Co-design & Evaluation of Visual Interventions for Head Posture Correction in Virtual Reality Games

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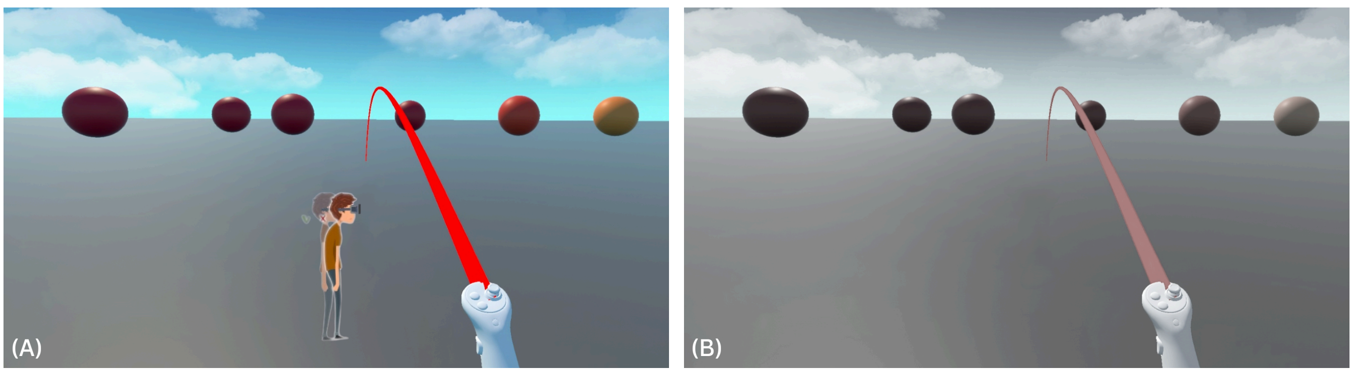

Figure 1: Using data from a virtual reality headset, we identified instances of improper head posture in gaming contexts and applied a visual intervention to correct them. Two design approaches for the intervention were explored: explicit visual indicator (A) and implicit background change (B). Results indicate that the interventions effectively decreased participants' average slouching level and time spent in improper head posture during gameplay.

ABSTRACT

While virtual reality (VR) games offer immersive experiences, prolonged improper head posture during VR gaming sessions can cause neck discomfort and injuries. To address this issue, we prototyped a framework to detect instances of improper head posture and apply various visual interventions to correct them. After assessing the prototype's usability in a co-design workshop with participants experienced in VR design and kinesiology, we refined the interventions in two main directions — using explicit visual indicators or employing implicit background changes. The refined interventions were subsequently tested in a controlled experiment involving a target selection task. The study results demonstrate that the interventions effectively helped participants maintain better head posture during VR gameplay compared to the control condition.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **User studies**.

KEYWORDS

Posture Correction, Virtual Reality Games

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1 INTRODUCTION

In recent years, VR gaming has experienced significant development and achieved commercial popularity [56], leading to a wide range of useful applications, including educational tools [63], medical simulation [53], and phobia treatment [19]. While VR games offer engaging experiences, during extended VR gaming sessions, the persistent neck strain caused by the weight of VR headsets can lead to muscle discomfort and injuries [36, 55, 65]. Moreover, as previous research has highlighted that maintaining good posture is a challenging problem in real-world office work [21], the issue becomes more demanding in VR gaming, where users might be too immersed in the gameplay to remain aware of their posture [23].

While various systems have been designed for posture correction during office computer use [60, 62], effective solutions within VR gaming remain scarce. One relevant prior work examined unobtrusive posture manipulation via moving content in the VR display [61]; however, this study only focused on correcting sitting posture in the context of VR office work. Nevertheless, gaming remains one of the most popular VR applications, where improper posture is particularly prevalent due to the extended period users spend immersed in gameplay compared to other applications [17, 56]. Furthermore, VR gaming experiences often require users to stand and move around, making it challenging to detect and correct improper posture. To the best of our knowledge, no prior research has investigated standing posture correction during VR gameplay, and this work aims to address this gap.

To effectively correct posture during VR gameplay, two key tasks must be addressed: 1) posture detection and 2) posture correction. Posture detection involves accurately tracking users' body motion during VR gameplay and identifying instances of improper posture, while posture correction entails providing feedback to encourage users to correct their posture.

First, regarding posture detection, we specifically targeted the two most common forms of improper standing head posture: forward head posture and slouching [31, 35]. Forward head posture involves the head consistently tilting forwards, placing strain on the neck and upper back muscles [20]. Slouching, on the other hand, is characterized by rounded shoulders and a curved thoracic spine, which can lead to misalignment and potential musculoskeletal issues [44]. Although there have been methods to detect these improper posture types using external sensors or motion tracking cameras [42, 43, 48], no prior work has attempted to achieve this directly through the sensors within the headset of a VR system. Hence, we developed a detection framework that utilizes angular and height data directly from the VR headset to identify both forward head posture and slouching instances.

Secondly, for posture correction, we developed a set of interventions that would activate whenever the detection framework identifies improper posture from the VR user. The current research focuses on visual interventions — feedback visible within the VR display — including explicit warnings such as pop-up notifications, and implicit warnings like a change in the environment color scheme. These interventions draw inspiration from prior research in posture intervention within the HCI and VR design literature [12, 39, 46].

To explore the seamless integration of corrective interventions into VR gaming experiences, we conducted a two-step investigation:

(1) We organized co-design workshops involving participants with expertise in kinesiology, UX/UI design, and VR programming. In these co-design sessions, participants evaluated the usability of our prototyped interventions, providing feedback and suggestions. They also brainstormed new design ideas, which we incorporated to refine the initial interventions.
(2) To assess the effectiveness of the refined interventions, we conducted a controlled experiment where participants engaged in an extended target selection game. Throughout each trial of the experiment, we tracked the participants' head posture, then analyzed the data to confirm the efficacy of the interventions in helping VR users maintain good head posture and correcting improper head posture during gameplay.

In summary, our research contributions are:

- A novel head posture detection technique that exclusively utilizes data collected from the VR system's headset.
- A co-design workshop to brainstorm and refine visual interventions for head posture correction during VR gaming.
- An evaluation study to comprehensively assess the usability and effectiveness of the proposed interventions.
- A detailed discussion of design principles and challenges associated with posture correction interventions in VR games.

2 RELATED WORK

This section provides an overview of relevant existing research literature, focusing on three main areas: Improper Posture in VR Usage, Posture Detection, and Posture Correction.

2.1 Improper Posture in VR Usage

Significant posture issues can arise from using a VR headset, due to its added weight on the user's neck and the immersive nature of the VR experience. Indeed, previous work in kinesiology has highlighted the discomfort caused by head-mounted equipment that adds significant weight to the neck [16, 68]. For example, in one study comparing the posture and neck muscle tension of Canadian Force helicopter pilots during routine simulated night and day flights, the findings revealed a notable increase in flexed posture and tensed neck muscles among night pilots, which was attributed to the prolonged use of head-mounted night goggles [16]. These night goggles weigh 500g on average [24], so VR users, wearing headsets weighing between 400g (the Oculus) and 800g [29], are also susceptible to similar issues, as the added weight and pressure from headset use can strain the neck muscles and lead to discomfort or injuries [8, 33, 36, 45, 55, 65].

Another common cause of posture issues in the real world is a lack of awareness of one's current posture. This is particularly prevalent among office workers who spend long hours in front of digital displays, often resulting in slouching, musculoskeletal discomfort, and other long-term posture problems [21]. This phenomenon is typically linked to extended screen focus and a lack of attention to posture [23]. Similarly, the immersive nature of VR experiences can distract users from maintaining proper posture, leading to improper posture habits [29].

Furthermore, individuals with pre-existing improper standing postures may experience heightened discomfort in VR. The physical demands of wearing VR headsets, combined with a lack of attention to posture during immersive experiences, can exacerbate improper posture habits and lead to increased muscle strain and discomfort [36, 44]. These factors highlight the need for innovative solutions to address the ergonomic challenges faced by VR users. Despite the growing popularity of VR technology, there remains a lack of comprehensive solutions to mitigate the risk of injuries and musculoskeletal disorders for VR users. The current research focuses on two key issues: detecting instances of improper head posture in VR, particularly forward head posture and slouching, and correcting them through visual interventions.

2.2 Posture Detection

A variety of posture detection techniques have been developed to identify improper posture in real-time. One well-studied method for detecting improper sitting posture involves using different types of sensors, most commonly pressure sensors, attached to chairs [14, 50, 54]. These sensors measure body contact with the chair and interpolate the current posture state with this data. However, VR gaming applications typically require users to stand and move within a designated VR workspace, making sensor-measured body contact not suitable for inferring posture state.

An alternative method for identifying improper standing posture involves using wearable sensors integrated into clothing, which measure muscle activation at the neck or back to infer posture state [15, 49, 71]. Another approach utilizes full-body tracking systems, such as Kinect cameras, to capture body pose and categorize posture as good or bad [9, 28, 66]. Although both methods are highly accurate and comprehensive for detecting both sitting and standing posture, they require specialized devices that are not readily accessible to the average VR gaming user. In particular, while wearable sensors provide detailed muscle activation data, integrating these sensors into everyday clothing can be cumbersome and impractical for regular VR use [25, 59]. Similarly, full-body tracking systems like the Kinect camera offer precise posture analysis but require a clear line of sight, as well as additional hardware that can be expensive and intrusive in a home VR setup [10, 74].

Given the limitations of existing posture detection technologies, this work aims to develop a more convenient and practical solution that seamlessly integrates into the VR gaming experience without requiring extra equipment. Drawing inspiration from previous studies in HCI that leverage data collected directly from the VR system's headset [33, 45, 61], we propose a framework for identifying improper standing head posture using the VR system's built-in Inertial Measurement Unit (IMU) sensors. The detection framework specifically targets the correction of slouching and forward head posture while standing in VR, offering an accurate, convenient, and cost-effective alternative to other detection methods.

2.3 Posture Correction

Previous HCI research has introduced various techniques for correcting improper postures during extended office work. These approaches include intrusive methods, such as pop-up notifications [28], haptic feedback from wearable devices [6], and screen locking [60]. Additionally, more unobtrusive solutions have been explored, such as ambient displays and avatars [26, 30], or manipulation of the external environment [62]. While these studies primarily focus on posture correction in real-world office work settings, we draw inspiration from the research to develop an initial set of posture correction interventions for VR gaming.

On the other hand, few studies have explored techniques for correcting improper posture in VR environments. Shin et al. explored an unobtrusive method for adjusting posture during VR office work [61], while another study investigated the efficacy of VR exercises in correcting forward head posture [64]. The current research contributes to this underexplored area by focusing on posture correction in a novel context: VR gaming. Unlike sedentary VR work, VR gaming involves more dynamic and varied movements, posing unique challenges for posture correction. Moreover, while Son [64] demonstrated the benefits of VR exercises for improving posture, maintaining proper posture during prolonged VR immersion, especially when the user's primary focus is not on posture improvement, remains a challenge. Therefore, the current research explores a range of interventions aimed at enhancing users' posture awareness during extended VR gaming sessions, without disrupting the primary gaming experience.

3 SYSTEM DESIGN

In this section, we discuss the architecture and design of our VR system, which includes two main components: a framework for posture detection and interventions for posture correction.

3.1 Posture Detection Framework

As mentioned earlier, the current research aims to detect two types of improper posture during VR gameplay: forward head posture and slouching. Rather than relying on external sensor hardware to measure standardized posture metrics, such as the back angle used in Shin et al. [61], we utilize the VR device's onboard sensors for head and neck posture detection. This approach allows for faster deployment to the general public. Prior work by Ho-Hee [64] on posture management similarly employed a non-standard method (ruler and threshold-based) to assess height and head angle. Additionally, while previous research often focuses on full-body posture using standardized metrics, our study specifically targets head posture. In line with our objectives, we chose non-standardized metrics measured with the built-in VR head-mounted display for posture detection.

To achieve this, we implemented a posture detection framework in Unity using a Meta Quest 1 VR system. The VR system's headset is equipped with IMU sensors, which we utilized to extract the positional and rotational values of the headset relative to the floor level at a rate of 10 times per second [51]. The detection framework then directly uses the rotational pitch value of the headset sensors to determine the head tilt angle, which indicates how much the user is looking downward. Additionally, we computed a normalized height by subtracting a pre-calibrated reference height from the current height, adjusting for the head tilt angle. This reference height, which varies between users, was collected while each user stood upright in proper posture, looking straight ahead — the height then corresponded to the y-value of the positional data extracted from the headset sensors [51]. A positive value of the normalized height indicates that the current height is higher than the reference, while a negative value indicates the opposite.

As shown in Figure 2, analyzing the head tilt angle helps determine if a user has a forward head posture. A positive head tilt angle means the user is looking upwards, while a negative angle means

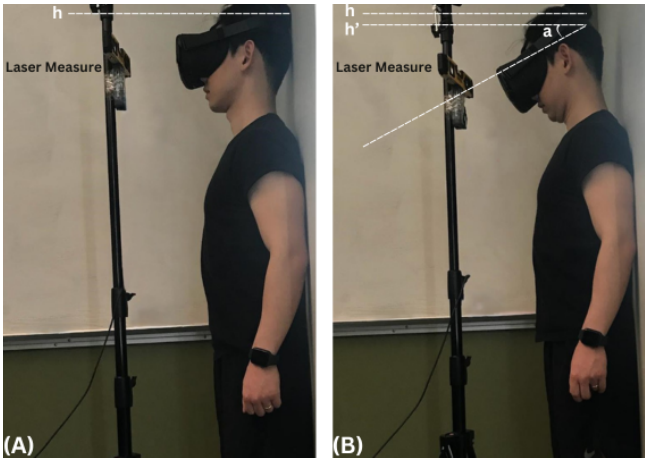

Figure 2: To validate the reference height h collected by the VR headset, we used a laser measurement tool (A). In our posture detection framework, the head tilt angle a was directly obtained from the headset sensors, while the normalized height was calculated as the difference between the reference height h and the current height h' (B).

the user is looking downwards. A lower head tilt angle indicates a greater downward gaze, which suggests improper posture. Conversely, the normalized height measurement provides insights into slouching behavior. A positive normalized height indicates that the user is reaching upwards or standing on their toes, while a negative value indicates slouching. When users slouch, the normalized height value decreases because the VR headset sits lower on their head compared to when they maintain proper posture, assuming a consistent head tilt angle.

In both the co-design and evaluation studies, we conducted a calibration process each time the participant entered the VR environment to establish reference values for the normalized height and head tilt angle of the VR system's headset in both good and bad posture states. Initially, users were instructed to maintain an upright posture while looking straight ahead for 3 seconds (Figure 2.a). During this period, positional and rotational data of the headset were collected and averaged to determine the reference values indicative of good posture. Subsequently, users were asked to gradually lower their heads until their head tilt angle approached the angle threshold and then maintain this posture for an additional 3 seconds (Figure 2.b). This approach allowed us to isolate reference values that indicate improper posture contributed by head tilting or slouching, ensuring accurate classification of posture states within the VR environment.

To verify the accuracy of our posture detection measurements, we conducted a validation test using a Bosch Blaze GLM165-40 Professional laser measurement tool, which has a precision of ±1.5mm [5]. We captured the actual heights of two volunteer participants under various posture conditions: looking straight ahead, looking downward up to 30 degrees, and slouching. These values were then compared to the data obtained from our detection framework to assess its performance. This validation process was applied only to the height data, as the head tilt angle is directly collected from reliable IMU sensors without requiring further adjustment. The calculated height data showed a low average error percentage of $0.031\% \pm 0.014\%$ compared to the laser measurements, with absolute error values of 0.50 ±0.22mm. This confirmed that our measurement system accurately reflects the user's head posture.

Additionally, we conducted a pilot study with three volunteer participants and found that setting an angle threshold of -10 degrees below eye level and a height threshold of -2 cm effectively distinguishes between good and bad posture. If either of these values falls below its respective threshold, we identify the user as having an improper posture. This approach was adapted from previous studies in ergonomics that also use pre-calibrated thresholds to quickly assess posture state [69, 72].

In addition to these thresholds, we consider the element of time. A high head tilt angle or normalized height may not necessarily indicate improper posture; factors such as random movements during gameplay or game mechanics that require stooping or looking downwards could influence these values. Therefore, we only classify a posture as bad if it persists for over 3 seconds. In other words, the user is considered to be in an improper posture only if the head tilt angle exceeds 10 degrees or the normalized height surpasses 2 cm continuously for 3 seconds. Again, these criteria were validated during the pilot study.

3.2 Posture Correction Interventions

We designed corrective interventions that are triggered whenever the posture detection framework detects improper posture in a user. We focused exclusively on visual interventions due to the convenience and flexibility of using only the VR headset display, without needing additional actuators. Furthermore, previous research in Human-Computer Interaction has shown success in using visual cues for posture correction in office settings, which we aim to adapt for VR environments [26, 32, 61]. Drawing inspiration from prior interventions in office settings, which range from explicit screen notifications [28] to subtle adjustments in the workspace environment [62], we prototyped four designs for posture correction in VR gaming, illustrated in Figure 3.

3.2.1 Icon. Previous HCI research has shown that effective visual interventions for posture can be as simple as a pop-up text or icon that alerts users to their improper posture [26, 28]. Our first intervention design (Figure 3.A) follows this approach, featuring a series of posture icons, each representing different posture levels. In this representation, the icon for good posture is distinguished by a green stripe, while icons for improper postures vary in the intensity of their red stripes. As users adjust their posture, the corresponding icon lights up while others dim, allowing users to gauge their posture alignment in real-time.

3.2.2 Grayscale. While explicit icons are easy for users to understand, previous research has noted that such explicitness can be obtrusive to the task at hand [22]. Consequently, subtle methods for posture correction have been explored, including ambient displays and inconspicuous changes in the external environment [26, 30]. Additionally, research has shown that behavior change and attention redirection can be elicited by screen grayscaling [40]. Combining these ideas, we designed a grayscale-based intervention (Figure

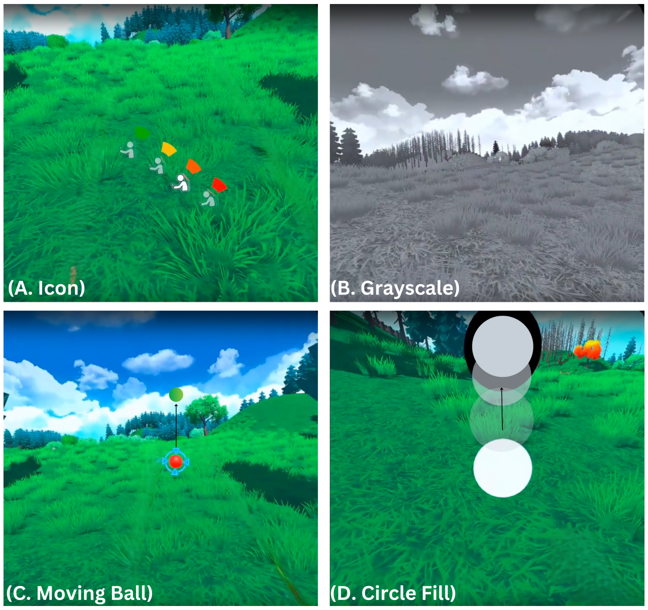

Figure 3: We developed prototypes of visual interventions for correcting posture, namely Icon (A), Grayscale (B), Moving Ball (C), and Circle Fill (D).

3.B), which notifies users of improper posture by switching the colored scene to grayscale and then reverting to color once users correct their posture. In this prototype, the scene immediately fades to grayscale when the user assumes an improper posture, and it instantly returns to full color as soon as the posture is corrected.

3.2.3 Moving Ball. We derived inspiration for our intervention from the work of Shin et al. (2019) [62], which explores unobtrusive posture correction using a robot arm display. Their method involves subtly adjusting users' posture by slowly repositioning the monitor. In our intervention (Figure 3.C), we employ a similar principle, utilizing a moving ball that ascends vertically to encourage users to adjust their posture gradually. Upon achieving the desired posture alignment, the ball transitions to a green color, indicating successful correction. To ensure that the moving ball captures users' attention, we introduce a rotating crosshair around it, similar to the targeting mechanisms commonly used in first-person shooter games.

3.2.4 Circle Fill. For this intervention (Figure 3.D), we applied a similar principle to the Moving Ball intervention, drawing inspiration from previous research on ambient displays and automated robotic movements [26, 62]. Specifically, the intervention consists of a white dot that tracks the user's head movements and a stationary black circle that marks the position the user's head should be in to maintain good posture. When the dot aligns with the circle, the user achieves the ideal posture. Users correct their posture by moving the dot to fill the inside of the circle, which makes the black circle disappear. Unlike the Moving Ball intervention, which requires users to look towards the ball to achieve proper posture, this intervention introduces a mini-challenge that encourages users to engage with it, thereby promoting correct posture.

4 USER STUDY 1: CO-DESIGN WORKSHOP

To evaluate the effectiveness of the posture detection framework, assess the usability of our prototype posture correction interventions, and explore other potential designs, we conducted a co-design workshop. The participants, who had experience in UX/UI design, VR programming, and kinesiology, were recruited because designing unobtrusive and effective interventions in VR settings is a challenging task that requires prior experience. We believed their background would contribute to assessing the prototyped designs accurately and generating promising ideas for new designs.

4.1 Participants

The co-design workshop involved 9 participants (3 female, 6 male), aligning with the typical range of 6 to 10 participants used in similar prior research on participatory design for virtual reality applications [13, 47, 58, 67]. The participants had an average age of 20.78 ± 0.62. They were university students with experience or coursework in UX/UI design, VR programming, or kinesiology. 6 participants self-identified as frequent gamers, with three of them regularly playing games in VR. Participants were divided into three groups corresponding to 3 different sessions of the co-design workshop (Table 1). Each group was formed to include at least one participant with experience in Kinesiology and one in VR Programming or UX/UI design, ensuring a balanced discussion in each workshop session. All participants consented to take part in the workshop, and the study was approved by our institutional review board.

Table 1: Participants and Group Information for the Co-Design Workshop

Group	Gender	Age	Prior Experience	Frequent Gamer
Group 1	Male	19	VR Programming	Yes
	Male	24	Kinesiology	Yes
	Female	20	UX/UI Design	No
Group 2	Male	19	VR Programming	Yes
	Male	19	VR Programming	Yes
	Male	23	Kinesiology	Yes
Group 3	Male	20	UX/UI Design	No
	Female	22	VR Programming	Yes
	Female	21	Kinesiology	No

4.2 Procedure

Our co-design workshop consisted of four main parts: an introduction, two brainstorming discussions, and a VR interaction segment. First, all participants were introduced to the goals and procedures of the co-design workshop. To facilitate group discussions, the participants also introduced themselves, including their names, backgrounds, and expertise, to the other group members. Next, in the first brainstorming discussion, each participant individually brainstormed and designed their posture correction interventions before sharing and discussing their ideas. In the subsequent VR interaction segment, participants experienced the posture correction interventions in VR that we had implemented as described in Section 3.2 and completed brief evaluation surveys on their usability. Finally, they engaged in another brainstorming discussion to refine their initial intervention designs or generate new ideas. Each co-design workshop session lasted up to 2 hours. Video recordings, evaluation survey data, and design sketches were collected for analysis. Further details about the workshop are as follows:

4.2.1 Brainstorming Discussion. An initial brainstorming segment was conducted before the VR interaction segment to allow participants to generate their unique ideas for posture correction interventions. Discussions were then held around the following questions:

- Why do you think this intervention would be effective?
- What do you think are the strengths of this intervention?
- Are there any disadvantages/trade-offs that you can think of regarding this intervention?
- What are some possible factors in VR gaming that may affect the effectiveness of this intervention?

Another brainstorming segment was run after the VR segment, allowing participants to enhance their initial designs or generate novel ideas. A new set of questions was used for the second discussion to examine how the participants' revised designs differed from their initial ones:

- How did the VR interventions affect your design?
- Why do you think this intervention would be effective compared with your previous design?
- What are the new strengths, disadvantages, and trade-offs of your new intervention?
- What are some possible factors in VR gaming that may affect the effectiveness of your new intervention?

Both sets of questions were adapted from previous studies on co-designing posture correction interventions [52, 70].

During each 5-minute brainstorming segment, to better understand the participants' intervention design, each participant was asked to sketch their designs on a paper. Figure 4 shows samples of participants' designs from both the first and second brainstorming discussions. The former interventions (Figure 4.A) include prominent warning popups and notifications that explicitly instruct the user to correct their posture. These warnings occupy a significant portion of the display, with one even requiring user interaction. In contrast, the latter interventions (Figure 4.B) are more subtle, featuring implicit notifications placed in the corner or along the side of the display. One intervention also proposes grayscaling the screen as a possible approach.

4.2.2 VR Interaction. After the first brainstorming segment and before the second, each participant experienced all four of our prototype VR interventions. They were instructed to intentionally assume an improper posture state for approximately 10 seconds to trigger each intervention, return to a good posture, and repeat this cycle five times or until they fully understood how each intervention worked. After experiencing all interventions, participants completed a short survey rating each intervention's intuitiveness, non-intrusiveness, and likelihood of future usage on a Likert scale from 1 to 7. The survey also included an open-ended question asking what participants liked or disliked about each intervention.

4.3 Results

This section summarizes the results of the co-design workshop, including average survey scores with standard errors, participants' open-ended feedback on the prototyped intervention designs, and their brainstormed interventions. We also discuss our refined interventions, which incorporate the participants' feedback and suggested designs. We chose not to conduct statistical tests on the survey scores due to the small number of participants, the exploratory nature of this study focusing on refining the visual interventions, and the plan to conduct a comprehensive evaluation study later.

4.3.1 Survey Score. As shown in Figure 5, while the Icon intervention was considered the most intrusive ($M = 2.89 \pm 0.73$), it was also rated the most intuitive ($M = 5.33 \pm 0.37$) and received the highest average score for future usage ($M = 5.33 \pm 0.44$). The Grayscale intervention had the highest average non-intrusiveness score ($M = 3.78 \pm 0.72$) and also received the second highest average ratings for intuitiveness ($M = 4.67 \pm 0.73$) and future usage ($M = 4.00 \pm 0.78$). On the other hand, not only did the Moving Ball intervention receive the lowest average ratings for both future usage ($M = 3.33 \pm 0.76$) and intuitiveness ($M = 4.11 \pm 0.70$), and it was also considered quite intrusive ($M = 3.00 \pm 0.67$). Finally, while the Circle Fill intervention was relatively intuitive ($M = 4.56 \pm 0.38$) and users rated it highly for future use ($M = 4.00 \pm 0.58$), it was perceived as more intrusive compared to the other interventions ($M = 3.33 \pm 0.47$).

4.3.2 Open-ended Feedback. The open-ended survey responses supported the rating data, with participants expressing clear preferences and dislikes for our prototyped posture correction interventions. First, they praised the Icon intervention for being straightforward and agreed that an explicit visual cue like an icon would help users easily understand and manage their posture in VR gameplay. In particular, P2 commented, *"Out of all the interventions, Icon is clearest and most understandable,"* while P4 mentioned, *"Icon can be used in any VR game, but the other [interventions] are not."* Other participants also agreed that Icon is the most adaptable intervention for future use due to its simplicity and flexibility for any VR application. However, participants also noted that the prototyped Icon design was overly complex and might distract users from the primary VR game. P1 mentioned, *"It took me a while to understand how the colors in the icon correspond to different levels of bad posture."* P2 added, *"I sometimes play puzzle-solving games in VR, and the colors of the Icon would be distracting."* Based on this feedback, we simplified the design to use only two levels — good posture and improper posture — for our refined Icon intervention.

Second, the Grayscale intervention was praised for being non-intrusive and understandable, but participants were concerned about its adaptability for integration into commercial VR applications. While P9 noted that she could easily recognize the connection between the grayscale screen and her improper posture, P4 commented, *"The grayscaling is very stark and bad for VR games with detailed graphics."* To address this issue, we redesigned the Grayscale intervention to include a less drastic shift in intensity, ensuring that in-game colors remain visible.

On the other hand, participants found both the Moving Ball and Circle Fill interventions difficult to understand and felt that they conflicted with the Icon intervention. P5 specifically mentioned that the Circle Fill intervention was too similar to the Moving Ball intervention, and both served the same purpose as the Icon but were less effective. Other participants agreed with this notion, with

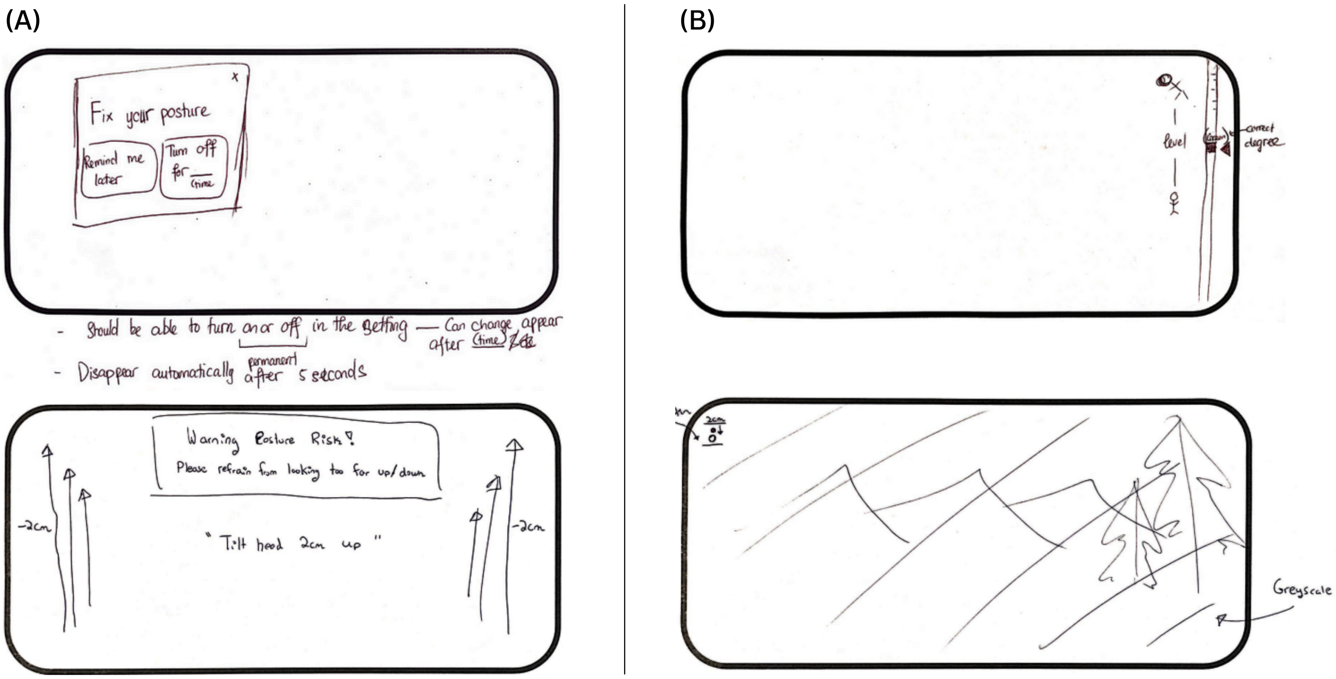

Figure 4: Participants' brainstormed interventions in the co-design workshop were compared before experiencing our prototyped interventions (A) and after experiencing them (B).

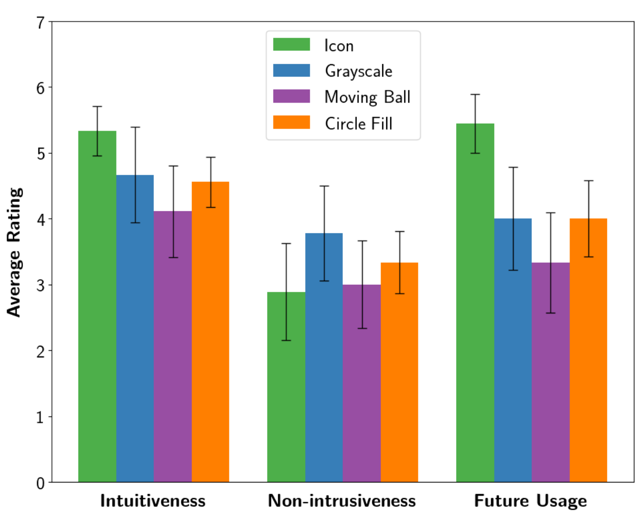

Figure 5: The average participant survey scores, along with standard errors, for the prototyped interventions measured across three factors: intuitiveness, non-intrusiveness, and likelihood of future use.

P6 stating, *"It took me a few tries to understand the mechanics of both [Moving Ball and Circle Fill] interventions. The Icon one was much more intuitive"*. P8 added, *"I would not use the [Moving Ball and Circle Fill] interventions for the competitive games I play."* However, some participants appreciated how the Moving Ball intervention naturally encouraged them to look upwards. For example, P1 said, *"I prefer Moving Ball to Icon because it made me naturally look up, rather than having to interpret the meaning of the icon."* Overall, 7 out of 9 responses to the Moving Ball and Circle Fill interventions were unenthusiastic, with positive feedback mainly noting their subtle influence on improving posture. Therefore, we decided not to use these designs in the refined intervention set and instead incorporated the feedback to develop a better ambient design for the refined Grayscale intervention.

4.3.3 Brainstormed Interventions. Figure 4.a displays participants' brainstormed interventions before the VR interaction segment, while Figure 4.b shows the modified interventions following the VR experience. Interestingly, before experiencing the prototyped VR interventions, all participants recommended using explicit visual feedback, yet afterward, they favored the less intrusive option of implicit background change provided by the Grayscale intervention. While participants noted that their initial designs were influenced by notifications and warning dialogs in mobile or desktop applications, through the VR experience, they realized that such designs would be much more intrusive in a VR environment. For example, P6 mentioned, *"I didn't expect how in-your-face the visual notifications would be in VR."* Additionally, participants observed that grayscaling could subtlely convey the gesture state, with P9 claiming, *"Grayscale did not interrupt my VR experience like the other [interventions]."* This shift in preference reinforced our decision to refine the interventions in two directions: explicit visual feedback and implicit background changes.

Furthermore, alongside the shift in preference towards the grayscaling intervention, participants moved from discrete interventions — providing warnings only when bad posture is detected — to more continuous interventions that gradually increase in intensity as posture worsens. P5 emphasized, *"I prefer interventions that gradually adjust based on my posture, rather than just giving a warning when it's already bad."* Our refined interventions incorporate this feedback by gradually adjusting the opacity of the explicit design and the grayscale level of the implicit design in correlation with the degree of improper posture.

Finally, although the design philosophy evolved between the first and second rounds of brainstorming, common themes remained. First, the interventions mainly fell into two categories: explicit visual feedback, such as warning signs, icons, or text signals, and implicit background changes, like grayscaling. Second, most interventions were inspired by personal experiences with posture during computer and phone use. Consequently, the designs featured familiar color schemes — red for improper posture notifications and green for proper posture — as well as common themes such as pop-up boxes and arrows (see Figure 4) to ensure user familiarity and usability. Finally, participants stressed the importance of customization for all interventions, allowing users to fine-tune each intervention according to their preferences. P7 added, *"I would like to change the intensity and style of the intervention to my liking."* We included these insights in our design guidelines for posture correction interventions.

4.3.4 Refined Interventions. As discussed previously, based on feedback from the VR interaction segment and ideas from the brainstorming segments, we refined our interventions in two directions: explicit visual feedback using a simple icon and implicit background change through grayscaling (Figure 1). In both interventions, we adopted a continuous approach where the icon's opacity and the grayscaling's intensity vary based on the severity and duration of improper posture. For simplicity, we will refer to these two refined interventions as Icon and Grayscale, respectively.

5 USER STUDY 2: EVALUATION STUDY

With the newly refined interventions, we conducted a controlled experiment to assess the effectiveness of each intervention in managing posture during VR gameplay, compared to a control condition with no intervention.

5.1 Hypothesis

We aim to test whether the refined interventions are effective in reducing the level and duration of improper posture in VR gaming users, as well as decreasing the number of intervention triggers. Therefore, our hypotheses are as follows:

- **H1.** The use of interventions will reduce participants' level of forward head posture, as indicated by an increase in head tilt angle.
- **H2.** The use of interventions will reduce participants' level of slouching, as indicated by an increase in normalized height.
- **H3.** Participants would spend less time in improper posture when interventions are deployed.
- **H4.** The actual number of times each intervention is triggered would be less than the number of times they would have been triggered in the control condition.

5.2 Participants

18 participants (11 males, 7 females) were recruited from the university, consistent with the participant range of 12 to 30 in prior works evaluating posture management systems for virtual reality [2, 57, 64]. The participants had an average age of 23.56 ± 0.72. Those who took part in the co-design workshop were not eligible for this evaluation study. All participants had no history of postural abnormalities or musculoskeletal disorders and reported little to no prior experience with virtual reality (VR) applications. The inclusion criteria ensured that participants had no pre-existing conditions that could affect their posture during the experiment. All participants consented to take part in the study, and the study was approved by our institutional review board.

5.3 Methods

We employed a within-subject methodology for our experiment, which included three distinct conditions. Each participant completed the same target selection task in VR three times: once without any interventions (control), once with the explicit *Icon* intervention, and once with the implicit *Gray* intervention. We collected quantitative data on participants' posture states, including their normalized height, head tilt angle, improper posture duration, and intervention trigger count. Additionally, we gathered qualitative survey responses on the interventions' intuitiveness, non-intrusiveness, and potential for future use, along with open-ended comments providing general thoughts and suggestions for each intervention.

5.3.1 Conditions. Each participant in the evaluation study performed a target selection task under three conditions, corresponding to the two refined interventions from the co-design workshop and a control condition, as follows:

- **Control:** No intervention was provided.
- **Icon:** When a participant was in an improper posture, an Icon would be displayed to explicitly instruct the participant to correct their posture
- **Grayscale:** When a participant was in an improper posture, the VR environment's background would be grayscaled to implicitly encourage them to correct their posture.

5.3.2 Task. Since the current research focuses on posture correction during VR gameplay, the evaluation task needs to simulate a typical VR gaming experience. The task had to be engaging enough to resemble a real game while also potentially distracting participants from their posture. To this end, we chose a target selection task [73], where participants used VR controllers to continuously select targets presented in front of them over 10 minutes (Figure 6). We chose the target selection task over other tasks such as navigation or object manipulation because not only is it a fundamental aspect of interaction in VR [18] that has been widely used in previous VR studies [3, 27, 41], but also it aligns well with our

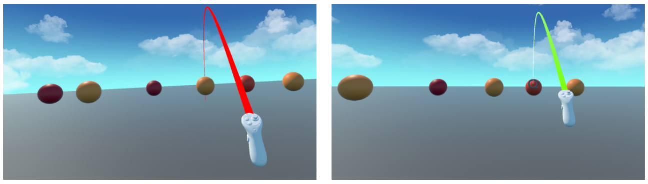

Figure 6: The target selection task requires participants to choose the correct ball based on its color and the ray cast from the VR controller. The ray remains red (left) until the participant selects the correct ball (right), on which the ray turns green.

objectives of both simulating a gaming experience and involving enough repetition to make participants neglect their posture.

Participants stood in a designated area and used a red ray cast from the VR controllers to point at and select targets appearing in various locations within the VR environment. All participants were right-handed and were instructed to hold the VR controller with the red ray in their right hand, while their left hand held the other controller that did not influence the task. After selecting a target, it would move to a new random location, requiring participants to select it again. The repetitive nature of the task was designed to potentially divert participants' attention from their posture. To enhance engagement and mimic a gaming experience, participants were informed that their performance would be scored and displayed at the end of the 10 minutes. However, we intentionally chose not to record these scores for analysis, as the primary focus of the experiment was on posture state as the dependent variable.

5.3.3 Procedure. First, each participant received instructions on how to complete the target selection task and then had a 2-minute practice run to become familiar with the VR equipment and task requirements. In addition, participants were informed that there might be visual changes in the VR display during some trials 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.

Next, each participant completed the target selection task under all three conditions, which were presented in a randomized order using a balanced Latin Square design. During the task, participants' posture state was continuously monitored and recorded at a rate of 10 times per second. After finishing the task under each condition, participants completed a brief post-trial questionnaire to provide feedback on the intervention's intuitiveness, intrusiveness, and likelihood of future usage. This questionnaire was not administered for the control condition.

After completing the tasks for all three conditions, participants took part in a post-study survey to share their comments and thoughts on the interventions and study design. Following this, a debriefing session was held to explain the purpose and details of the experiment. The study was conducted in a controlled laboratory environment, with each session lasting approximately 45 minutes. The sessions included instructions, a practice run, the execution of tasks under all three conditions, and debriefing.

5.3.4 Data Collection. We collected quantitative data on each participant's posture, including normalized height (in meters, to measure slouching), head tilt angle (in degrees, to measure forward head posture), time spent in improper posture (in minutes), and trigger count (the number of times interventions were triggered or would have been triggered in the control condition). Additionally, the post-trial questionnaire gathered qualitative ratings on each intervention's intuitiveness, non-intrusiveness, and likelihood of future use on a Likert scale from 1 to 7. It also surveyed general comments and suggestions for improving the intervention design or study procedure.

5.3.5 Analysis. The quantitative data on normalized height, head tilt angle, time spent in improper posture, and trigger count were plotted and visually inspected to identify any outliers or anomalies. While the duration of improper posture and trigger count data were within normal ranges, we identified outliers in the normalized height and head tilt angle data, with values falling outside the 15th and 85th percentiles (greater than 0.1 meters for normalized height and greater than 30 degrees for head tilt angle). These extreme values likely resulted from users looking far down at the ground or up toward the virtual sky (for head tilt angle), or intentionally dipping or jumping their bodies (for normalized height). We observed that such values were infrequent and typically appeared at the start and end of each trial, likely due to users preparing for or finishing the task, which caused their behavior to differ from when they were actively engaged in the task. To address these issues, we implemented two preprocessing steps:

(1) To eliminate most of the outlier values at the beginning and end of each trial, we removed the first and last 50 entries from each trial, corresponding to the initial and final 5 seconds.
(2) To adjust the remaining outliers to more reasonable values, we restricted the data points to a range of ±30 degrees for head tilt angle and ±0.1 meters for normalized height. Values outside these ranges were clipped to the nearest boundary, while values within the ranges remained unchanged.

After preprocessing the quantitative data, we conducted Kolmogorov-Smirnov tests to assess the normality of pitch, normalized height, improper posture duration, and trigger count for each condition. If the data satisfied the normality assumption, we performed one-way ANOVAs to compare results across the three conditions. Otherwise, we used the Kruskal-Wallis test instead. When these tests showed significant differences, we conducted post-hoc pairwise comparisons—using t-tests for normally distributed data or Dunn tests for non-normal data—with Bonferroni corrections to identify specific differences between the conditions. For the participants' ratings of future usage, intuitiveness, and non-intrusiveness, we applied Wilk-Shapiro tests to check for normality. Based on the results, we used t-tests to compare ratings between the Icon and Grayscale conditions if the data were normally distributed, or Whitney-Mann U-tests if the data did not meet normality assumptions.

5.4 Results

This section summarizes the results of the evaluation study, including average statistics with standard errors for both quantitative measurements and qualitative survey scores. We also review the outcomes of statistical tests and present participants' responses to the open-ended survey questions.

5.4.1 Quantitative Data. Although the Control condition had a lower average head tilt angle ($M = 0.542 \pm 1.753$) compared to both the Icon condition ($M = 3.125 \pm 1.409$) and the Grayscale condition ($M = 2.241 \pm 1.231$), ANOVA tests showed that the differences were not statistically significant ($F(2, 51) = 0.79, p = 0.461, \eta^2 = 0.03$). The findings reject hypothesis H1, suggesting that the interventions did not effectively regulate the average head tilt angle or, consequently, correct forward head posture.

On the other hand, Kruskal-Wallis tests showed a significant difference in normalized height between the conditions ($H^*(2, 51) = 6.423, p^* = 0.04, \eta^2 = 0.121$). Specifically, participants in the Control condition had a lower normalized height ($M = -0.015 \pm 0.0049$) compared to those in both the Icon condition ($M = 0.002 \pm 0.0032$) and the Grayscale condition ($M = -0.001 \pm 0.0013$). The post-hoc Dunn tests revealed that the statistical significance was mainly due to the Control condition differing from the Icon condition ($p^* = 0.025$) and the Grayscale condition ($p^* = 0.032$). There was no significant difference between the Icon and Grayscale conditions ($p = 0.915$). The results support hypothesis H2, which predicted that posture correction interventions would increase participants' normalized height, indicating less slouching. Additionally, the Icon and Grayscale interventions were found to be equally effective in managing slouching in VR users.

ANOVA tests revealed a significant difference in the duration of improper posture between the conditions ($F^*(2, 51) = 4.171, p^* = 0.021, \eta^2 = 0.141$). On average, participants in the Control condition spent 4.837 ± 0.991 minutes out of 10 in improper posture, which was longer compared to the Icon condition ($M = 2.409 \pm 0.703$ minutes) and the Grayscale condition ($M = 1.8 \pm 0.585$ minutes). Nevertheless, the post-hoc t-tests only revealed a significant difference between the Control and Grayscale conditions ($t^*(34) = 2.601, p^* = 0.041$). No significant differences were found between the Control and Icon conditions ($t(34) = 1.998, p = 0.161$) or between the Icon and Grayscale conditions ($t(34) = -0.619, p = 1.0$). The statistics support hypothesis H3, showing that the refined interventions, particularly Grayscale, effectively reduced the duration of improper posture compared to the Control condition. This result is surprising because the qualitative findings later revealed that participants preferred the Icon intervention, even though the Grayscale intervention was more effective in minimizing improper posture.

Finally, the average number of times the interventions were triggered or would have been triggered were as follows: Control condition, $M = 10.11 \pm 3.041$; Icon condition, $M = 10.89 \pm 2.189$; and Grayscale condition, $M = 11.94 \pm 2.975$. Kruskal-Wallis tests found that the differences were not statistically significant ($H(2, 51) = 1.241, p = 0.538, \eta^2 = 0.023$). Therefore, hypothesis H4 is rejected, indicating that the use of interventions did not reduce the number of times interventions were triggered.

5.4.2 Participants' Ratings. Future usage ratings were higher for the Icon condition ($M = 4.72 \pm 0.23$) compared to the Grayscale condition ($M = 3.56 \pm 0.35$), with a significant difference found with the Whitney-Mann U-test ($U^{**}(34) = 256.000, p^{**} = 0.002$). Additionally, intuitiveness was rated higher for the Icon condition ($M = 5.28 \pm 0.33$) than for the Grayscale condition ($M = 3.67 \pm 0.38$), with t-tests showing a statistically significant difference ($t^{**}(34) = 3.199, p^{**} = 0.003$). This indicates that participants are more likely to use the Icon intervention in their VR gaming applications due to its greater ease of understanding. However, t-tests also found no difference in non-intrusiveness between the Icon ($M = 4.22 \pm 0.33$) and Grayscale conditions ($M = 4.61 \pm 0.37$), as shown by the non-significant result ($t(34) = -0.783, p = 0.439$), suggesting that participants perceived both interventions as similarly non-intrusive. This result contrasted with the findings from the co-design workshop, where the Icon intervention was perceived as more intrusive than the Grayscale intervention.

Additionally, the post-study questionnaire, which asked participants to choose their preferred intervention, found that most favored the Icon intervention. Specifically, 75% of participants preferred the Icon intervention, while only 25% preferred the Grayscale intervention. Participants' open-ended responses highlighted this preference. P4 noted, *"The icon made me more aware of my posture compared to the grayscale. The grayscale kept me more engaged and less bored, but I didn't think about changing my posture when I saw the color change."* Similarly, P12 commented, *"The icon made it clear that it was about my posture, whereas the grayscale didn't make it obvious what to adjust to bring it back to normal."*

6 DISCUSSION

In this section, we interpret the results of the current research, outline design guidelines for posture correction interventions, address the study's limitations, and suggest directions for future research on managing posture in VR applications.

6.1 Result Interpretation

We found that hypothesis H1 was not supported by the data, indicating that the interventions did not effectively regulate forward head posture. One explanation for this is the nature of the target selection task. Since the targets were programmed to be at the participants' eye level, they implicitly encouraged the participants to maintain a forward-facing posture for extended periods, thereby minimizing variations in head tilt angle that hypothesis H1 aimed to explore. In other words, to complete the task, there was no need for participants to tilt their heads up and down. While this study design helped separate instances where the game intentionally requires head movement from those where the user has improper posture, it also made the collected data less likely to support hypothesis H1.

Nevertheless, the interventions effectively regulated slouching, as evidenced by the supported hypothesis H2. This can be attributed to the target selection task encouraging participants to maintain a straightforward position throughout the study. By minimizing forward head posture, improper posture was more likely to manifest as slouching, which the interventions successfully reduced.

Regarding hypotheses H3 and H4, the results indicated that while the duration of improper posture was reduced with intervention use, the number of intervention triggers was not. This discrepancy may be due to the method used to record triggers. In our study, a trigger was logged each time the intervention was activated, regardless of how long the participant maintained improper posture. Consequently, even prolonged instances of improper posture would

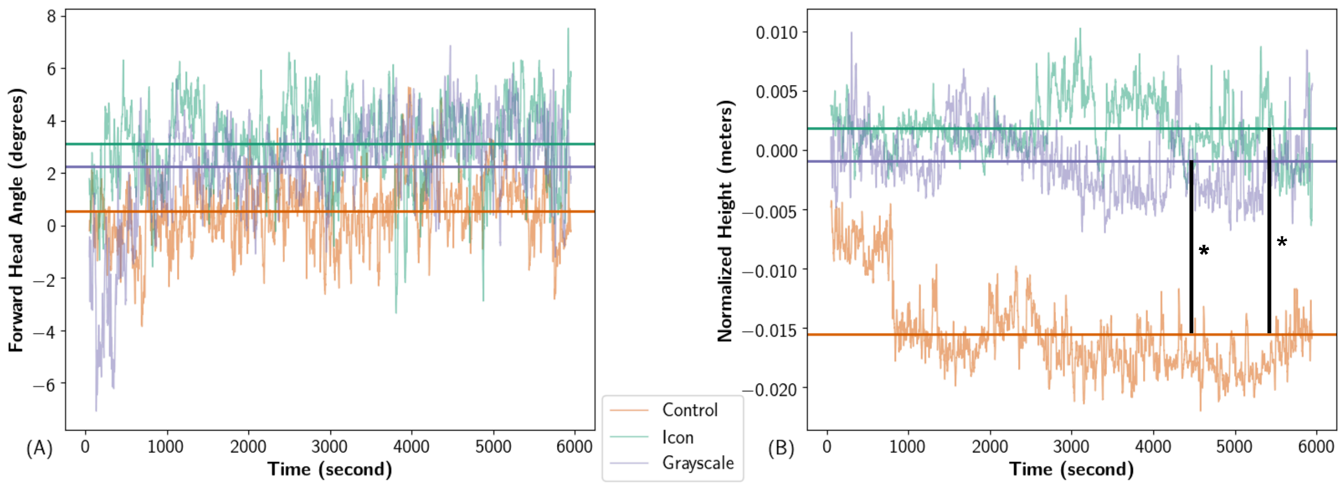

Figure 7: Average head tilt angle (left) and average normalized height (right) across participants plotted against time for all three conditions. There was no significant difference in head tilt angle across the three conditions. However, a significant difference was observed in normalized height: both the Icon and Grayscale conditions showed higher normalized heights compared to the Control condition ($p < 0.05$, *).

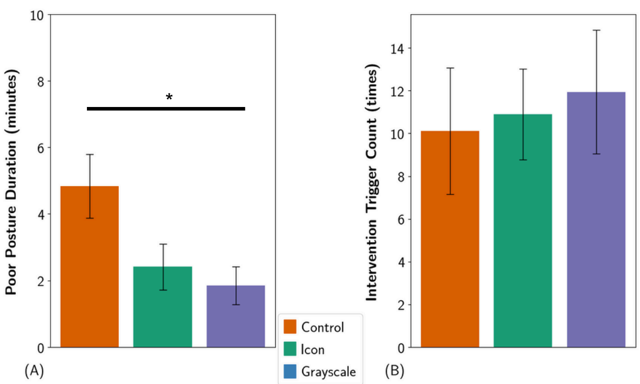

Figure 8: We compared the average duration of improper posture (A) and the number of intervention triggers (B) across various conditions. The duration of improper posture in the Control condition was significantly longer than in the Grayscale condition ($p < 0.05$, *).

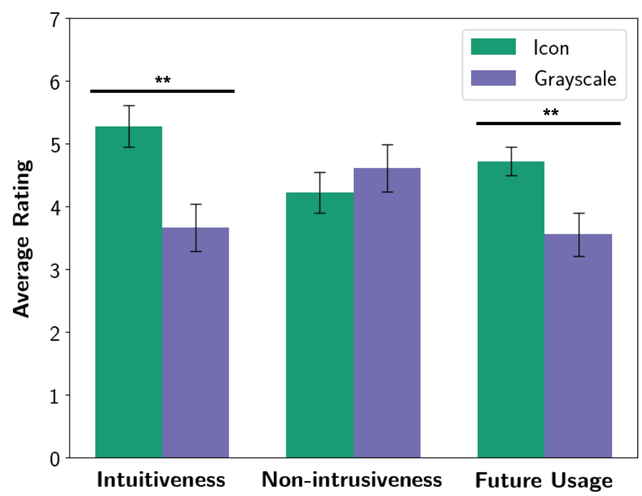

Figure 9: The average ratings of intuitiveness, non-intrusiveness, and likeliness for future usage between the icon intervention and the grayscale intervention. The icon intervention received significantly higher ratings for intuitiveness ($p < 0.01$, **) and likeliness for future usage ($p < 0.01$, **), while there was no significant difference between the two conditions for non-intrusiveness.

be recorded as a single trigger. This approach likely explains why hypothesis H3, which focused on the duration of improper posture, showed significant results, while hypothesis H4 did not.

Regarding the qualitative results, we found that the Icon intervention was rated higher for both future usage and intuitiveness compared to the Grayscale intervention. This aligns with our earlier findings from the co-design workshop, reinforcing the idea that while implicit background changes like grayscaling can be effective for regulating improper posture in VR gameplay, participants found that an explicit visual cue, such as an icon, is more easily understood and better suited for future use. This preference is further supported by the post-study questionnaire, which showed that 75% of participants preferred the Icon intervention, while only 25% preferred the Grayscale intervention.

Nevertheless, there were differences between the survey results of the co-design workshop and the evaluation study. While the co-design workshop found that participants considered the Grayscale intervention less intrusive than the Icon intervention, the evaluation study did not show higher non-intrusiveness ratings for the Grayscale intervention compared to the Icon. This discrepancy may be due to the design of the target selection task: the target colors were chosen to be similar but distinguishable to increase task difficulty. When the Grayscale intervention was applied, the similarity in colors was amplified, making it more challenging to differentiate between correct and incorrect targets. This increased difficulty likely contributed to a higher perception of intrusiveness in the evaluation study.

Interestingly, while participants rated the Grayscale intervention lower than the Icon intervention in the evaluation study—reporting similar levels of non-intrusiveness but lower intuitiveness and likelihood of future use—the Grayscale intervention was more effective at reducing the duration of improper posture. Specifically, the time spent in improper posture was significantly reduced with the Grayscale intervention compared to the Control condition, whereas no significant difference was observed with the Icon intervention. Therefore, despite the Grayscale intervention being potentially less intuitive, it should still be considered for tasks that allow for subtle regulation of improper posture. Additionally, improving the implementation of the Grayscale intervention to better fit the task could make it less intrusive and more understandable for users.

Overall, the results of this study highlight the potential effectiveness of posture correction interventions in VR environments, particularly for reducing slouching and decreasing time spent in improper posture. Consistent with previous HCI research that utilized data from VR system headsets [33, 45, 61], we also demonstrate that data collected directly from the headset can be used to effectively manage users' posture during VR gameplay. While users preferred the explicit visual icon intervention, the quantitative data indicate that implicit background changes can be more effective and useful depending on the task. With more detailed and refined designs, these interventions could achieve greater user acceptance and be more widely adopted in commercial VR applications.

6.2 Design Guidelines

Alongside the statistical findings, we gathered valuable comments and suggestions about the interventions from participants in both the co-design workshop and the evaluation study. Based on this feedback, we propose the following design guidelines for posture correction interventions.

6.2.1 Balancing intuitiveness and intrusiveness with simplicity and familiarity. Participants in the co-design workshop identified a tension between making interventions clear enough to be effective and subtle enough to avoid being intrusive. To address this, they suggested keeping the designs simple and clear. This includes using familiar icons with color schemes, or short and legible text pop-ups for explicit visual feedback and employing grayscaling or other noticeable changes for background modifications. Participants preferred these straightforward designs over more complex ones, like Moving Ball and Circle Fill. Given that these simple designs effectively managed slouching in the evaluation study, we highly recommend using similar approaches for other posture correction interventions. In summary, posture correction interventions should follow one of two design directions: explicit visual feedback or implicit background changes, carefully balancing intuitiveness and intrusiveness. This aligns with previous studies on posture intervention [60, 62], which have shown that notifications or adjustments designed to correct posture must be noticeable enough to influence user behavior, yet subtle enough to avoid becoming disruptive.

Nevertheless, implementing these simple designs in fast-paced or competitive video games requires extra considerations. One participant mentioned the use of these interventions in competitive gameplay can be highly disruptive. In such environments, where quick reflexes and focus are critical, even subtle interventions may disrupt the player's flow and performance. Designers must ensure that any intervention, whether explicit or implicit, does not distract or cause frustration during intense gameplay. Additionally, the simplicity of the design should not compromise its effectiveness in correcting posture without interfering with the player's primary objectives in the game.

6.2.2 Customization. Customization emerged as a significant factor, with participants in the co-design workshop expressing interest in personalizing the interventions by choosing various icons and adjusting grayscale levels to suit their preferences. Previous studies in user interface and user experience have highlighted that allowing user customization leads to fewer errors, greater user acceptance, and higher satisfaction [1, 7, 34, 38]. In the current context, as mentioned previously, participants in the evaluation study noted that grayscaling made the target selection task more challenging. For instance, P13 commented, *"It would be nice if I could make the grayscaling affect only the sky color, instead of the targets."* Some participants mentioned that they already had difficulty distinguishing colors, and the Grayscale intervention exacerbated this issue. This underscores the need for customizable interventions tailored to different tasks, contexts, and demographics in VR applications.

However, implementing customizable interventions in VR presents several software challenges. One significant issue is ensuring real-time performance while applying dynamic changes, as VR environments require constant rendering and processing to maintain immersion. Additionally, allowing users to adjust visual elements like icons or grayscale levels introduces complexity in managing multiple settings that must be seamlessly integrated with the VR system's existing interface. The customization features also need to be intuitive, requiring careful design to ensure that users can easily navigate these options without disrupting the VR experience.

6.2.3 Gradual Notification. One prominent feedback from participants in the co-design workshop was that our prototyped designs were too abrupt, appearing suddenly when participants adopted improper posture and disappearing just as quickly when they corrected it. To address this, they suggested using more gradual changes in the intensity of interventions and incorporating a fade-in/fade-out mechanism for pop-up visual cues. These adjustments would make the interventions more noticeable and less jarring. The evaluation study showed that these implemented changes effectively managed improper posture. This aligns with previous research on feedback for behavior change, which suggests that gradual feedback is more effective than instant feedback in influencing a person's behavior [4, 62]. Therefore, we recommend that future designs of posture correction interventions in VR applications apply this design principle.

6.3 Limitations & Future Works

As previously discussed, the inability of the refined interventions to manage forward head posture can be attributed to the design of the target selection task used in our study. The task inherently biases participants toward minimizing forward head posture, making improper posture more likely to manifest as slouching, which our interventions successfully regulated. Future research could implement experimental tasks that better capture these nuances, potentially examining the effectiveness of interventions targeting head tilt correction versus those addressing slouching behaviors.

We also found that the duration of improper posture decreased with intervention use, but the number of intervention triggers did not. This discrepancy is largely due to how we defined what counts as an intervention trigger. Future studies might benefit from a more longitudinal approach with a clearer definition of intervention triggers. This could help determine whether, in the long term, using these posture interventions in VR applications encourages users to maintain good posture consistently, thereby reducing the number of intervention triggers.

Additionally, some participants reported that the task was too mundane, suggesting it may not accurately simulate the engagement levels typical of real VR gaming experiences. Additionally, our task was color-based, which was affected by the Grayscale intervention. Future studies should design a more engaging and streamlined task in which participants find the experience more immersive and reflective of real-world VR gaming. The task should also be designed to accommodate different intervention strategies without compromising their effectiveness. For example, using contrasting shapes or patterns instead of relying solely on color can help mitigate the impact of the Grayscale intervention. This approach will not only improve the validity of the study but also offer valuable insights into designing effective and enjoyable VR experiences that promote good posture.

Another avenue for future research is to incorporate additional sensing and feedback modalities into the posture detection and correction framework of the VR system. While the current study focuses solely on visual interventions, previous studies have demonstrated that audio and haptic feedback can be just as effective in managing posture across various contexts [11, 37]. Expanding the use of these modalities could enhance the effectiveness and adaptability of VR-based posture correction systems.

Lastly, further research is also needed to explore how posture correction interventions can be made more inclusive and accessible for individuals with disabilities or visual impairments. Current solutions, such as using icons or grayscale visual feedback, may not be suitable or effective for these groups. Future studies could investigate alternative methods to ensure that posture correction systems are usable and beneficial for a wider range of users, regardless of their abilities or sensory limitations.

7 CONCLUSION

In conclusion, our work provides the first comprehensive exploration into the use of posture management tools within VR gaming applications. We developed a novel posture detection framework, evaluated various designs for posture correction interventions, and conducted a controlled study that validated the efficacy of our approach in reducing slouching and time spent in improper posture. This research paves the way for the development of future VR gaming experiences and other applications that are not only engaging but also promote healthy user posture. By integrating effective posture correction techniques and user-centric design principles, these advancements will ensure that users can enjoy immersive experiences without compromising their physical well-being. Moving forward, future research should explore alternative visual designs and different feedback modalities for posture correction interventions that can further optimize user experience and effectiveness.

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