Slow Robots for Unobtrusive Posture Correction

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Figure 1: We moved a robotic monitor in very slow motions to correct users' posture unobtrusively. Our system identify users' current posture based on the center of their eyes (A). When users sit unbalanced (B1), the monitor slowly moves (B2). When users correct posture due to the monitor motions (C3), the monitor resets to default setting (C4).

ABSTRACT

Prolonged static and unbalanced sitting postures during computer usage contribute to musculoskeletal discomfort. In this paper, we investigated the use of a very slow moving monitor for unobtrusive posture correction.

In a first study, we identified display velocities below the perception threshold and observed how users (without being aware) responded by gradually following the monitor's motion. From the result, we designed a robotic monitor that moves imperceptible to counterbalance unbalanced sitting postures and induces posture correction.

In an evaluation study (n=12), we had participants work for four hours without and with our prototype (8 in total). Results showed that actuation increased the frequency of non-disruptive swift posture corrections and significantly reduced the duration of unbalanced sitting. Most users appreciated the monitor correcting their posture and reported less physical fatigue. With slow robots, we make the first step toward using actuated objects for unobtrusive behavioral changes.

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CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; • **Computer systems organization →** Robotics.

KEYWORDS

Robot Monitor; Slow Interaction; Ergonomics

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1 INTRODUCTION

Desk-related work is a known cause of musculoskeletal discomfort [8, 22, 42, 44]. Increasingly, ergonomists have recognized sitting as a health threat [41] and frequently adjusting posture has been suggested to reduce discomfort and maintain physical health. For that reason, highly adjustable chairs have been designed to afford a range of body postures between sitting and standing [27].

In HCI, several posture monitoring and notification systems have been proposed. Previous studies have shown [10] that the more obtrusive the notification, the more effective it can be for evoking posture changes. However, there are concerns about the negative effect of frequent interruptions on task performance [1, 50].

Instead of alerting users, we set out to investigate an unobtrusive, yet effective, posture correction method. We hypothesized that users will follow a moving display not only with their eyes but also with their head, neck, and upper body, thereby inducing a posture change. Our idea is based on prior findings about human perception and behaviors that indicate coordinated eye and head movement when following a moving target [35]. Likewise, several studies in HCI have reported a similar effects, such as with proximity [12], mouse pointers [23], and display content [31]. We also built on the perception phenomenon of "change blindness" people's poor ability to detect changes in visual stimuli [33]. Change blindness has been researched extensively with visual stimuli but, as far as we know, not with actuated physical objects.

In this paper, we actuated a monitor with a robotic arm and moved it slowly, below the perception threshold. When a user sits unbalanced, the robotic monitor moves in the opposite direction and angle of the unbalanced posture. When the user corrects their posture, the monitor resets to the default recommended position and angle.

First, we conducted a user study that confirmed people respond to a slow-moving monitor with a slow and correlating posture change. The results suggested that a monitor speed lower than 0.5 mm/s is hard to detect and might be below the human perception threshold. In the main study, we had 12 participants work with our prototype under two conditions (with and without actuation) for four hours each or eight hours in total. We observed a significant decrease in the duration of unbalanced postures and also found non-disruptive but swift posture change. Based on the results, we learned that a physical object can be moved so slow that users cannot perceive it's motion and we can utilize this effect in HCI.

The contributions of this paper are 1) the design of an actuated monitor that moves below the perception threshold, 2) an observation study on how and when users react to very slow motions, and 3) an evaluation study that shows the effectiveness of the interaction in a real-world scenario with a diverse set of activities over several hours.

We understand the ergonomic limitations of this study. In reality, frequent posture changes are seen as more important than maintaining a balanced posture. In fact, we encountered users ignoring the monitor to maintain an unhealthy but comfortable posture in the study. However, in this paper, posture correction is a sample application of slow and unobtrusive interaction. Support for multiple poses rather than a single recommended pose is future work.

2 RELATED WORK

Our design builds on related work on posture monitoring and notification systems as well as the work on actuated and shape-changing objects.

Posture Monitoring Systems

A number of systems in HCI provide feedback on posture with the aim of reducing musculoskeletal discomfort [10]. Such systems employ a variety of posture-detection techniques including wearable sensors embedded in clothing [21, 45], pressure sensitive mats on the floor [7], table-top surfaces [34], chairs [24], and camera-based systems [40].

Interaction types range from calm interactions taking place in the periphery [46], to obtrusive interactions occurring at the center of attention or foreground [13]. Examples of calm designs involve objects or visualizations that mimic the inclination of a user's back angle [15]. More intrusive examples would include notifications through a pop-up window [14], a smartphone [19], or vibrotactile feedback through a wearable device, a chair [49], or shaking the monitor [4]. The most forceful notifications interrupt users' tasks by locking the screen or even disturbing other users [32].

Posture Correction Systems

Instead of notifications, other systems adapt to the user or aim to correct their posture for them. The Stir electric height-changing desk [6] suggests an occasional height change with a gentle up and down motion. The Salli Autosmart desk [34] monitors users' activity and automatically changes the height accordingly. We built upon these prior efforts but our goal is to make the interaction unobtrusive [31], taking place in the background of the interaction [13].

Robot Furniture

Environment that adapts to users [25, 36, 39, 48] have been investigated, and a large body of work describes interactions with actuated or shape-changing furniture. Researchers have designed a desk that dynamically and adaptively moves around users [38], modifies its shape [37, 43], or changes the angle of its surface [9] based on users' needs and collaboration scenarios. Similarly, the Living Desktop [2] system actuates objects on the desktop and features a display that swivels automatically to face the user. The ActiveErgo [47] system automatically adjusts the height of the desk and monitor to a user's anthropometric data.

Liu and Picard presented a monitor on an actuated display and let the robot move in subtle ways to express its affective state [20]. Breazeal, Wang, and Picard studied the influence

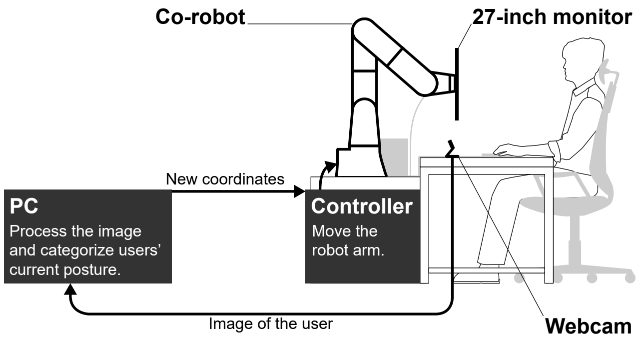

Figure 2: We attached a 27-inch monitor to a co-robot, Kuka iiwa 7 R800, that can move at slow speeds without noise and vibration. We used the same setting for both the speed perception study and evaluation study.

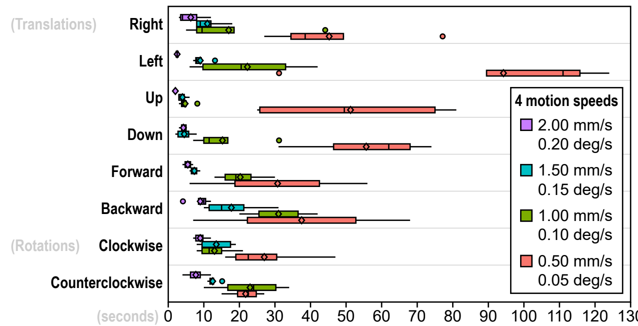

Figure 3: The time participants took to recognize each monitor motion in different speeds. The faster the monitor moved, the earlier the participants sensed its motion.

of a user's posture on their affective state and work performance [4]. By manipulating a monitor's height and angle, participants were led to pose in neutral, slumped, and upright sitting postures. We share the same spirit of that approach, but our work significantly extends their research in that we provide real time interactions between a slowly moving monitor and users for unobtrusive posture correction.

As far as we know, none of the related studies have systematically evaluated the slow, real-time interaction between a robotic monitor and the users' posture.

3 USER STUDY 1: SPEED PERCEPTION

We conducted a speed perception study to identify motion speeds that are below users' perception thresholds and observe users posture changes as a result of monitor motions. We tested 32 motion variables (Figure 3). We had eight motions (right, left, up, down, forward, and backward translations; and clockwise and counterclockwise rotations) and moved each motion at four different speeds (0.5, 1.0, 1.5, and 2.0 mm/s for translation, 0.05, 0.10, 0.15, and 0.20 deg/s for rotation, which moved the corner of the 27-inch monitor 0.3, 0.6, 0.9, and 1.2 mm/s). Based on informal tests, we expected that the slowest speed would not be detected but the fastest most likely would.

During a reading task we asked participants to indicate when they noticed the monitor moving. At the center of the screen, we created an A6 portrait-sized window. We had participants sit 500 mm away from the monitor (within the recommended distance of 300-750 mm), and positioned the top edge of the window to the participants' eye height. Prototype implementation details are presented in the next section.

The monitor rotated up to 30 degrees and moved up to 100 mm sideways and upwards, and up to 50 mm for the other motions to prevent it from touching the desk. Participants indicated motion detection by pressing a key. After each trial, the monitor reset to its default position at a fast speed (30 mm/s for linear motions and 3 deg/s for rotation). We randomized the order and interval (20 to 60 seconds) between each trail. The study lasted about 1.5 hours including a brief interview on how participants detected the monitor motion.

We recruited six university students (4 males and 2 females, mean age= 26.00, SD= 2.28) who spend most of their time in front of a monitor. Prior to the interaction, we instructed them to sit in a comfortable but straight posture, focus on reading and continue reading the text after detecting the motion. We compensated each participant with 10 USD for their participation.

Results

The participants detected the monitor motions correctly most of the time, except for P1 who reported false positives when the monitor was not moving. When the monitor moved relatively fast, they immediately noticed that it was moving. However, when the monitor moved slowly, they failed to notice the motion, but after a while they realized its displacement.

The results showed a proportional relationship between motion speeds and the participants' response times (Figure 3). The faster the monitor moved, the faster they recognized the monitor motion. In the case of the translations, the participants recognized changes after around 10 seconds when the monitor moved at 1.5 mm/s (M= 13.17, SD= 6.45) and 2.0 mm/s (M= 5.58, SD= 3.12). When the monitor moved at 1.0 mm/s, the participants took 24.11 seconds on average (SD= 10.08) to recognize the changes. The most unobtrusive speed was 0.5 mm/s, which took 64.22 seconds (SD= 20.17) for participants to notice the displacement. At this speed, two participants failed to see any changes in vertical motions, and the other two participants missed the backward motion until it reset to the default position. The participants also

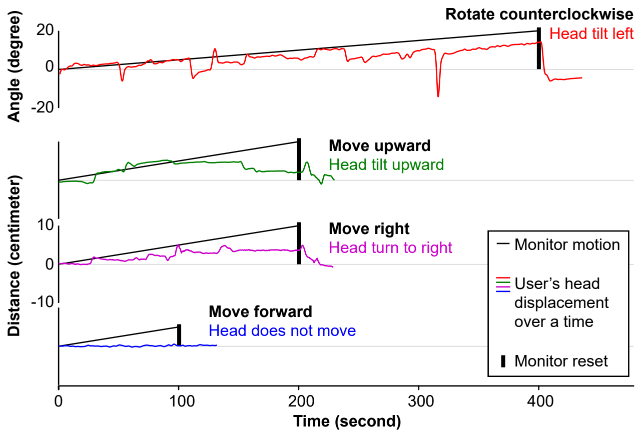

Figure 4: The smooth posture changes of Participant 5 in response to the slowest monitor motions (0.05 deg/s rotation and 0.5 mm/s translations). The colored curves represent head displacement over time. He slowly turned his head to followed the monitor motions to continue reading, except for the forward motion that did not disturb his view.

easily detected the fastest rotation speed (M= 8.38, SD= 27.73) and took about five more seconds for each slower speed.

We observed slow posture changes (Figure 4) in the webcam recordings. The participants turned or tilted their head gradually or in small steps to follow the position and angle of the text. They were the most responsive to horizontal and angular changes. We observed gradual changes for vertical motions as well, but they were not as clear as other posture changes since the participants tilted their heads up and down to read the text. Regarding the forward and backward motions, the participants did not lean forward or backward. They were the least sensitive to the backward motion and they could continue reading without any difficulties.

4 MOTION DESIGN

Based on related work and the speed perception study, we designed a system for both posture recognition and posture correction in the attentional background [5]. The main concept of our system is to detect unbalanced postures and initiating the monitor motion to induce posture changes. The interaction was in four steps as shown in Figure 5. First, a user's unbalanced sitting triggers the monitor to move in the attentional background. Second, the monitor moves to counterbalance the posture until the user corrects own posture. Third, the user starts to move and reaches a default balanced posture. Finally, the monitor resets to its default setting. To design this interaction, we considered the speed and direction of the monitor motion, false positive interactions, and reset conditions.

We defined the target balanced posture according to ergonomic guidelines for working at a desk [17, 28]. Based on that, we created a 'safe zone' that users needed to stay in, or else they wiould trigger the monitor motions (Figure 6).

The pose of upper body is defined to a large extent by the cervical spine C7 (neck) and lumbar spine L5 (lower back) [3, 30]. Therefore, we were concerned with the position and angle of C7 (Figure 6a) and L5 (Figure 6b) on the cardinal planes for designing monitor motions. The monitor moved sideways with a small rotation and upward motion when users changed the angle of L5 along the sagittal plane (leaning left/right). We considered the angle of C7 on the sagittal plane as well and implemented clockwise and counterclockwise rotations (head tilt left/right). When users decreased the angle of C7 or L5 along the coronal plane (leaning forward), the monitor moved toward the user to push them away from the monitor. In contrast, when users moved their L5 closer to the monitor while increasing its angle (leaning backward), moving the monitor away from users had less impact than moving closer. Therefore, we designed an upward motion with tilting to pull users' torsos upward.

From the first user study, we learned that a 27-inch monitor can move without being noticed under 0.5 mm/s for translations. While a slower motion would be less intrusive to users, the faster the monitor moves, the earlier users will correct their posture. Therefore, we compromised the default speed to 1.0 mm/s for translations and 0.05 deg/s for rotation.

We expected that users would momentarily change their pose (e.g. touch their faces, stretch, or fidget) and introduced delays to avoid false positives. From a pilot study with two participants, we observed that five seconds was sufficient. The pilot study also showed that participants sometimes ignored the monitor motion and kept their comfortable but unbalanced postures. As a result the monitor moved to a position that made it impossible to work, which caused the participants to eventually change their posture. For those cases, we let the monitor quickly reset to the original position (30 mm/s for linear motion and 3 deg/s for rotation) to minimize discomfort after posture correction.

5 SYSTEM IMPLEMENTATION

We implemented our system with a 27-inch monitor mounted on the end effector of the co-robot (collaborative robot) LBR iiwa 7 R800 from KUKA [18] (Figure 2) that can move at a constant, slow speed without noise and vibration. This co-robot is a seven-DoF (degrees of freedom) lightweight robotic arm with a maximum reach of 800 mm and an integrated force sensor to react in case of unexpected human contact.

Our system estimated a user's posture by tracking their eyes [12, 16]. We assumed a fixed position of the chair, calculated the distance and angle between the eyes, and estimated the inclination of the upper body. The distance between the

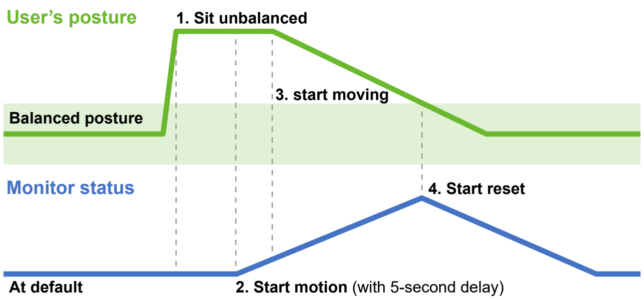

Figure 5: We designed a four-step interaction. First, a user sit unbalanced (1), then the monitor starts motion after 5-second delay (2). The user would then change their posture, following the motion (3). When the system sees updated posture is balanced, the monitor will start to reset (4).

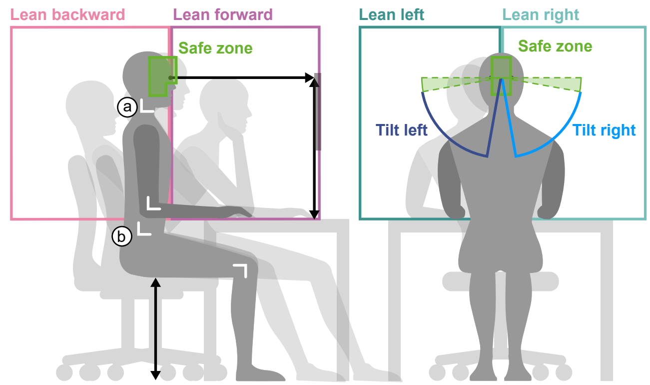

Figure 6: A safe zone around a target balanced posture. We calculated the position and angle between the user's eyes to define their current posture. When users posed outside of the safe zone, a corresponding monitor motion was initiated.

eyes was transformed into the Z position, and the coordinates of the center point between the eyes represented the X and Y positions. The angle between the horizontal line and the vector line of the eyes was defined as the head's roll angle.

We designed an image processing system using OpenCV 3.3. This software takes a color image from a webcam, applies a Local Binary Patterns face cascade classifier [29] and defines the Region of Interest (ROI) as a square surrounding the face. Then, a Haar feature-based eye cascade classifier [11] is applied to find the location of the user's eyes. To speed up the detection range, the subsequent detections are only applied around the previous ROI. During the evaluation study, our system detected a face 92.56% (SD=10.40) of the time. The variation was mainly caused by three participants covering their face with their hands. In such case the system paused until the face was detected again.

The calculated face coordinates were compared against the predefined volumetric zones with different priorities. If the user's face was inside multiple zones, the zone with higher priority took precedence. To avoid detection artifacts, the users needed to maintain their location for at least 1 second before the system detected the change of zones. Finally, if the user stayed in a zone for more than five seconds, the system actuated the robot arm [26].

6 USER STUDY 2: EVALUATION STUDY

We conducted the second study in a real-life setting for ecological validity and observed posture correction for four hours. Participants were free to pose and perform their regular computer tasks with a 10-minute break per hour. We let them bring their own laptop, but asked them to only work with our external monitor.

We expected large inter-participant differences in working habits. Thus, we designed a two-day study comparing the baseline behaviors (i.e., without actuation) with the treatment behaviors (i.e., with actuation) and had participants work for four hours on consecutive days (eight hours in total). We expected that actuation on the first day would result in unwanted learning effects such as being more aware of own poses. Therefore, we actuated the monitor only on the second day and compared the influence of monitor motions on maintaining a balanced posture. We expected that participants' performances would be different in the morning and afternoon. Therefore, we divided participants into two groups (3 males and 3 females in each group) and assigned am or pm sessions for counterbalancing.

We logged participants' postures with three cameras as well as monitor motions. We measured the participants' workload through a NASA-TLX survey (7-point Likert scale, 1= low, 4= neutral, 7= high) with two modifications and conducted an exit interview. We expected the participants to report physical demand regardless of interaction after four hours of working, so we included physical demand in the interview to obtain more detailed answers. We also added an annoyance scale [1] to further examine the workload of interacting with the monitor; "How disturbing was the monitor motion to your activity?".

We recruited 12 university students and office workers (6 males and 6 females, mean age= 24.55, SD= 2.77) who spent most of their time doing computer tasks. We maintained the same study setup as our speed perception study, except for the chair. We changed it to an office chair with a neck support to better support relaxed and balanced sitting postures. Each participant was compensated with 80 USD.

Prior to the main interaction session, we had a fitting procedure to find comfortable and ergonomically correct sitting postures. We followed ergonomic guidelines [17, 28] for the

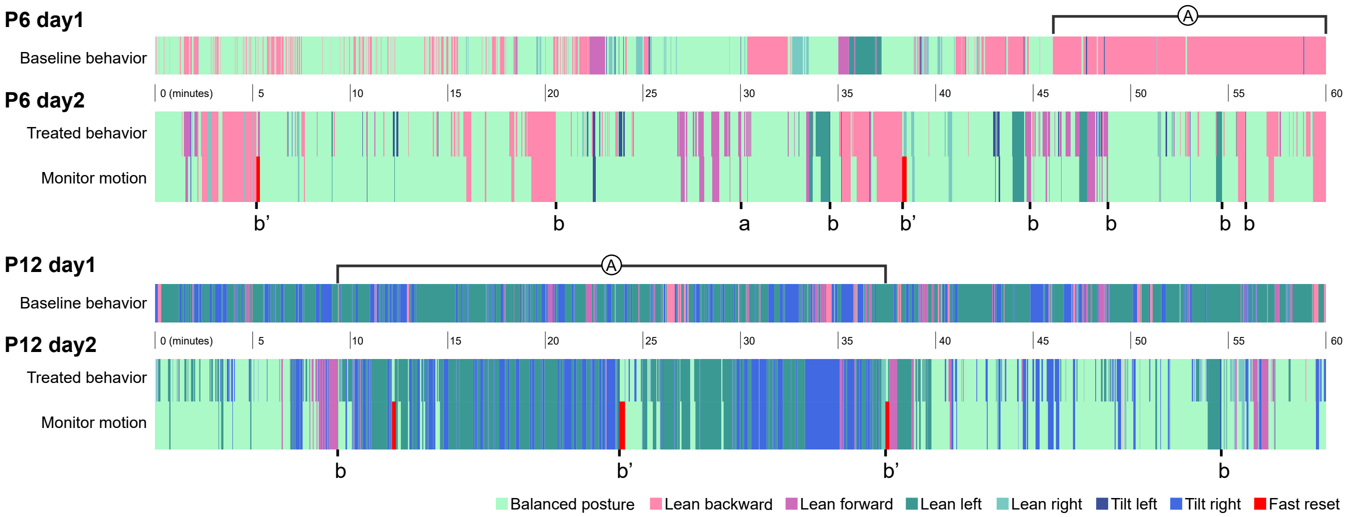

Figure 7: We organized the participants' unbalanced postures and charted their monitor motions on a timeline. We marked successful interactions and distinguished slow posture changes (a), swift posture changes (b), and interactions ending with the fast reset (b'). With our system, the participants changed posture more frequently (A).

initial setting and let participants further adjust the monitor position and chair height for their comfort and preferences. Then we let the participants work for 10 minutes to test their setting and make final adjustments.

We only gave neutral explanations about the study to avoid instructing the participants how to respond to the monitor motions: "The monitor will move to support your health while working". The participants were free to touch the monitor, but they could not reposition the monitor. One researcher sat outside of the participants' view to observe and manage the system. If users changed the position of their chair, we asked them to re-center the chair, which occasionally happened after returning from a break. The participants also wore noise canceling headphones and listened to their preferred music.

7 RESULTS

Interacting with our prototype induced posture corrections and significantly decreased the duration of unbalanced posture. In contrast to the smooth motion observed in the speed perception study, here we found that participants mostly corrected their posture with a quick motion, yet without noticeable disruption. This swift posture correction was observed on both days, but more often on the second day.

Sitting and Working Habits

We observed various sitting and working habits from the participants. Most of the participants had their favorite unbalanced postures and habits that made them lean to one side (e.g. supporting their head with their arm or using only one of the arm rests). During Day 1, after keeping an unbalanced posture for a while, they occasionally changed back to a balanced posture. In contrast, P9, P10, and P13 stayed in an unbalanced posture almost the entire time while P2 and P7 maintained a balanced posture and started to lean backward at end of the study.

How they arranged the screen influenced their posture as well. For four hours, each participant performed one or two main computer tasks (e.g. reading, writing, coding, 3D modeling, graphic design, web searching, and/or watching video tutorials) while frequently switching to small tasks (e.g. chatting, social media, reading webcomics, and watching funny videos). They worked with multiple applications running at the same time and organized their application windows in three different ways. When focused on one task, they used a single fullscreen window and switched between applications by using a keyboard shortcut. A two-column layout was used for summarizing or document editing. A main window with several smaller windows was for managing multiple tasks. The participants tended to focus on a certain side of the monitor and lean toward it.

Subjective Response

The modified NASA-TLX survey showed that interacting with the monitor did not have a negative influence on the participants' performance. None of the participants realized that the monitor was moving and only noticed the displacement. Although they reported a little annoyance (M= 4.33, SD= 1.30) and effort to concentrate (M= 4.92, SD= 0.90), they explained that it was because the system did not allow them

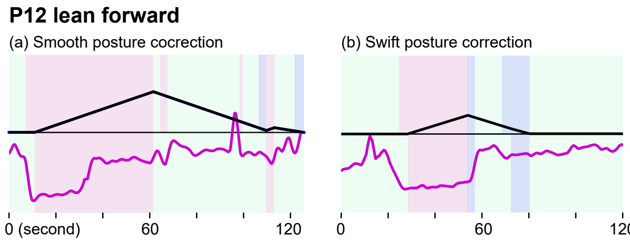

Figure 8: In addition to smooth posture changes (a) similar to the speed perception study, we observed swift posture changes (b) in the evaluation study.

to maintain the unbalanced postures. Nevertheless, they appreciated the interaction as it induced posture changes before they felt physical discomfort from unbalanced sitting. Through within-pair t-tests we could not find significant effects on the level of performance ($t= 0.43$, $p= 0.34$) and focus ($t= 0.62$, $p= 0.28$) between both conditions.

The participants described the physical demand of the interactions during the exit-interview. All participants reported that correcting their posture was not physically demanding. P1 answered that he paid little attention on his pose and realized that he changed his posture later. However, four participants added that maintaining a single balanced posture for a long duration was indeed tiring.

Although we did not explicitly clarify that the study was about posture correction, all of the participants guessed that the monitor was trying to correct their posture, except P2 who maintained balanced posture and experienced interaction infrequently. They understood the purpose of the motions after realizing that it moved opposite to their unbalanced posture. However, in some cases participants did not recognize their leaning back motion as unbalanced and reported the correction motion (moving upward) as confusing even though they unconsciously and effectively corrected their posture.

Posture Correction

As the participants occasionally corrected their posture by changing activities and stretching, we reviewed the motion data (Figure 7) with actual video and marked successful interactions. Through paired t-tests, we compared the total duration of unbalanced postures between the baseline and treatment measurements and observed significant decreases ($t= 3.54$, $p= 0.002$). The frequency of posture corrections significantly increased on the second day by about 66% ($t= 3.689$, $p= 0.002$) and resulted in shorter durations of unbalanced sitting. We investigated the influence of gender or daytime on the proportion of posture changes as well, but there were no significant differences between genders ($t= 1.90$, $p= 0.06$) or between am and pm groups ($t= 1.30$, $p= 0.12$).

We observed the same smooth posture changes (Figure 8a) we found in the first study, but the participants mostly corrected their posture in a swift, single action when they noticed that the monitor had changed (Figure 8b). Similar to the first type, they maintained focus on their work; participants changed posture without stopping typing or reading.

We also observed that participants knowingly maintained unbalanced postures for long periods and triggered the fast reset, which we see as a limitation of the prototype. The post-interview provided several explanations. At the start of the study, some participants did not understand how to react to the motions. Others got tired toward the end of the study, or just wanted to maintain comfortable but unbalanced postures. This happened more frequently to P3, P5, P8, P10, and P12. Although the interaction interrupted the participants' task, they swiftly corrected their posture and continued working.

Qualitative Response

Interacting with an actuated monitor for the first time influenced the participants' attitude toward the monitor and their posture. First, they showed a sense of anthropomorphism toward the monitor. P1, P2, and P10 constantly referred to the monitor as a friend. P3 reported that he was collaborating with the monitor for better health. Second, the participants were curious about the logic of interaction. As we did not explain how the monitor moves, they intentionally leaned in a certain direction and observed the monitor motions. Especially, P4, P5, and P8 dramatically leaned toward one side and suddenly changed posture to see how responsive the system was.

The interaction affected the participants' attention during their work as well. The experience of a successful interaction for posture correction made the participant be more conscious about their posture. Half of the participants highlighted that they checked their posture more frequently even when the monitor was not moving. Lastly, three participants commented that realizing the displacement of the monitor helped them refresh their mind and re-focus on their work.

8 DISCUSSION

In the speed perception study, we identified motion speeds under the perception threshold and that the participants follow the monitor with smooth posture changes. In the main study, we observed the participants' diverse working styles, sitting habits, and found an additional swift posture change. Based on our observations we share considerations for designing slow interaction for posture changes and applications in other domains.

Correcting Posture vs Adapting to a Posture

In the evaluation, we observed participants pose in an unbalanced way, not only because they sought physical comfort but also as they adapted to the on-screen content. For instance, participants adjusted the distance from the monitor between reading a text and searching images as well as when the size of the text changed. Focusing on one side of the wide screen (e.g. when working with two applications side by side) made participants lean toward the same side. In contrast, our current system did not take the on-screen content into account and reset to the one default setting. By considering the changes in tasks, text size, and screen usage, the system would learn multiple healthy monitor positions and adaptively support users' posture.

Posture-Dependent Thresholds

In contrast to the speed perception study, in which the participants changed posture gradually, they mostly changed posture in a swift motion during the second study. To better understand the difference between two studies, we analyzed the events in more depth with activity change, screen usage, and hand position. We observed that participants frequently changed their view between multiple windows within the wide screen and changed the threshold for following the monitor.

For instance, participants maintained leaning postures longer by changing their focus on the screen. From the interview, P6 commented "When I was focusing on coding, I suddenly realized that the monitor moved upward (he was leaning backward), so I used only the bottom part of the screen. But the monitor kept moving upward so I straightened my back and the monitor came down." In the case of P12, she moved a window to the left side of the screen to continue leaning left.

We also observed different thresholds for changing posture based on how the participants posed. When the angle of cervical spine C7 and lumbar spine L5 exceeded a certain degree, the participants changed posture with more effort. Supporting their head with one arm often increased the angle of C7 and required more strength for lifting the head from the hand. Leaning backward without back support made participants lift up their bodies and adjust how they sat on the chair. Therefore, we argue that further investigation on preventing extreme unbalanced posture is required.

Personalizing Interactions

Each participant had unique characteristics and understanding on their posture that would need to be integrated into the interactions. From the interview, participants reported that they wanted to maintain an unbalanced posture because they were tired. P10 commented that she knew her posture was bad and wanted to go back to a balanced posture after she relaxed for a while. In the case of P6, he commented that he was used to sitting unbalanced and would need gradual practice for maintaining balanced sitting. As a result, they sometimes went back to an unbalanced posture after the monitor reset to the default setting. Based on the responses, we believe a communication method for rejecting interactions should be studied. Stir's M1 standing desk handles this issue with a snoozing feature that allows users to reject posture changes when they are focused on their work [6].

To minimize discomfort for extreme positions and angle changes, we implemented the fast reset even though it could be obtrusive. However, some participants enjoyed the fast motion and commented that it was not intrusive to them. P3 and P4 mentioned that they were used to working in a busy office. Therefore, the fast motion did not distract their work and worked as a clear signal for correcting a posture. In the case of P8, who experienced the largest amount of fast resets, commented that the monitor was not coming back fast enough for him. Although our main interest was unobtrusive posture changes, further investigation into fast speeds and the balance between background and foreground interactions would be required to support a variety of poses.

9 CONCLUSION AND FUTURE WORK

We introduced the concept of slow robots that move below the perception threshold without noise, vibration, and intrusiveness. We demonstrated that this concept can be applied to posture correction. We believe that it also can be applied in other furniture items (e.g. desks, chairs, and kitchen countertops) and other domains such as patients lying on a bed or slow assistive robots for precision manipulation (e.g. surgery or jewelry making). Slow robots could also optimize other aspects of an environment that does not require high speeds.

Our future work would be, first, expanding the detection system to integrate activity changes and screen usage into the system. Better pose tracking would allow more flexible setups such as adjustable chairs. Second, we would include multiple balanced postures to enhance the usability of our system. Finally, we would investigate the support for comfortable poses or snooze functions that allow users to negotiate their status with the system. Another avenue is to explore future work environments such as virtual moving monitors in VR and AR.

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