GymSoles++: Combining Google Glass with Smart Insoles to Improve Body Posture when Performing Squats

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ABSTRACT

In pandemic times, public facilities, such as gymnasiums and other sports facilities are closed. Hence, keeping oneself physically fit becomes particularly difficult as well as getting help from a fitness trainer or instructor is almost impossible. We propose an alternative solution, GymSoles++, a virtual trainer supporting the user with their exercise. This allows users to maintain the correct body posture to avoid injuries when performing exercises such as squats. We combine Google Glass with an unobtrusive sensing approach, an insole-based wearable system that provides feedback on the user's centre of pressure (CoP) via vibrotactile and visual aids. Previous research has shown that solely visualizing the CoP can significantly improve body posture and thus effectively assist users when performing squats and dead-lifts. In this research, we explored different feedback modalities and conclude that a vibrotactile insole is a practical and effective solution.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; *Haptic devices*; User studies.

KEYWORDS

Smart Insoles, Improving Body Posture, Workout, Well-being, Center of Pressure, Google Glass, Squats, Visual & Vibrotactile Feedback

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Figure 1: User performing squats with the GymSoles++ prototype. The pressure sensitive insole calculates the body's Center of Pressure (CoP). The insole also incorporates 8 vibration motors that map the CoP to vibrotactile feedback. The CoP is also visually displayed on a Google Glass.

1 INTRODUCTION

A global pandemic, such as COVID-19 has significant social costs [21], including an impact on physical and mental health [19, 24]. While regular exercise is recommended by physicians, pandemic measures, namely social distancing, reduce the possibility of physical activity [43]. The proper execution of exercises is important to achieve desired training goals and to prevent the occurrence of various injuries. Exercises, such as squats and dead-lifts, are elemental full body exercises [10, 49] and contribute to a healthy body when executed properly. Existing assistive systems to evaluate exercises, such as squats and dead-lifts, usually rely on expensive motion tracking systems [9], or on multiple Inertial Measurement Unit (IMU) systems [30]. Both solutions have clear limitations in a gym setting, as they are highly obtrusive, require inconvenient setup, and extensive calibration. Alternative solutions, such as force plates, are bulky and generally developed for laboratory use. We view smart insoles to be a possible solution, as they provide rich information and overcome many issues previously mentioned [33]. Currently, commercial smart insoles, such as Nike+ [1] and Adidas MiCoach [29], track user activity including step counting and stride information. While these metrics may be useful, the lack of immediate feedback severely limits their effectiveness.

Previous research [15] introduced a shoe utilizing foot pressure data, with the focus to improve body posture during squats and dead-lift exercises. The user's needs had been identified and possible system requirements were derived by conducting expert interviews with four professional trainers. Consequently, a proof-of-concept system was developed and user studies were carried out to evaluate two feedback types interpreting the Centre of Pressure (CoP); 1.

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Vibrotactile feedback at the side walls of a shoe and 2. Visual feedback on a screen. Independent from the feedback type, it has been found that solely visualizing the CoP resulted in an improved body posture. Considering the insights provided, we further developed the system satisfying the users' and reviewers' suggestions.

In GymSoles++, we introduce a flexible force-sensitive vibrotactile insole connected to a Peripheral Head-Mounted Display (a pair of Google Glass) providing visual feedback wherever the user is performing exercises (*see Figure 1*). Unlike the previous system [15], GymSoles++ is fully mobile and provides a further tweaked feedback aiming to be less obtrusive.

2 RELATED WORK

2.1 Optical Motion Tracking

The motion tracking systems are highly accurate and commonly used in laboratory studies in bio-mechanics [7], sports and exercise science [7, 9]. Immobility and extensive calibration processes render these systems difficult to use in a typical gym setup. Moreover, improper marker placement and unfavourable lighting conditions will substantially reduce the accuracy. As an alternative, goniometer-based signal camera-based systems have been introduced in the literature [12, 44]. The Coach's Eye [17] is a mobile application that use multiple cameras to analyse movements of exercises such as squats, weight lifting, aerobics etc. [28]. Not using markers make it easier to use, however, in a gym setup camera-based systems raise create privacy concerns.

2.2 Inertial Measurement Units

In literature, Inertial Measurement units (IMU) based tracking systems were first introduced as a low cost and a portable solution for motion tracking [30]. Although a single IMU is often sufficient for applications such as activity recognition [23, 41], step count detection and counting exercise repetitions [35], multiple units are required to identify joint angles in applications such as posture detection, exercise tracking [46, 48], gait analysis [13, 50] and rehabilitation [4]. However, using multiple IMU has drawbacks, as it requires extensive calibration [26], thoughtful sensor placement to minimize skin movement [18], and a careful segment-to-body alignment [45] which needs expert knowledge.

2.3 Exercise Tracking using Force Plates

Laboratory grade force plates, such as AMTI [39], Kistler [6], and hawking dynamics [14] have been used in applications which require analysis of impact forces and balance in sports and rehabilitation [34, 42]. The ground reaction force and displacement of the Center of Pressure (CoP) are the key parameters that these devices measure. Nintendo's Wii Balance board [11], as well as some force plates introduced in academic research are inexpensive alternative with pressure plates. While high accuracy is the main advantage of these platforms, the lack of portability limits their usage to the laboratory.

2.4 Insoles and Bend Sensors

There are several prior work which used bend sensors to identify motions [2, 37]. In those work, knee guards embedded with bend sensors were used to train exercises such as squats and deadlifts. Unobtrusiveness is the main advantage of smart insole based tracking compared to other approaches. Prior research in smart insoles has largely focused on analyzing gait for rehabilitation [3, 36] and measuring sports performance [20, 40]. Moreover, commercially available pressure insoles [1, 29] have also been used in research for step counting, stride counting, gait analysis, and activity recognition [16, 27]. In literature, smart insoles are used to identify body postures and floor types [33, 38]. Recent work uses insoles to improve exercise posture by sensing the user's center of pressure and visualizing it [15].

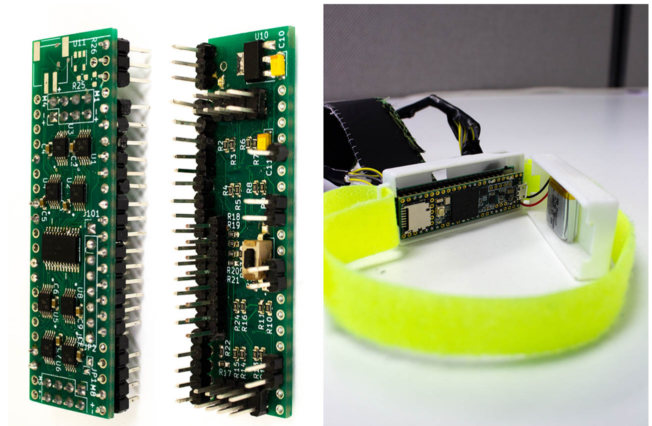

Figure 2: Customized PCB consisting of 8 Motor Drivers and Multiplexers. It is designed to plug a Teensy 3.6

3 GYMSOLES++

GymSoles++ visualizes the user's CoP and thus contributes to an improvement of exercise postures when performing squats and dead-lifts. This finding was validated in a previous study [15] with 13 participants using an early version of the prototype (*See Figure 3 - Left & Figure 4 - Left*).

3.1 Motivation

The motivation of this work is based on a variety of suggestions and other qualitative insights gathered from the earlier evaluation. The two main action points concerned the limited mobility and bulkiness of the prototype, as users asked for a less obtrusive feedback. Designing subtle feedback seems to be particularly challenging as feedback should just noticeable, but not obtrusive. As a first step, we developed a fully mobile prototype that allows the user to move freely. We 3d-printed a flexible insole and attached vibration motors to it. As the foot's cornea reduces the perception of sensitivity, the vibrotactile feedback under the feet may be perceived as less obtrusive. To evidence this, we found it interesting to compare the insole vibration against the previous prototype, which provided vibration feedback at the side walls of the shoe. Moreover, another goal was to evaluate vibrotactile feedback against visual feedback. In addition to the previous evaluation, where we used a stationary LCD screen, we also developed a visualisation on a peripheral head-mounted display (PHMD) [32] – a pair of Google Glass.

Figure 3: Left: Shoe prototype (UK size: 10-11). The sensing.tex FSR-based plantar pressure insole is inserted and 8 vibration motors (ROB-08449) are attached at the inside of the shoe's wall. Right: 3D-printed insole Prototype (UK size: 10-11). The sensing.tex pressure insole is convered by a 6mm thick rubber layer (ninjaflex 85A filament) that incorporates 8 vibration motors.

3.2 Pressure Sensitive Insole

We used a commercially available pressure insole (UK size 10-11) from sensing.tex [31] to collect pressure data in both shoe prototype and insole prototype. It consists of 16 pressure force-sensitive pressure sensor points that somewhat align with critical pressure points identified in prior work [25]. The hardware that we will describe in next section was used to interface the pressure insole with a teensy 3.6. The CoP was calculated as described in previous work [15].

3.3 Miniaturized Hardware

To make the system truly mobile, we developed a custom PCB (*see Figure 2*). The board is capable of computing the pressure data from the sensing.tex insole and controlling 8 vibration motors. Therefore, the PCB incorporates 8 DRV 2605L Motor Drivers. An I2C multiplexer, TCA9448A, interfaces with a Teensy 3.6, as all the drivers have the same fixed I2C address. A voltage divider circuit is integrated to interface with the pressure sensitive insole. A Bluetooth Low Energy modem by Nordic is also included enabling wireless communication with our visual feedback systems, such as the Google Glass. The entire hardware is enclosed into a small white box that is to be strapped around the ankle.

3.4 Vibrotactile Feedback

The previous GymSoles incorporated vibration motors attached to the side wall of a shoe (*see Figure 3 - Left*). As the sock reduces attenuation, the motors were driven with max power, creating an extra noise. In GymSoles++, we designed a flexible vibrotactile insole, which has 8 motors embedded into the insole itself (*see Figure 3 - Right*). The insole was 3D printed by using Ninja-Flex flexible filament. The placement of the motors were primarily decided according to the density of the cutaneous sensory extremities of the sole. Although thick cornea of the foot sole dampens perception, when embedding the motors this way, the prototype provides feedback by directly stimulating cutaneous sensory receptors of the soles. Hence, we set the vibration intensity to a lower level than before to minimise the noise generated. The rubber insole was 3d-printed from a ninjaflex 85A filament.

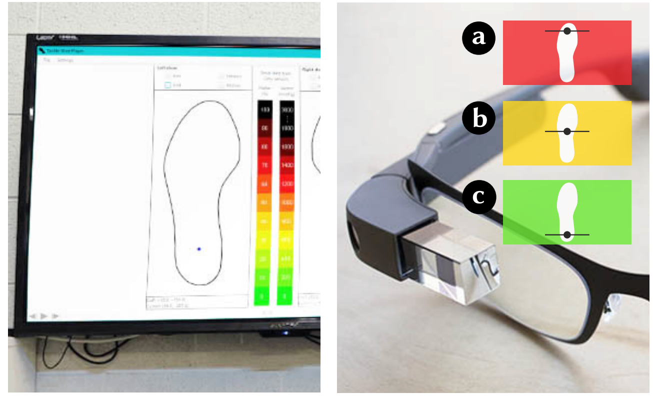

Figure 4: Left: Visualization at the static Monitor. The black dot visualizes the user's CoP. Right: Visualization at the PHMD of our choice: Google Glass. a) CoP is at the forefoot, b) CoP shifting towards the heel, c) CoP is indicated to be correctly resting at the heel. The changing background color enables the user to perceive this information with his peripheral vision, without visually focusing the display.

3.5 Visual Feedback

Previously, a Java application developed for a large monitor provided visual feedback (*see Figure 4 - Left*). If the display is situated unfavourably, this forces the user to angle the head in a manner that loses focus. As a solution, we modified the visualisation and fit it as an Android app running on Google Glass. To make the visualisation clearer, the background color was also changed, such as from green to red, according to the deviation of CoP from the correct location. This way, the user can perceive visual feedback without focusing on the display (*see Figure 4 - Right*). Once visually focused on the screen, the user can see a more precise visualization of his CoP. Our PHMD, Google Glass, receives CoP data from our prototype via Bluetooth LE.

4 EVALUATION

We conducted a user study to evaluate the preference of feedback types and the overall usability of the system.

4.1 Apparatus

In this study, we used the sensing.tex pressure sensitive insole to calculate the CoP. The CoP is visualized on four different devices, which are:

- Vibration 1: Shoe Prototype (*see Figure 3 - Left*)
- Vibration 2: Rubber Insole Prototype (*see Figure 3 - Right*)
- Visual 1: 24" Monitor (*see Figure 4 - Left*)
- Visual 2: Google Glass PHMD (*see Figure 4 - Right*)

4.2 Participants

We recruited 10 healthy participants (8 males and 2 females), aged between 21 and 34 (M = 26.3, SD= 4.59). Participants were selected according to their foot size. This was necessary, as the participant's feet must match the prototype's size (UK size 10-11).

4.3 Task and Procedures

After filling the consent form, we invited participants to perform 10 repetitions of squats while wearing the different devices. Before the participant would perform squats, we first provided a demonstration of the correct squat form. Then, we conducted a within subject study where participants performed squats with four feedback conditions, (1) Vibrotactile Feedback from the side walls of the shoe, (2) Vibrotactile Feedback from the insole, (3) Visual feedback from the LED screen, (4) Visual feedback from Google Glass. The sequence of conditions was counterbalanced across all participants to remove invalid results due to a possible learning effect.

4.4 Data Gathering

After performing squats in each condition, we asked participants to fill out the System Usability Scale (SUS) questionnaire [8]. The SUS is used to gain insights on the system's usability. Additionally, we asked the study participants to rate their preference for each condition, as well as their reasons for such ratings, followed by an open ended question.

4.5 Results

4.5.1 Usability. The vibrotatctile insole (Condition Vib.2) scored the highest usability, with M = 80.75 points (SD = 12.96). The lowest usability score was M = 74.75 (SD = 17.85), which the shoe prototype with vibration at the side walls received (Condition Vib.1) – *See also Figure 5*. However, a one-way ANOVA for correlated samples could not reveal any significant differences between all four configurations ($F_{3,36}$=.31, p >.05). Although, there is no significant difference, Brooke [8] states that a system receiving a usability score above 68 can be considered usable. A score of 80 well exceeds the average for an acceptable system and indicates condition Vib.2 to be of excellent usability [5]. Therefore, we can recommend that a vibrotactile insole seems to be a good choice in providing CoP feedback to improve body posture.

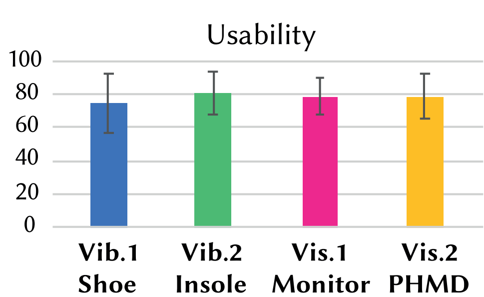

Figure 5: Displaying the SUS score. The vibrotactile insole scored the highest usability, although no significant difference was found.

4.5.2 Preference. In terms of user preference, the visualization on the monitor (Condition Vis.1) scored slightly higher (M=5.44; SD=1.67;) than any other feedback types. However, a one-way ANOVA for correlated samples did not identify significant differences ($F_{3,36}$=.51, p >.05) (*See Figure 6*). Further, the standard deviation across all conditions is very high, indicating that preferences seem to be strongly individual. Qualitative feedback supports this assumption.

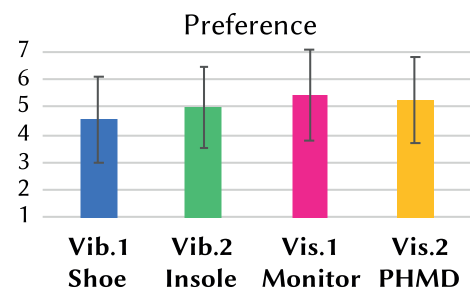

Figure 6: Results of the rated preference on a 7-pnt Likert scale; no significant difference.

4.5.3 Qualitative Feedback. Most participants (6/10) preferred Google Glass (Condition Vis.2). Some of them mentioned that it would not hinder them, as they can freely look around: *"...In the case of visual feedback, I prefer Google Glass, because it does not constrain the view direction"*. Also, some participants mentioned that the visual feedback on Google Glass was more intuitive, since a color change from green to red occurs to indicate a deviation from the correct CoP profile. The color change is also visible without visually focusing on the screen. The participants who rated the vibrotactile insole (Condition Vib.2) as their highest preference mentioned that insole feedback was more perceivable compared to the shoe prototype. Moreover, two participants mentioned that a combination of Google Glass and the insole prototype seems to be most powerful: *"I think that the combination [of] insole and Google Glass would be super strong..."*

5 PUBLIC DEMONSTRATION

To gather qualitative feedback from the public, we previously demonstrated an early version of the GymSoles++ system at the Dubai Design Week. The live demonstration took take place in a 2x2 meters wide area where participants could experience GymSoles++. Users were able to either perceive a mimicked CoP movement or their own CoP movement when performing squats. Visitors were introduced to the project with a video running on a tablet computer and offered to wear the vibrotactile insole. Moreover, the visitor wore Google Glass and saw how the CoP deviates when bending the upper body or performing squats. While a single visitor is experiencing GymSoles++, other visitors could see what is happening by either watching the participant and the visualised real-time feedback, or watching the introduction video shown on the tablet computer (*Figure 4*). Qualitative user feedback confirmed our system to be of great interest by the public. Also, it became clear that many users were unaware of their wrong execution style before using the prototype.

Figure 7: Presentation Booth at the Dubai Design Week: The visitor can actively take part in the demonstration, while stepping into prepared sandals. Another rubber insole (in orange color) could be touched by hands. The visual stimulus is conveyed on a monitor, as well as on Google Glass. A Tablet computer runs a video introducing the project.

6 DISCUSSION

Although we did not observe any significant differences in terms of usability or preference, qualitative feedback indicated that Google Glass for visual feedback worked best. Users preferred the Google Glass mainly because it allowed them to look around freely. However, it could also be because of the user's excitement towards technology such as smart eyewear. Some participants mentioned that they liked the colour change of the Google Glass's peripheral display and identified that it seems more intuitive than keep looking at a large screen. Our project indicates that any peripheral display that can provide similar feedback could be used instead, such as a one-pixel display based on an RGB LED [47].

Overall, the vibrotactile insole showed a higher preference over the vibration motors embedded shoe. As we hypothesised at the beginning, insole feedback was more perceivable than the feedback provided via side walls of the shoe. This could be mainly because of the higher sensitivity of the sole of the foot. Moreover, the insole was designed to stimulate the cutaneous sensory extremities of the foot.

Also, some participants mentioned that vibration could also be provided whenever the user deviates from the correct pressure profile. To implement this, we need to match the CoP profile with the upper body movements. An IMU mounted on the shoe can be used to get information about upper body movements. Another method would be using the IMU of the Google Glass to identify upper body movements. Some participants suggested that combining Google Glass with the vibrotactile insole could be powerful.

In the study presented, we asked participants to perform squats only. However, GymSoles++ can be easily used to improve other full-body exercises such as dead-lifts and lunges [15]. It is also possible to identify certain CoP patterns and upper body motion patterns using the CoP profile and the IMU of Google Glass. Hence, our work can be extended to identify different exercises automatically and lead to the correct exercise profile intuitively.

In addition to enhancing exercises, the GymSoles++ could also identify balance and gait parameters while walking. In conditions like limb length discrepancy (LLD) [22], people often tend to put more weight on one side of the body resulting in uneven pressure distributions. LLD can also be acute when sitting in a bad posture for long hours. In such situations, GymSoles++ could provide feedback to the user to maintain the correct weight distribution to avoid long-term complications. Moreover, during running, people often tend to put extra pressure on one foot resulting in injuries and temporary numbness. The GymSoles++ can also be used to provide feedback about such situations as vibration feedback. However, to accomplish this, it is essential to develop high fidelity robust prototype. The current prototype was not tested in running activities yet.

In the current evaluation, we only recruited relatively younger adults. However, for some older adults, especially people with peripheral neuropathy, providing vibrotactile feedback via an insole may not work due to diminished sensations. Also, peripheral feedback closer to the eyes may not work perfectly due to the diminished vision of some older adults. Although GymSoles++ seems useful for older adults for daily exercise training, tuning vibration parameters and selecting the correct visual display need careful designing and further evaluations. Moreover, using a peripheral display with gamification aspects may provide an incentive to regularly perform full-body exercises. Also, sonification, the use of non-speech audio to convey information, such as movements can be easily done by using the Google Glass born conduction speakers. We believe that sonification in combination with gamification aspects during exercises will encourage the users to perform these exercises on a daily basis, which is particularly important during pandemics in while being in isolation.

Technology-wise, GymSoles++ is fully wearable and standalone. Although the electronics were miniaturised and can attach to the ankle, some participants mentioned that they like to see all the electronics embedded in the insole itself. In the future, we will further improve our device by using a flexible PCB integrated into a silicon-based insole. In this way, we would be able to protect electronics from moisture and excessive pressure. Also, the ankle strap can be modified in aesthetically pleasing manner, so users can wear the device as fashionable sports wearable.

7 CONCLUSION

In this paper, we presented GymSoles++, a wearable system that helps improve ones body posture when performing full-body exercises, such as squats. Previous research evidenced that solely visualizing the CoP in real-time results in a significantly improved body posture [15]. In this work, we contributed with an improvement of the wearable system, which is now a fully mobile stand-alone system. The improvements were based on insights gathered from previous user studies and suggested by external reviewers. Besides the technical advancement, we also improved the feedback by aiming to be less obtrusive. Our evaluation showed the new system to be highly usable as rated by 10 participants. We explored different designs and hope to inspire other designers and researchers with the intent of commercialisation.

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