Automatic Slouching Detection and Correction Utilizing Electrical Muscle Stimulation

Category: Research

Figure 1: Improper posture can have long term health ramifications. Presented here are images of slouched and corrected posture using Electrical Muscle Stimulation: (A)Mobile Gaming - Slouched Posture, (B)Mobile Gaming - Corrected posture, (C)Text Entry - Slouched posture, (D) Text Entry - Corrected posture

Abstract

Habitually poor posture can lead to repetitive strain injuries that lower an individual's quality of life and productivity. Slouching over computer screens and smart phones is one common example that leads to soreness, and stiffness in the neck, shoulders, upper and lower back regions. To help cultivate good postural habits, researchers have proposed slouch detection systems that alert users when their posture requires attention. However, such notifications are disruptive and can be easily ignored. We address these issues with a new physiological feedback system that uses inertial measurement unit sensors to detect slouching, and electrical muscle stimulation to automatically correct posture. In a user study involving 36 participants, we compare our automatic approach against two alternative feedback systems and through two unique contexts-text entry and gaming. We find that our approach was perceived to be more accurate, interesting, and outperforms alternative techniques in the gaming but not text entry scenario.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Wearable computing—Preventive Healthcare Posture correction—Slouching—Electrical Muscle Stimulation;

1 Introduction

The alignment of our body parts, bolstered by the correct muscular tension against gravity, plays a crucial role in maintaining good and healthy posture. Poor posture in working environments leads to Repetitive Strain Injuries (RSI) and long-term musculoskeletal disorders [43], which are becoming increasingly prevalent in working age population. Improper occupational standards, poor workstation arrangements, and gaming in unnatural seated positions are often the biggest factors contributing to RSI at workplace and at home. Poor posture has also been linked to health deterioration and low productivity [2]. Repetitive processes, such as the use of computer systems and smart phones, present a high risk of RSI, examples of which include wrist extension, neck cradling, forward neck, slouching, and uneven weight distribution on the legs. In this paper, we address slouching, which is one of these RSI. The RSI associated with slouching, if not detected, analyzed, and corrected at an early stage, may lead to the development of poor posture habits which induce intense pain, trigger point pain, and muscle tightness in the chest, neck, shoulders, and back regions.

In the United States, nearly $90 billion [8] are spent every year for the treatment of RSI and lower back pain arising out of poor workplace postures, primarily slouching [10]. Recently, a study showed that slouching affects the transverses abdominus muscle [43] which is responsible stabilizing the torso in an upright position while standing and sitting. The muscle dysfunction, or dystrophy, caused by slouching is directly associated with lower back pain. Lower back pain/injuries are one of the noted root causes of disability in the world, where it is estimated that around 80% of the world population will experience it at some point in their lives [19, 46]. Current intervention technologies only deal with the detection of slouching and rely completely on the user's willingness to self-correct their postures when a feedback alert is presented. As a result, there is a dire need for the implementation of a wearable intervention technology capable of automatically detecting slouched posture and subsequently correcting posture to help users maintain good posture during their work and gaming activities.

Electrical muscle stimulation (EMS) can be applied to cause involuntary muscular contractions and generate a physiological response [9, 42, 49]. In this work, we integrated EMS with a slouch detection system to automatically correct poor habitually slouched posture and restore correct posture through these involuntary muscular contractions. The main contributions of this work include the development of a wearable intervention prototype that can autonomously detect slouching and correct posture through a physiological feedback loop utilizing EMS. We also evaluate the performance of our approach in breaking the habit of slouching through automatic detection and subsequent correction of slouched posture, and for training and developing good postural habits.

2 Related Work

Although, there is a consensus that posture can be improved and fixed through ergonomic solutions such as adjusting desk and chair heights, monitor viewing angles, and keyboard and mouse positions [2], there exists only a small number of reliable techniques

for continued posture monitoring and detection of poor posture especially slouching. With the increase in computational power, sensor technology, and advances in wearable technology, posture monitoring has been attracting increased attention for developing detection and alert-based wearables that allows users to self-correct their posture based on feedback from the system [13, 16, 23]. This development of sensors and their integration into wearables has also enabled real time monitoring and live feedback systems that are independent of the location of the work environment. Despite these efforts and due to the novelty of wearable intervention technologies, current researchers are focused on developing more accurate monitoring techniques and development of predictive algorithms for better detection of poor posture. As a result, aspects such as integration of embedded sensors into wearables, aesthetics, usability, wearability, and user comfort are often neglected. Most slouching posture detection techniques employ a variety of sensors such as IMUs, Force sensitive resistors, Electromagnetic inclinometer [3], fiber-optic sensors [4], cameras [51], and smart garments [1, 12] for monitoring, detection and alerting the users.

2.1 Posture Detection with Real Time Feedback

Slouching posture detection with real time feedback mainly employs three types of feedback via visual, audio, and haptic through which information about the users' posture, and the need to self-correct their posture is conveyed through visual notifications on their computer monitors/smart phones, voice/auditory alarms, and vibration alerts, respectively. Researchers integrated audio feedback with strain gauges [38], instrumented helmets [55], accelerometers [12], gyroscopes [53], and IMUs [1] for detection of poor posture and development of good posture habits. Similarly, real time visual feedback approaches utilizing a set of IMUs for posture monitoring were developed [16, 23] to deliver visual feedback via smartphone applications.

Real time visual and audio feedback was integrated with wearable posture detection systems such as *Zishi* [52], *SPoMo* [40] and *Spineangel* [44]. *Zishi*, an instrumented vest integrated with IMU sensors on the upper and lower spine, delivered alerts using visual and audio channels through a smartphone application. *SPoMo* utilized a set of IMUs for monitoring spinal position in seated posture while *Spineangel* was developed as a wearable belt with IMUs to investigate the relationship between poor posture and lower back pain. Building upon this, *Limber* [22] was designed as a minimally disruptive method for detecting poor posture and alerting in an office style workplace. Their system incorporated IMUs (accelerometer and strain gauges) on the shoulders, spine, and neck to detect poor posture while sitting and implemented a positive and negative feedback system based on correct and incorrect postures, respectively. Researchers also developed hybrid posture detection techniques utilizing electromagnetic technology and accelerometers [3], inductive sensors [47] and real-time vibrotactile feedback was provided to users for self-correction. Additionally, researchers also integrated haptic feedback with IMUs for postural balance [54], and gait training [13]. Xu et al. [54] devised a system that utilized eight IMUs placed on either side of the torso to monitor trunk tilt and provide vibrotactile feedback. Advancing upon this, Gopalai et al. [13] utilized a wireless IMU attached to the trunk and a wobble board for providing real time biofeedback via vibrational alerts for postural control. Further, a comparative study on posture detection aimed at improving spinal posture concluded that the IMU-based system performed more accurately than the vision-based system [51]. Also, a qualitative assessment of different commercially available wearables for posture detection (LUMO Lift, LUMO Back and Prana), and correction through real time haptic, and visual feedback systems concluded that haptic feedback based on real time monitoring enabled a shared responsibility for detecting poor posture and subsequently delivering real time feedback/ alerts to the user to correct themselves [35].

2.2 Electrical Muscle Stimulation

EMS is a non-invasive technique for delivering electrical stimuli to muscles, nerves and joints via surface electrodes positioned on the skin to deliver an acute/chronic therapeutic effect. Traditionally, electrical stimulation was utilized for therapeutic pain management to alleviate chronic muscle strain, acute muscle spasms, and in rehabilitation to regain muscle strength [5, 9] and normal movement after injury or surgery [49]. EMS has also been utilized for the application of a cyclical, moderate intensity electrical impulses to selected muscles for generating physiological responses. It has been used for generating functional movements that resemble voluntary muscle contractions like evoking hand opening [9], to stimulate reflexes for swallowing disorders [45], to enable neuro-prosthesis control [42], and to restore functions that have been lost through injury, surgery, or muscle disuse.

2.3 EMS in Human Computer Interaction

EMS has found new interest in human computer interaction (HCI) for applications in gaming, augmented reality, and virtual reality (VR) training [20, 24–27, 48]. This presents an opportunity for developing novel interaction techniques using adaptive wearable interfaces. Researchers have applied EMS technology to different interactive applications such as activity training, immersive feedback technologies and spatial user interfaces. On account of its ability to invoke involuntary muscular contractions, EMS has been utilized in activity training to enable users to acquire and develop new skills such as playing musical instruments [50], learning object affordance [31], and developing preemptive reflex reactions [18, 36]. Additionally, EMS-based feedback systems integrated with augmented, virtual, and mixed reality technologies have been developed for providing users with additional immersion and engagement. EMS was utilized in developing a wearable stimulation device for sharing and augmenting kinesthetic feedback [37] to facilitate virtual experiences of hand tremors in Parkinson's disease. *Impacto* [28] was designed and developed to provide the haptic sensation of hitting and being hit in VR. EMS was also utilized to increase realism in VR applications by actuating emotions such as inducing fear and pain in *In-pulse* [21] and transfer of emotional states between users in *Emotion Actuator* [15]. Lopes et al., [29, 32] developed realistic physical experiences in VR by providing haptic feedback to walls and obstacles. They also developed force feedback for mobile devices [34] by employing EMS to invoke involuntary muscular contractions to tilt the device sideways. Further, they extended EMS-based force feedback to mixed reality gaming to add physical forces to virtual objects [33]. Similarly, Fabriz et al., [11], utilized EMS to simulate impact in an augmented reality tennis game to deliver a more immersive experience. Further, integration of input, and output interfaces with EMS technology has allowed development of physiological feedback loops and enabled a novel communication technique. EMS has been employed in actuated navigation [41], actuated sketching [34], and delivery of discrete notifications and conversations [14]. EMS has also been utilized for enabling unconscious motor learning such as heel striking [6] and co-create visual art works [7]. *Pose-IO* developed by Lopes et al., [30] allowed users to interact without visual, and audio senses and completely rely on proprioceptive sense.

The above-mentioned interactive applications demonstrate that EMS provides more defined, implicit, and strong sensations than visual, audio, and haptic feedback mechanisms. These applications also exhibit miniaturization of feedback hardware compared to actuated motors in exoskeletons. The current literature suggests that postural correction utilizing EMS has not been fully explored and thereby presented an opportunity for the development of novel wearable intervention technology for the detection and subsequent

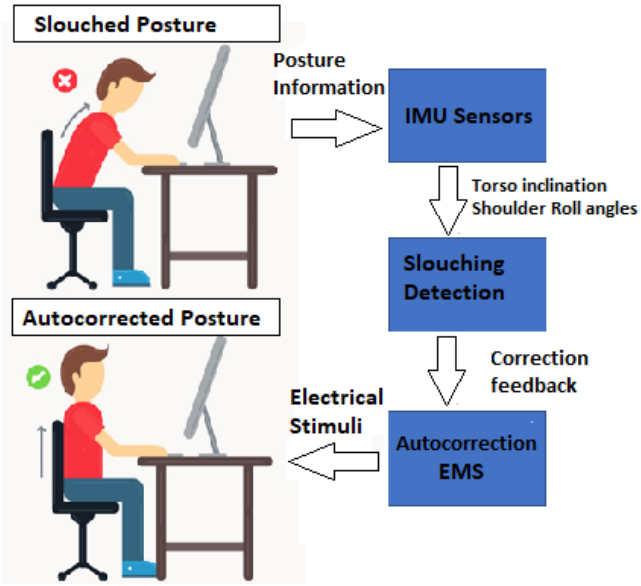

Figure 2: Physiological Feedback Loop: Automatic Slouching Detection and Correction System

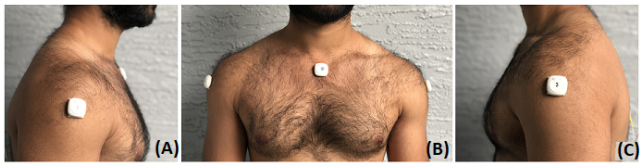

Figure 3: Wireless IMU sensor placement for posture monitoring and detecting slouched posture:(A) Side view showing sensor placement on left deltoid, (B) Front view showing sensor placement below center of collar bone above the chest, (C) Side view showing sensor placement on right deltoid

correction of slouched posture. In comparison, prior research on posture detection always relied on the user's willingness to self-correct their posture upon being presented with feedback, while our autonomous system was capable of automatically correcting the slouched posture upon detection.

3 Automatic Slouching Detection and Correction utilizing EMS

We developed a physiological feedback loop based wearable intervention prototype relying on IMU sensors and EMS (illustrated in Figure 2). The prototype utilized three Metawear MMC wireless sensors for measuring angular changes, and openEMSstim package [26] for presenting the EMS feedback. We utilized the Metawear C# SDK for developing a user interface and to integrate the EMS hardware to complete the physiological feedback loop. The change in posture was calculated from the angular information obtained from the IMU sensors. As slouching was mainly characterized by the torso inclination and forward rolling of the shoulders [17], IMU 1 was to be placed at the center of the collar bone above the chest (illustrated in Figure 3 (B)) and the other IMU's 2 and 3 were to be placed on the center of each deltoid (illustrated in Figure 3 (A) & (C)). The user's torso inclination angle was calculated from the pitch of IMU1, and the roll angles on the shoulders were calculated from the roll of IMU's 2 and 3. Our system detected slouching when the user's current torso inclination and shoulder roll angles, both approached and remained at a threshold level for a period of 5 seconds. The threshold level is preset as $-3°$ of the torso inclination and shoulder roll angles recorded in the slouched position during calibration. $-3°$ was chosen to overcome measurement errors without increasing false positives and 5 seconds timer duration ensured random movements do not lead to false positive slouch detection. These design choices were validated during our pre-study trials. The threshold angle of $-3°$ was used to initiate the 5 seconds timer, and the slouch angles detected were recorded at the end of the timer when the feedback was presented. The purpose of timer was to ensure false positives due to participant behavior do not trigger the feedback response. When slouching was detected, the automatic correction feedback was presented by applying electrical stimulus to the rhomboid muscles (illustrated in Figure 4) for generating a pulling force in the opposite direction from the slouched posture and thereby, generating a physiological response to bring the user back to the upright or correct position. Two pairs of electrodes were utilized for contraction of the rhomboid muscles which causes the shoulders blades to be pulled back, thus unrolling the shoulders and bringing the torso back to the upright posture. IMU and EMS calibration play a crucial role in the effectiveness of the system. The calibration process included correcting IMUs offset value in the upright position of the user and recording the angular change in the slouched posture with respect to the upright position. The EMS intensity calibration was manually incremented to deliver an intensity that was optimal for generating involuntary muscular contraction and avoid any pain. This EMS intensity provided to the user for generating the necessary pulling force for correcting the slouched posture and restoring the upright position was recorded and utilized during the experiment. The TENS device was able to deliver intensities between (0-100mA). A continuous 75 Hz square wave pulse at the recorded EMS intensity and a pulse width of 100 μs was supplied as the electrical stimulus to the users.

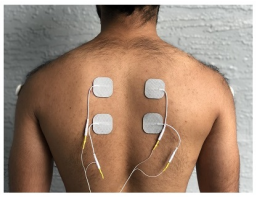

Figure 4: EMS Electrode placement on rhomboid muscles for autocorrection using EMS feedback

4 Methods

The goal of our study was to evaluate the overall effectiveness and user perception of an automatic detection and correction feedback system (EMS) which would not disrupt the task or require additional cognitive load by the user to self-correct their posture. Hence, we compared it against traditional audio and visual feedback mechanisms that required self-correction by the user. The visual and audio feedback modalities required users to self-correct their posture based on visual and the audio sound notifications presented to them, respectively. We also identified two common causes of slouching in day to day activities such as computer related workplace tasks, and mobile gaming [17, 39], and investigated the effectiveness and user perception of our automatic slouching detection and correction prototype across these common causes of slouching. Our objective was to determine if our automatic posture detection and correction system using EMS would be a viable technique for correcting slouched posture as compared to the visual and the audio feedback channels while being engaged in a computer related workplace task and playing a mobile game.

Table 1: User ranking on posture awareness, devices and EMS

User Experience	Application	Mean	S.D
Exposure to Posture Alert Devices	Text Entry	1.61	1.16
	Mobile game	1.89	1.09
Exposure to EMS	Text Entry	2.33	1.37
	Mobile game	2.06	1.43
Experienced posture problems	Text Entry	4.22	1.55
	Mobile game	4.33	1.49
Experienced slouching	Text Entry	5.06	1.50
	Mobile game	5.4	0.96

Note: User experience ranking based on a 7-point scale where 1 means never / no experience and 7 means frequently / very experienced

4.1 Subjects and Apparatus

We recruited 36 Participants (Male=31, Female=5) for the study with 18 participants for each application- text entry and mobile game. All participants recruited were above the age of 18 years and the mean of the age of participants was 22.05 years ($S.D. = 3.13$). All participants were able bodied and had corrective 20/20 vision. We used three Metawear MMC IMU sensors for monitoring the torso inclination angles and the shoulder roll angles. The EMS was generated with an off-the-shelf Tens Unit (TNS SM2MF) and controlled by the openEMSstim package for activating and modulating the intensity of the electrical stimuli supplied to the muscles. The hardware used for the text entry application was a 14" Intel i7 Laptop, and a 2nd generation iPhone SE was used for the mobile game application. From the pre-questionnaires, participants ranking of their prior exposure to posture alert devices and EMS, and experience with posture problems and slouching are noted and illustrated in Table 1. Participants ranked their exposure and experience on a 7-point scale with 1 meaning never/ no experience and 7 meaning frequently/ very experienced.

4.2 Experimental Design

A 2 by 3 mixed subjects experiment with 36 participants was conducted to investigate the performance and feasibility of our approach. The within subject factor was feedback type and the between subject factor was application type. We tested our system across two applications: text entry and mobile game, and across three feedback types: visual, audio, and EMS. The visual and audio feedback types required self-correction by the users while the EMS feedback was an automatic feedback type that could automatically correct the user's posture when slouched posture was detected. We compared the performance of EMS and auto-correction against the visual and audio feedback techniques. The average correction response times and user perception of the system in detecting slouched postures and subsequently either self-correcting themselves based on visual or audio alert feedback or automatically correcting their posture using EMS were also evaluated. The text entry application required the users to complete a text entry task and the mobile game application required the users to play a Battle Royale game called "PlayerUnknown's Battlegrounds (PUBG) Mobile[1]" on a smartphone. We selected PUBG mobile based on popularity (400 million players), level of engagement and demographics (primarily students and office workers aged 15-35 years who may be prone to long work or gaming hours). In both applications, the users were required to complete all three modalities:

- Modality 1: Visual alert feedback and self-correction
- Modality 2: Audio alert feedback and self-correction
- Modality 3: EMS feedback and automatic correction

The order of the modalities introduced to the users was counterbalanced to include all permutations and to minimize learning effects. In each application, all participants were required to complete all three modalities to complete the study. The independent variables in the study were the three different modalities and the dependent variables were the average correction response times and parameters of user perception such as overall experience, effectiveness of slouching detection, effectiveness of correction feedback, user engagement and task disruption, and modality comfort. Each study session lasted approximately 75 minutes and the participants were compensated $15 for their participation.

4.3 Research Hypotheses

While slouching detection and alert feedback systems have been designed and tested by researchers, we note that slouching posture correction response times and user perception of the systems have not been measured or reported. As such, in our work we expect that there may be significant difference in average correction response times and user perception parameters across the three modalities which would influence the user experience. Therefore, our study was designed to help determine the effects of self-correction using visual, and audio feedback, and automatic correction using EMS on user experience across the two applications. We have five research hypotheses with two parts (a and b) for investigating into the user perception of our approach in the text entry and the mobile game contexts.

- **H1:** In the text entry (a) or the mobile game (b), the average correction response time to slouching feedback will be faster in EMS feedback compared to the visual and audio alert feedback.
- **H2:** In the text entry (a) or the mobile game (b), the user perception of accuracy of slouching posture correction in EMS feedback will be greater than visual and audio alert feedback.
- **H3:** In the text entry (a) or the mobile game (b), comfort in EMS feedback will not be significantly different compared to visual and audio alert feedback.
- **H4:** In the text entry (a) or the mobile game (b), task disruption in EMS feedback will not be significantly different compared to than visual and audio alert feedback.
- **H5:** In the text entry (a) or the mobile game (b), automatic correction using EMS feedback delivers better user experience compared to visual and audio alert feedback.

4.4 COVID-19 Considerations

Due to the ongoing COVID-19 pandemic, we wanted to ensure safety for the participants and researchers. Following our institutions guidelines, all individuals were required to always wear face masks. Between each participant, we sanitized all devices and surfaces that the participants and researchers would be in contact with, to ensure safety during the study. Furthermore, all users were required to wear a face mask to participate in the study, but we provided each individual face masks, hand sanitizer, cleaning wipes, latex gloves, to reduce risk of contracting the disease. Though we cleaned all surfaces between participants, we allowed each individual to clean devices as desired.

4.5 Experimental Procedures

The participants were supplied with a consent form that details the nature of the experiment, safety, risks, compliance required and information about compensation. The participants are required to review the consent form and provide verbal consent for the study

[1] https://www.pubg.com/

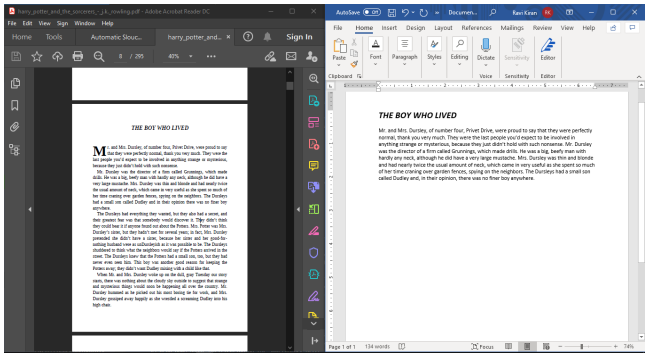

Figure 5: Text entry study showing 50-50 split screen with a PDF document (zoom set to 40%) on the left and the Word document (zoom set to page width) on the right. Participants were required to read from the PDF document and type in to the word document.

session to start. The participants were then asked to complete a pre-questionnaire that collected basic information about their knowledge on posture related issues at the workplace, intervention technology and knowledge of EMS.

Next, the participants were prepared for the study by placing adhesive IMU sensors on the deltoids and the center of the collar bone above the chest (as shown in Figure 3) for data collection and detecting slouching position. Adhesive EMS electrodes were placed on the rhomboid muscles prior to the EMS feedback session for correcting slouching (as shown in Figure 4). After sensor set-up, the participants were required to be seated in an upright position in front of a laptop computer/smartphone with their hands placed on the keyboard or holding the smartphone. Participants were then calibrated for the upright and slouched positions. First, the IMU sensors were corrected for the offset value in the users' upright position and then users were required to emulate a slouched position by inclining their torso and rolling their shoulders forward. These upright and the slouched posture angles were thus recorded.

Prior to the EMS feedback session, the participants were required to be calibrated only once for the EMS intensity to generate a physiological response of sitting upright. The participants were fitted with two pairs of EMS electrodes on their rhomboid muscles. EMS intensity calibration process was done manually for each participant, and moderators incremented the intensity until an involuntary muscular contraction causing posture correction is affected. During calibration, participants were asked to slouch, and moderators manually incremented the EMS intensity. As EMS also produces a tactile or haptic effect even at low intensities, participants were asked to not respond to the tactile or haptic effect to ensure haptic/tactile component of EMS does not contribute to the automatic correction process in any way. Moderators additionally asked participants to verbally respond specifically to the following questions during calibration to ensure rhomboid muscular contraction and participant comfort: 1) when they initially felt the stimulation (haptic sensation), 2) when the intensity was generating an involuntary muscular contraction and/ or when they are experiencing the pulling force towards the upright posture, 3) when any pain is experienced. For each participant, when involuntary muscular contraction was confirmed verbally by participant and visually verified by moderators, the optimal EMS intensity that was generating an involuntary muscular contraction to correct the slouched posture, was recorded, and selected for EMS part of the study.

All the above steps are similar for both the text entry and the mobile gaming applications. In the text entry task, users were asked to read from a PDF document and type into a word document. The PDF and word documents were presented in a 50-50 split screen.

Figure 6: Mobile game study showing lobby Area of PUBG mobile prior to start of the game

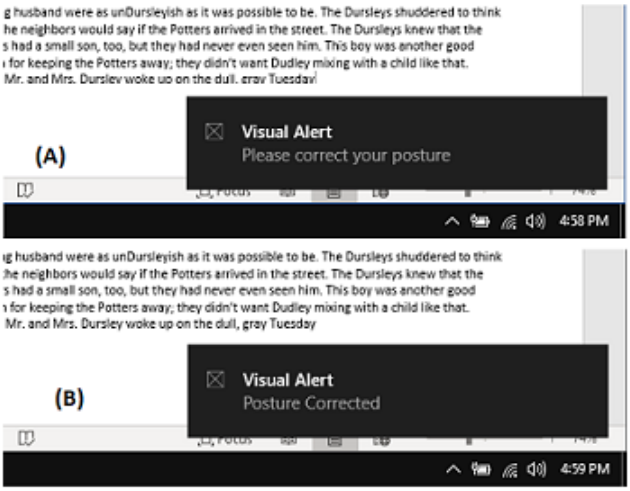

Figure 7: Text entry study-visual feedback: showing Windows 10 Pop visual notification on the bottom right of the screen (A) To correct posture when slouching is detected (B) After Posture has been corrected

For the purpose of conducting the study, the PDF zoom was set to 40% to promote or cause slouching while reading (illustrated in Figure 5). In the mobile game task, users were asked to play PUBG mobile (illustrated in Figure 6). In both applications, the user's posture was monitored for slouching and upright positions during the study. The study comprised of three parts: visual, audio, and EMS feedback. Each part of the study is 15 minutes in duration. Upon completion of each part, participants were required to complete a post-questionnaire about their experience. All participants were required to finish all three parts for completing the study.

4.5.1 Visual feedback and self-correction

Text Entry Application: When slouching was detected by the system based on the IMU sensor feedback, a windows 10 visual popup notification "Please correct your posture" is displayed on the bottom right corner of the monitor (illustrated in Figure 7a) and the users were required to sit upright and self-correct their slouched posture till a second visual popup notification "Posture corrected" is displayed to the user (illustrated in Figure 7b). The response times for correcting the slouched posture were recorded.

Mobile Game Application: When slouching was detected by the system based on the IMU sensor feedback, an SMS is sent from the C# application to the smart phone with the message "Posture alert: Please correct your posture" and is displayed as drop down

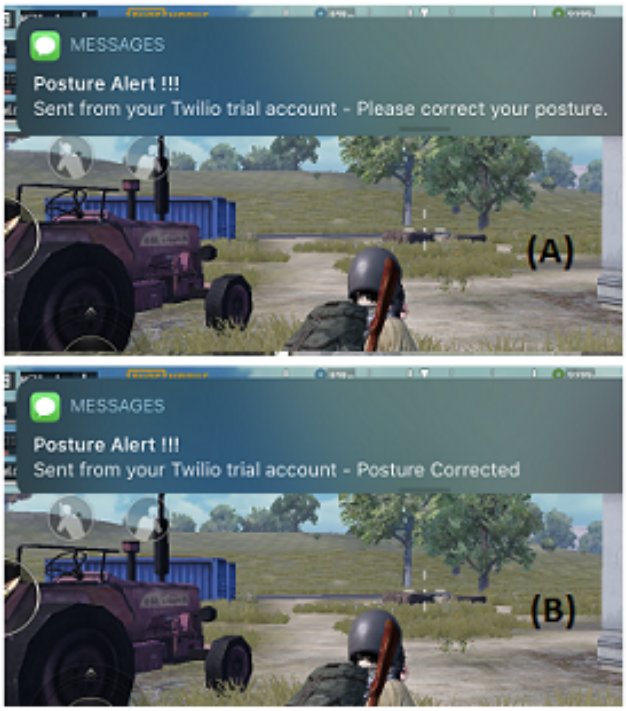

Figure 8: Mobile game study-visual feedback: showing visual notification badges drop down from the top of the display (A) To correct posture when slouching is detected (B) After Posture has been corrected

badge notification on the smartphone (illustrated in Figure 8a). After receiving the visual alert notification, the users were required to sit upright, and self-correct their slouched posture till another SMS containing the message "Posture corrected" is displayed to the user (illustrated in Figure 8b). The response times for correcting the slouched posture were recorded.

4.5.2 Audio feedback and self-correction

Text Entry Application: When slouching was detected by the system, an audio notification "Please correct your posture" is activated and the users were required to sit upright, and self-correct their slouched posture till a another audio notification "Posture corrected" is presented to the user. The response times for correcting the slouched posture were recorded.

Mobile Game Application: When slouching was detected by the system, an audio notification bell sound is activated and the users were required to sit upright, and self-correct their slouched posture till another audio notification bell is activated to the user. The response times for correcting the slouched posture were recorded.

4.5.3 EMS feedback and auto-correction

Text Entry and Mobile Game Applications:. When slouching was detected by the system, the EMS is activated to apply the recorded EMS intensity to the rhomboid muscles to invoke an involuntary muscle contraction. This muscle contraction produces a pulling force in the opposite direction to the slouched posture and to generate the physiological response of sitting upright by correcting the torso inclination and shoulder roll caused by slouching. Figure 1(A) and (C) illustrate the slouched posture during the mobile game and the text entry studies respectively. Figure 1(B) and (D) illustrate the corrected posture after EMS has been applied in the mobile game and the text entry studies respectively. The EMS is deactivated once the upright position is detected. The response times for correcting the slouched posture were recorded.

On the completion of the study, participants were required to complete a comparative post questionnaire regarding their experience in all three modalities. All data from the sensors and the EMS was automatically recorded in the system for further analysis and reporting.

Table 2: Average slouch angles in degrees

Slouch angle	Application	Mean	S.D
Torso Inclination angle	Text Entry	21.00°	3.88°
	Mobile game	18.24°	2.80°
Shoulder roll angle	Text Entry	15.10°	3.00°
	Mobile game	13.84°	2.22°

5 Results

The mean frequency of slouching in the text entry condition was $(7.72, 10, and 8.72)$ for the audio, visual and EMS feedback modalities respectively and $(7.05, 9.11, and 8.38)$ for the audio, visual and EMS feedback modalities, respectively in the mobile game condition. The average torso inclination and shoulder roll angles were recorded for slouched posture during the calibration process and utilized for detection of slouching which are illustrated in Table 2. For text entry, mean torso inclination angle was 21° $(S.D = 3.88°)$, while the mean shoulder roll angle was 15.1° $(S.D = 3°)$. For the mobile game, mean torso inclination angle was 18.24° $(S.D = 2.8°)$, while the mean shoulder roll angle was 13.84° $(S.D = 2.22°)$. For the text entry application, the mean electrical stimulation intensity required to correct slouched posture was $39.72mA$ $(S.D = 13.17mA)$ while for the mobile game task, the mean electrical stimulation was $47.22mA$ $(S.D = 11.08mA)$. To address H1, one-way repeated measures ANOVA were performed on the average correction response times for slouching correction across all feedback types in the text entry application and the mobile game task separately. To address H2 through H5, non-parametric Friedman tests of differences among repeated measures was conducted on the users' ranking of effectiveness of correction feedback, comfort, task disruption and overall experience. Wilcoxon signed rank test was performed if significant differences were found. The results were consolidated and presented below in Table 3.

For H1(a), a one-way repeated measures ANOVA conducted on the influence of correction feedback type on the average correction response times taken for correcting posture after slouching is detected and correction feedback is presented to the user. The correction feedback type consisted of three levels (visual, audio, and EMS). All effects were statistically significant at the .05 significance level. The main effect for the correction feedback type yielded an F ratio of $F(2,34) = 5.382, p < .05$, indicating a significant difference between visual feedback $(M = 3.86, S.D = 1.27)$, audio feedback $(M = 3.9, S.D = 1.28)$ and EMS feedback $(M = 2.89, S.D = 1.74)$. For H1(b), the one-way repeated measures ANOVA conducted on the influence of correction feedback type on the average correction response times taken for correcting posture after slouching is detected and correction feedback is presented to the user. The correction feedback type consisted of three levels (visual, audio, and EMS). All effects were statistically significant at the .05 significance level. The main effect for the correction feedback type yielded an F ratio of $F(2,34) = 20.66, p < .001$, indicating a significant difference between visual feedback $(M = 5.98, S.D = 2.4)$, audio feedback $(M = 4.44, S.D = 0.75)$ and EMS feedback $(M = 2.70, S.D = 1.04)$. For the text entry application, average correction response times were faster for EMS feedback than the visual

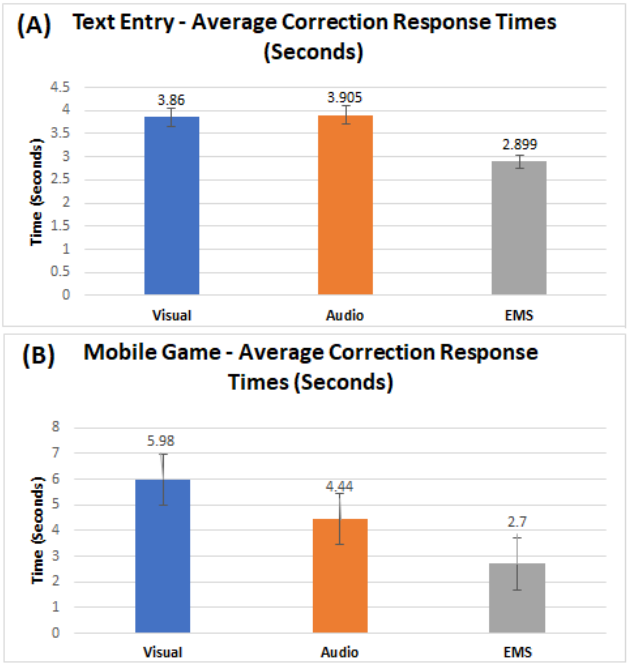

Figure 9: Average Correction Response Times (in Seconds) across (A) Text Entry and (B) Mobile Game for all correction feedback types - (1) Visual, (2) Audio, (3) EMS. Error Bars: 95% CI.

feedback ($t_{17} = -0.961, p < 0.05$), but no significant differences were found between EMS and audio feedback types, and between visual and audio feedback types. For the mobile game application, average correction response times were faster for audio feedback than the visual feedback ($t_{17} = -1.538, p < 0.05$), the EMS feedback was faster than Visual feedback ($t_{17} = -3.276, p < 0.01$), and also faster than the audio feedback ($t_{17} = -1.737, p < 0.001$).The post-hoc analysis between the three feedback types shows that the hypothesis H1(a) tested false in that the average correction response times were faster in the EMS feedback type compared to the visual feedback but not the audio feedback. In the case of H1(b), the hypothesis tested true, in that the average correction response times were faster in the EMS feedback type compared to the visual, and audio feedback types as illustrated in Figure 9 (A) and (B).

To address H2(a) and (b), non-parametric Friedman tests of differences among repeated measures was conducted on the users' ranking of the accuracy of correction feedback type in the text entry and mobile game applications separately. The test rendered $\chi^2 = 3.591, p = 0.166$ which was insignificant ($p > .05$) for the text entry application, while for the mobile game application, the test rendered ($\chi^2 = 7.259, p = 0.027$) which was significant ($p < .05$). A Post-hoc analysis with Wilcoxon signed-rank tests was conducted for the mobile game application with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Median perceived accuracy of slouching correction for the Visual, Audio, EMS feedback were $6, 6, 7$ respectively. There was a statistically significant difference between the visual and the EMS correction feedback type ($Z = -2.591, p = 0.010$), and also between EMS and audio correction feedback type ($Z = -2.585, p = 0.010$). However, there was no significant difference between audio and visual correction feedback types($Z = -0.942, p = 0.346$). Therefore, H2(a) tested false and indicated that the users perceived all three feedback types equally accurate in the text entry application. Whereas H2(b) tested true and indicated that the users perceived that the accuracy of EMS correction feedback was more effective than the visual and the audio feedback in the mobile game application.

Table 3: Friedman test results on the user ranking for H2-H5

User perception	Application	χ^2	p
Accuracy of Correction Feedback	Text Entry	3.592	0.166
	Mobile game	7.259	0.027*
Comfort	Text Entry	1.345	0.510
	Mobile game	4.550	0.103
Task Disruption	Text Entry	0.092	0.955
	Mobile game	5.607	0.061
Experienced slouching	Text Entry	0.407	0.816
	Mobile game	0.400	0.819

Note: $*$ indicates significant difference $P < 0.05$

For H3(a) and (b), non-parametric Friedman tests of differences among repeated measures was conducted on the users' ranking of comfort across all feedback types in the text entry and mobile game applications separately. The test rendered $\chi^2 = 1.345$ and $p = 0.510$ which was insignificant ($p > .05$) for the text entry application, while for the mobile game application, the test rendered $\chi^2 = 4.550$ and $p = 0.103$ which was insignificant ($p > .05$). Therefore, both H3(a) and (b) tested true and indicated that users perceived all three feedback types equally comfortable in the text entry and the mobile game application.

For H4(a) and (b), non-parametric Friedman tests of differences among repeated measures was conducted on the users' ranking of task disruption across all feedback types in the text entry and mobile game applications separately. The test rendered $\chi^2 = 0.092$ and $p = 0.955$ which was insignificant ($p > .05$) for the text entry application, while for the mobile game application, the test rendered $\chi^2 = 5.607$ and $p = 0.061$ which was insignificant ($p > .05$). Therefore, both H4(a) and (b) tested true and indicated that users perceived EMS correction feedback's disruption no worse than the other two feedback types in the text entry and the mobile game application.

For H5(a) and (b), non-parametric Friedman tests of differences among repeated measures was conducted on the users' ranking of overall experience across all feedback types in the text entry and mobile game applications separately. The test rendered $\chi^2 = 0.407$ and $p = 0.816$ which was insignificant ($p > .05$) for the text entry application, while for the mobile game application, the test rendered $\chi^2 = 0.400$ and $p = 0.819$ which was insignificant ($p > .05$). Therefore, both H4(a) and (b) tested false and indicated that users perceived overall experience across all feedback types equally good in the text entry and the mobile game application.

For text entry application, on a 7 point scale of how much users shared responsibility with the auto-correction utilizing EMS where 1 means not at all and 7 means completely, the mean shared responsibility of 2.77 ($S.D = 1.7$), while for mobile game condition, users reported that they helped/ aided auto-correction with a mean shared responsibility of 2.5 ($S.D = 0.95$). On a 7 point scale for how interesting EMS concept was to use for posture correction, where 1 means not at all and 7 means completely, the mean ranking received for EMS concept being interesting was 6.58 ($S.D = 1.01$). Seventy-five percent of the study population (27 out of 36 users) reported that they would purchase EMS feedback for slouched posture correction if it were commercially available.

From the post-questionnaires, participants responses to open-ended "comments on experience with EMS" showed that EMS feedback felt *"more natural"*, *"not easily ignorable"* and better than audio and visual modalities as they cause *"over/ under correction"* of posture. Additionally, participants also reported about the EMS feedback that *"the system accurately initiated the stimulus when slouched and stopped after posture was corrected."* and that EMS *"would enable me to not worry about my posture during highly en-*

gaging tasks." One user responded that EMS is *"unobtrusive and discrete method of auto-correcting posture."* and EMS was the*"least disruptive"*. Further, users reported *"I cannot listen to some one while i am trying to read and type."*, and *"the visual notifications were annoying and distracting when i was typing."* indicating that the audio and visual feedback were placing a cognitive load on the user. Other user comments include *"this can be a good training device but EMS requires getting used to"*, *"it actively and immediately corrected my slouched posture"*, *"training device for maintaining proper posture"*, *"the tingling sensation feels weird but good"*, *"this can seriously help people with posture problems."*

6 Discussion

The goal of the current analyses was to evaluate the performance and user perception of the EMS feedback and automatic correction of slouched posture. Five main research questions were addressed that evaluated if significant differences were found between visual, audio and EMS feedback across both application types. The results of these analyses indicate the potential of our physiological feedback loop as a viable alternative technique for poor posture detection and correction. The EMS feedback and auto-correction was perceived as an effective feedback mechanism, minimized correction time, performed across multiple applications without disrupting the task, comfortable yet could not be ignored.

Our automatic slouching correction using EMS feedback system outperformed the visual and audio feedback types based on the average correction response times. This may have been due to the fact that visual and audio feedback place an additional cognitive load on the user while being engaged in their task and rely completely on the user's willingness to self-correct their posture. The EMS feedback, however, does not require the user's attention to correct their posture. This has made our automatic correction using EMS feedback significantly faster than the other two feedback types.

Users also perceived that EMS feedback corrected their posture more accurately than the other two feedback types that required self-correction. Users reported that self-correction in the visual and the audio feedback types caused them to always over-correct their posture as their awareness of it was minimal while being engaged in the task at hand. Whereas EMS feedback did not require the user's attention and always accurately activated when slouched posture was detected and deactivated after posture had been corrected. The user rankings on accuracy of EMS feedback indicated that EMS feedback was perceived to be more accurate in the mobile game application than the text entry application. This interesting finding may have been due to different factors such as nature of the two applications, complexity of the task, users' connection to the device and varied range of motion involved in auto-correction using EMS feedback across the two applications.

Additionally, it was also interesting to note that EMS feedback and auto-correction were perceived equally comfortable and no more disruptive than traditional visual and audio alert feedback but with the added advantage of automatic correction. This may have been because EMS feedback relied entirely on the user's physiology and delivered a somatosensory feedback that discretely enabled posture awareness without disruption. Additionally, the EMS feedback allowed the audio and visual faculties to be engaged in the task and not be distracted by the audio and visual feedback that required their attention and disrupted their workflow or game play.

Further, users also exhibited and reported a shared responsibility in aiding the auto-correction feedback mechanism. This may have been due to fact that the system increased awareness of their posture and the sensory confirmation presented by the EMS feedback loop by activation and deactivation when slouched or upright posture was detected, respectively. It could also be that they learned the working of the system or perceived that they were involved in the posture correction. Users also reported that they helped the auto-correction process slightly as they progressed through the duration of the task and gradually started utilizing it as a training device. With respect to sensitivity of the EMS feedback, some users were more sensitive to the EMS than others. As shown in the results section, the EMS intensity varied across the study population. This could be due to factors such as different body types, muscle physiology, and activity levels. EMS feedback is a minimally invasive technique and could be intrusive and disruptive if not applied at the correct locations and improperly calibrated. Our system was perceived no more disruptive than the alternative feedback types due to the careful calibration of the EMS intensity with user feedback on their level of comfort and the generation of the desired physiological response during the calibration phase. In general, EMS was also able to deliver an equally good overall experience as the other two feedback types and shows promising potential to be developed as a viable alternative option for maintaining good posture or developing good postural habits.

Finally, users perceived that EMS was an interesting concept to use for automatic posture correction while they were engaged in their tasks. Twenty out of 36 users reported that EMS feedback and auto-correction was their most preferred feedback type while 75% of the study population was willing to purchase the automatic correction using EMS feedback if it were a commercially available product. Therefore, our autonomous system could be a valuable alternative or an addition to existing environment, health, and safety (EHS) protocols at workplaces for enhancing productivity, worker health and in preventive health care.

7 Limitations and Future Work

Although limitations include placement of the sensors and electrodes, we plan to integrate them into wearable clothing and devising an auto-calibration system that can be customized to each individual's comfort. Another limitation of the current study was the gender of the users, the proportion of the male users was higher than the female users (Male=31, Female=5). We plan to conduct a further study to balance the male to female ratio.

Our future work includes the development of an instrumented wearable garment that can be worn and contains provisions to embed the sensors and electrodes and house the EMS feedback unit along with a dedicated smartphone application. Additionally, we plan to test the automatic detection and correction of slouching under different physical conditions such as standing, walking, and carrying different loads on users' backs. We also plan to extend the concept of posture correction using EMS to different workplace postures such as wrist extension, text neck, and asymmetric weight distribution on the legs.

8 Conclusion

In conclusion, we have demonstrated that our physiological feedback loop based automatic slouching detection and correction with EMS is a viable approach to supporting posture correction. Our auto-correction system utilizing EMS feedback demonstrated significantly faster posture correction response times compared to the self-correction in the visual and audio feedback. Our approach also showed that users perceived EMS feedback to be more accurate, just as comfortable and produced no more disruption than the alternative techniques it was tested against in both the text entry and the mobile game applications. Therefore, automatic slouching detection and correction utilizing EMS shows promising results and can be developed as an alternative method for posture correction. Our approach could prove useful in preventive healthcare to avoid workplace related RSI and be particularly beneficial to people involved in highly engaging tasks such as gaming, diagnostic monitoring, and defense control tasks.

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