thought the color notification was noticeable, but they were unconfident about whether they could capture the change of color. This indicated participants' lack of confidence when identifying color-related changes, which echoed the result of Study 1 that color change required more effort to identify than luminance change.

5.5.5 Enhancement in Violation Duration During Intervention. For the relative posture quality index in Figure 13 (b), most RPI values were less than 1, indicating that participants' posture violation duration was reduced during the intervention. However, we discovered that a typical reason for the outliers enhancement of violation duration during the intervention was the tiny baseline violation duration. For example, S3 had a very low baseline violation duration of 22.2 seconds out of a 20-minute learning period in the flame-tablet condition, which indicated that S3 had a very healthy posture habit before intervention. Thus, a slight variation in the violation time during flame intervention (55.2 seconds) resulted in a significant increase in the RPI value. This indicated RPI's limitation in reflecting participants' posture change when the violation duration baseline was small.

5.5.6 Posture Change Patterns After Presenting the Notification. We summarized three types of posture change after the system presented the notification: multiple corrections, single correction, and ignore notification pattern. In the multiple correction pattern (Figure 16 1a) and single correction pattern (Figure 16 2a), there was a turning point when participants suddenly realized the notification and started adjusting their posture. In multiple correction patterns, participants always adjusted posture around the threshold at first and did not stay in the correct posture for more than 2 seconds, so the notification didn't disappear. Then the participant would start more posture adjustments indicated by more turning points until they fully corrected their posture. In the single correction pattern, participants corrected their posture at once with only one turning point. Although such sudden posture changes might potentially interrupt participants' workflow, we noted that there are circumstances where notifications were fully delivered, yet participants chose to delay their postural corrections. As shown in Figure 16 3a, this delayed response pattern suggested that participants might have an adaptive reaction timing due to their current state of task engagement and cognitive focus. They might consciously or unconsciously defer their postural adjustments until a more opportune moment. This indicated a nuanced interaction between notification delivery and participants' attention management.

6 Discussion

Our work extends posture correction feedback design by introducing desk-surface projection as a novel visual modality and by exploring a broader design space, including dimensions that have not been examined before. In this section, we discuss our design implications and findings to guide future practices on how to design the least intrusive projection notification system for posture correction.

6.1 Design Implications

Consider Vision Field and Light Change Types When Creating Notification. Through the notification elicitation study in Study 1, we discovered that light change types and the visual field are key dimensions affecting participants' perception of notifications. While color change was used in ambient design to present visual notifications in the previous study [23], Study 1's result showed that participants needed more effort to identify the color change than luminance change (Figure 6). We also found that color change showed higher temporal sensitivity than luminance change in peripheral vision (Figure 4), meaning that as the transition slowed down, people needed more time to detect color change. This was consistent with Study 3, where participants reported less confidence in identifying color-change notifications compared to other

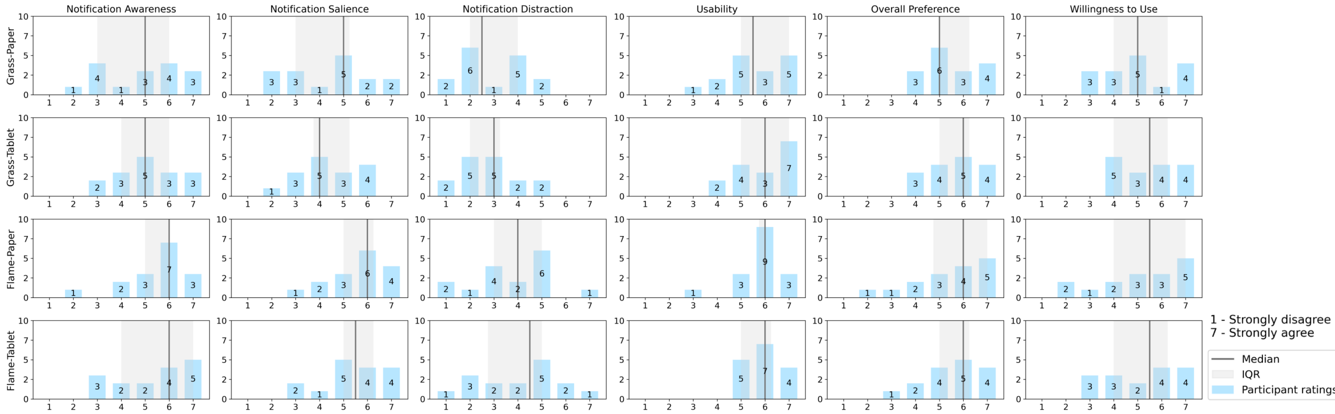

Figure 14: Participant evaluation results across four notification conditions (Grass-Paper, Grass-Tablet, Flame-Paper, Flame-Tablet) on six measures: notification awareness, salience, distraction, usability, overall preference, and willingness to use. Bars show participant rating distributions on 7-point Likert scales (1=strongly disagree, 7=strongly agree). Numbers indicate median values, with gray lines showing interquartile ranges. In general, flame was more salient than grass and caused more distraction at the same time, indicating there is a trade-off between noticeability and distraction. But both flame and grass had high usability, preference, and willingness to use ratings.

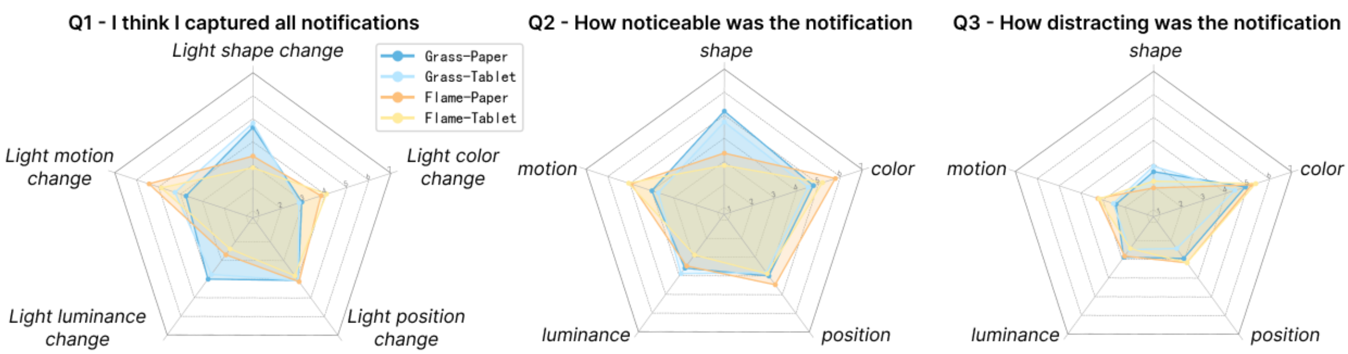

Figure 15: Participant perceptions of notification design elements across four conditions (Grass-Paper, Grass-Tablet, Flame-Paper, Flame-Tablet). Each axis represents different basic light change parameters (shape, color, position, luminance, motion) summarized from the design space. In color change dimensions for all conditions, there was a decrease from noticeability (Q2) to the confidence of identifying color change (Q1), which showed participants' uncertainty about capturing color change. Color change also has the highest distraction rating, which echoed the result of Study 1 that light color change needed more effort to identify.

dimensions (Figure 15). This phenomenon also aligned with previous studies that discovered the perceived effort for Motion and Luminance popout effects is consistently less than that for Color and Shape [26]. Thus, when designing the projection notification, we suggested using color change as an ornament element for creating aesthetic ambient atmosphere and using other types of changes, like luminance and motion change, to encode key information.

Another element to consider when designing a projection notification system is the vision field. Although previous research always adopted only the peripheral area for ambient notification, our study showed that gradually presenting notification from the peripheral to the center, which was the flame condition in Study 3, could also create notification at low obtrusiveness. From the perspective of user experience, the dynamics of presenting information from peripheral to central vision was described as a more "active" notification strategy than the notifications which were only displayed in peripheral vision. Participant feedback in the evaluation study indicated that although it was more noticeable, it took less effort to identify the notification, and participants showed a high willingness to use it. Thus, in the future, the dynamics of moving notification from peripheral to central vision field could also be considered as a method for less intrusive notification.

Creating Interaction Content That Can Nudge Users' Behavior Change and Align with Users' Mental Model. In Study 2, our design space offered a preliminary conceptual framework for designing projection notifications for posture correction, which could be further combined with existing theory to create more sophisticated

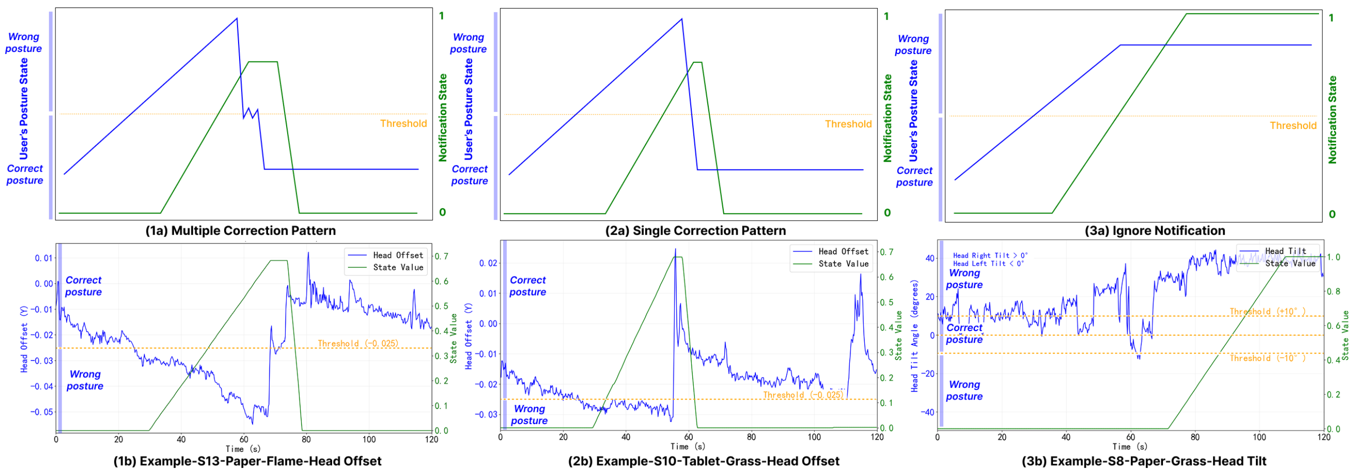

Figure 16: Three typical reaction patterns of participants' posture correction process were identified. In the multiple correction pattern (1a, 1b), participants made multiple adjustments to their posture until it was completely corrected. The reason was often that the initial correction fluctuated around the threshold boundary. At this point, the notification paused changing but did not disappear. Therefore, participants continued to adjust until they remained within the correct range for more than 2 seconds, then the notification completely disappeared. In the single correction pattern (2a, 2b), participants adjusted to the correct posture at once. After a two-second delay, the notification disappeared. In the ignore notification pattern (3a,3b), the participant ignored the notification and kept holding the wrong posture. The notification remained in state 1 until the user started posture correction.

notification approaches. The idea of using ambient projection to improve users' posture aligned with the nudge theory, which was initially introduced in behavioral economics to design systems that introduce subtle changes in information presentation to guide users towards desired choices and behaviors [62]. Nudge theory has been used in ambient design to trigger users' behavior changes, such as the choice of taking stairs rather than the elevator [55], encourage office workers to take a break [22, 32], and residential energy consumption [17]. Caraban et al. analyzed the interaction mechanism of nudge in HCI and formed 23 mechanisms of nudging [9], which could be combined with the design space to create richer projection content. For example, the grass prototype aligned with the mechanism of *ambient feedback* and *instigating empathy*, which used ambient projected grass that withered when users' posture was violated to nudge users holding a good posture to protect the grass. The *instigating empathy mechanism* could further integrate with the *Trends in Metaphor* mapping strategy in the design space to create a mechanism that could arouse users' empathy to protect metaphor through their positive posture change. The flame prototype aligned with *just-in-time prompts* and *fear nudges* mechanisms, which created escalating visual threats that spread toward the user's visual center during poor posture, evoking feelings of environmental danger and loss of safe space, and thus drove users to pursue corrective postural behaviors and avoid the perceived threat. The design of fear nudges could be further combined with the *Create Interference* strategy in the design space for future projection design.

Despite the semantic layer of the content, the content's interaction design should also be considered to fit users' mental model—the knowledge basis for constructing reasonable actions and explanations about why a set of actions is appropriate [10, 35]. In the projection notification system, designing interaction that aligns with users' mental model means that the interaction is intuitively combined with users' posture changes. For example, in the grass prototype, the direction that the grass bent down aligned with the users' head-bending direction, which created the intuitive interaction that the head bent the grass.

Advancing Toward a Personalized Projection Notification System. During the development and evaluation of our projection notification system, we discovered that personalization was crucial for supporting long-term posture correction and proposed personalization across three key aspects.

First, content personalization should encompass both semantic customization and spatial positioning to better serve diverse user needs. For semantic customization, users should be able to select or create custom metaphors, as suggested by E10 during the expert co-design workshop. By replacing generic metaphors with user-defined objects, this could better increase user engagement and nudge users' empathy to protect the metaphors. For spatial positioning, users should be able to customize notification placement to avoid task-critical areas, particularly for writing tasks that require larger workspace areas.

Second, the system should enable notification salience personalization to manage the trade-off between effectiveness and disruption via adjustable parameters. The system can support users in customizing the transition time of notifications as well as the brightness and color properties of different notification states. Additionally, diverse interaction strategy options should be available since users perceived different designs (such as flame versus grass) with varying prominence levels.

Third, personalization of correction thresholds and plans should account for significant individual differences in users' baseline posture health and error patterns. This is demonstrated by participants like S3, who showed excellent initial posture with baseline errors rarely exceeding one minute, versus S12, who exhibited distinct rightward head deviation patterns and found the current 10° threshold too strict. Therefore, future designs should establish personalized thresholds that facilitate gradual posture improvement through initially lenient parameters that gradually become more stringent over time.

Parameterize Projected Content to Create a Gradually Changing Visual Stimulus. During the design of grass and flame, to create consistent changes, we utilized the Shader Graph component in Unity to create a shader and extracted the material property for posture parameters mapping, making the objects' slow visual changing process consistent and coherent by controlling the parameters of the shader. This can be combined with knowledge in the computer graphics field to parameterize the modeling [25], rendering [59], and animation [12, 45] to make the slow visual stimulus change coherent. For example, the procedural scene generation [43] can be used to create a coherent pictorial metaphor change for posture notification. The controllable motion change of the smoke [2] can create consistent weather changes, like foggy or rainy, to indicate deviated posture. Based on these technical foundations, we suggest that future projection content creation should consider both the technical feasibility and aesthetics to create parameterized digital content that supports gradual, slow visual notification.

6.2 Limitations and Future Work

PosProjector took the first step in employing projection as an ambient notification system for posture correction in desk-based learning contexts. Nevertheless, the study carried several limitations that highlight opportunities for future research.

Firstly, concerning the vision field, it was calculated preliminarily in this system. However, during the study process, participants' precise vision field slightly changed according to their reading area. Thus, current predefined central and peripheral vision fields could only act as a rough estimation. To support a more precise vision field definition, the system may further support users' personalized adjustments or calculate users' vision in real time. In addition, although the nearsighted participants wore glasses or contact lenses to correct their vision, we acknowledged that there might still be effects related to visual field differences caused by wearing glasses or contact lenses.

Secondly, for the sitting posture, we predefined the upright posture as the standard posture. However, different people might have different comfortable postures. Thus, future studies could consider personalizing the original health posture for users. For the visual feedback, we only explored the color and luminance differences in the notification elicitation study. As the system's light change types extended to five kinds in the design space and final prototype, further studies could be conducted on users' different perception patterns regarding these five light change types and the interaction effects between different elements.

Thirdly, although projectors offer advantages in accessibility and ease of setup, they are sensitive to ambient lighting conditions. Brighter or non-uniform light environments may reduce the visibility and clarity of the projected cues. In addition, our study did not investigate long-term usage or habituation patterns. Although Study 3 demonstrated posture-improvement effects across three days, these results might be partially influenced by novelty or Hawthorne effects. Future work should examine whether the system remains effective as users become accustomed to the notifications over an extended period.

7 Conclusions

In conclusion, our work provided the first comprehensive exploration into the use of projection-based notification systems for posture correction in desk-based learning environments. We first developed a projection notification framework through systematic investigation of fundamental design dimensions, including notification position and light change types. We expanded this into a comprehensive five-dimensional design space through expert co-design workshops that identified novel strategies for encoding posture-related notifications, such as Trends in Metaphors and Consequences of Force. Finally, we developed PosProjector, a projection notification system that included two notification strategies derived from the design space, and evaluated the system across paper and tablet learning activities.

Through the three-stage mixed methods research, this study paved the way for the development of future posture correction systems that are not only effective but also seamlessly integrate into users' learning environments. By integrating the use of a projector, parameterized design, and dynamic use of the visual field, our system created a novel gradual notification system that could support users' posture health under flexible learning scenarios. Future research can further explore the dynamic display of notifications according to users' learning state, as well as personalization of the posture correction plan and notification content.

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A Experiment Details

A.1 Initial Design Space and Implementation

For the **light change types**, we included color change [15, 46] and luminance change [19, 31, 42], which were two commonly used notification methods in previous studies. Since blue makes a good peripheral background color [11], we implemented a transition from blue (HSV: 240, 100, 100) to red (HSV: 0, 100, 100) for color change notification, and a transition from black (HSV: 0, 100, 0) to red (HSV: 0, 100, 100) for luminance change notification, which visually manifested as a fading appearance of red light in projection.

For the **notification position**, we included center and peripheral vision fields as two distinct notification positions according to the related work in section 2.3. For the implementation of the two notification positions, we calculated them on the desk through trigonometric functions. Considering participants' central vision might slightly shift during reading, we adopted an expanded macular region (18 degrees from the visual center) for center visual field calculation in our study (Figure 17). As previous research indicates that individuals in a seated reading position typically maintain an average viewing angle of 63 degrees between their line of sight and the horizontal plane of the book [28], we used 63 degrees for trigonometric calculations. We selected 40cm as the fixed calculation height from the desk surface to the eyes, which was the approximate average eye-desk distance based on the anthropometric data [53]. To make sure everyone has a similar vision field distribution on the desk, participants' eye-desk distance was calibrated to 40cm every time before they started the experiment through an adjustable chair. The final calculation results were illustrated in the figure 17. By connecting the four boundary points with an ellipse, we established an approximate center visual field for our experiments. The peripheral visual ring zone was offset outwards from central vision, with its inner boundary exceeding an A4 landscape paper to ensure a clear distinction from the central visual region, and prevent the peripheral area from overlapping with the reading material (paper).

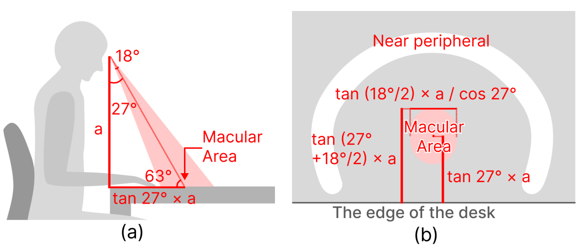

Figure 17: Calculation for the approximate macular vision field with all measurements rounded to one decimal place. (a) shows the side view of the macular vision. (b) shows the top view of the macular vision area and near peripheral area used to present notification in this study, defined by the distance from the edge of the desk. We use a = 40 cm to calculate macular area in this study.

A.2 Participants' Demographic Information of Study 2: Expert Co-Design Workshop

Participants were recruited via personal networks and a snowball sampling strategy, including individuals both inside and outside the authors' laboratory. The demographic information is shown in Table 1.

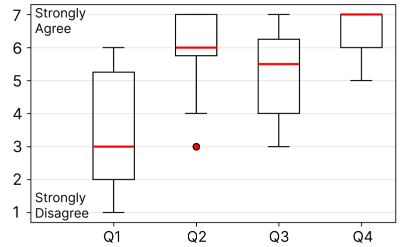

Figure 18: Participants' attitude towards their posture while learning. Q1: I have the awareness of holding good posture while studying. Q2: I want to improve my study posture. Q3: I have tried to improve my posture. Q4: I believe good posture helps learning and health.

A.3 Pre-Survey Investigating Participants' Motivation in Study 3

A survey conducted before the experiment (Figure 18) revealed that most participants were unaware of maintaining good posture while studying. However, they wanted to improve their posture while studying, or had tried to do so. And they believed good posture would enhance their learning and health. In summary, while participants lacked current awareness of posture maintenance, they demonstrated strong motivation to improve it.

A.4 System Configuration of Study 2 and 3

The detailed configuration of PosProjector system was in Figure 19. The projection was mounted on a tripod, and the position was adjusted to fit the predefined visual field that we calculated. A lamp was used to ensure the desk's average luminance is larger than the recommended minimum of 500 lux for healthy reading and writing activities. The working area is covered with a white background to avoid the desks' color affecting the projection light.

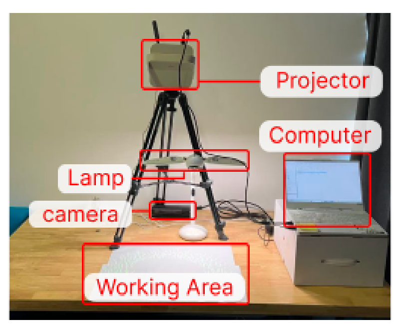

Figure 19: System configuration in Studies 2 and 3.

ID	Age	Sex	Prior Experience	Years of Research Experience	Academic Status
E1	24	M	Human Computer Interaction	3	Master
E2	24	M	Human Computer Interaction	2	Master
E3	23	F	Interaction Design	1	Master
E4	26	M	Human Computer Interaction, VR/AR	4	Doctoral
E5	25	F	Human Computer Interaction, VR/AR	5	Doctoral
E6	24	F	User Experience Design	3	Master
E7	24	M	Human Computer Interaction, Interaction Design	2	Master
E8	24	F	Human Computer Interaction, VR/AR, Interaction Design	3	Master
E9	27	M	Human Factors Engineering, Interaction Design	5	Doctoral
E10	26	M	Human Computer Interaction, Game Design, User Experience Design	3	Doctoral

Table 1: Participants' demographic information in the expert co-design workshop.