Haptic Shoe

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Abstract— **Incorrect running form is a common cause of overuse injuries in distance runners, both experts and novices. Rear-foot striking and overpronation are two key factors contributing to running injuries [6, 7, 8]. Haptic-infused shoes have been moderately successful in detecting foot position and conveying complex information. We developed a haptic shoe that detects incorrect running form through data provided by pressure sensors in the sole and an IMU; based on the output of the sensors, vibrotactile and kinesthetic feedback are generated to prompt the user to correct their form. Initial user testing results indicate that our prototype can effectively detect foot position and provide discernible haptic feedback to prompt form correction. Further investigation is needed to determine the efficacy of our system in the more dynamic, longer-distance running scenario for which this system is designed.**

I. Introduction

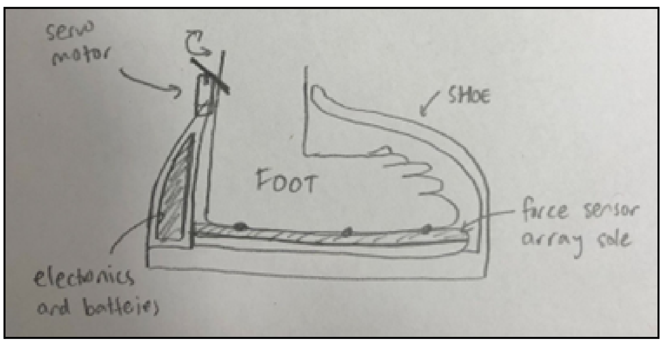

Figure 1. Full Haptic Shoe system sketch

Incorrect running form hinders optimal athletic performance and leads to injuries. 47% of high school distance runners experience injuries that damper their training and progress in the sport; the situation becomes even more dismal at the collegiate level [1]. The most common types of running injuries are Patellofemoral pain pain around the kneecap, IT band issues: pain around the outside of the knee, Plantar fasciitis: pain in the arch or heel of the foot, and medial tibial stress syndrome.

Rear-foot strikers tend to have higher rates of musculoskeletal injuries relative to mid-foot and front-foot strikers [6]. Large angular displacement between heel strike and maximum everted position is significantly correlated with medial tibial stress while running [7,8]. There are factors other than biomechanics that increase the risk of running overuse injuries such as nutrition and mileage, however, providing runners cues to correct rearfoot strike and their foot angle, could help prevent injury due to their biomechanics.

Haptic-infused systems have been developed to detect and convey rich information in the running domain. Haptic ankle devices have improved the guide-running experience for blind marathon runners by allowing the matching of running tempo and synchronization [2]; haptic-assisted synchronization was also found to encourage runners and improve confidence in guidance. Haptic-infused shoes with insole pressure sensors, foot position trackers, tactile displays, and haptic feedback (such as vibrations) have conveyed complex information in a variety of scenarios including mixed-reality environments [3,4,5].

We aimed to detect improper running form and provide dynamic haptic feedback to assist runners to correct their form and avoid injuries while maximizing athletic performance.

II. Methods

A. Device Description

The hybrid haptic device we developed consisted of two fundamental modules: the foot position sensing module and the haptic feedback module. We detect foot position through a two-pronged approach: we made custom piezo-resistive force sensors to detect the user's landing position (i.e. front-foot, mid-foot, rear-foot) and we used an inertial measurement unit (IMU) to detect the user's foot angle (i.e. overpronation). Our haptic feedback module is designed to provide two types of responses: vibro-tactile feedback in form of vibration waves generated using vibration motors embedded in the sole and kinesthetic feedback in the form of gentle taps to the user's Achilles tendon powered by a servo-motor.

The two modules of our haptic shoe are controlled using an Arduino. When the system detects rear-foot striking, it generates a vibration wave originating from the heel to the front of the foot to motivate the user to shift their weight along this wave towards the front of their foot; Similarly, a wave from the front to the heel is generated when front-striking is detected. When the system detects overpronation, the servo-motor provides a gentle tap on the right of the user's Achilles tendon to prompt the user to correct the foot angle.

C. Preliminary Results

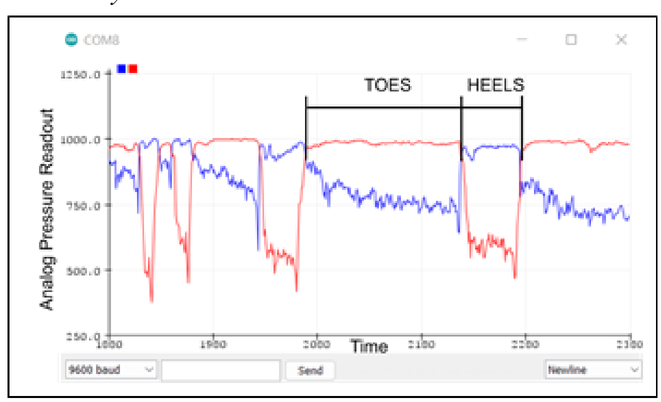

Figure 2. Pressure sensor readout for toe pressure sensor (red) and heel pressure sensor (blue)

During user testing, our prototype in its current form was able to provide the type of corrective feedback that we envisioned. Users were able to discern the varying types of

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haptic feedback and their underlying intentions. The device was tested both statically and with a user running and haptic signals were discerned with 100% accuracy in both scenarios. However, longer-term testing will be necessary to evaluate whether the use of haptic feedback running shoes has an effect on running biomechanics and overuse injury rate.

Figure 2 shows the direct readout from the custom force sensors which we used to detect heel strike and toe strike. In figure 2, the blue data represents the analog pressure readout from the pressure sensor positioned in the back of the shoe and the red data represents the analog pressure readout from the pressure sensor positioned in the toe of the shoe. As the user shifted their weight from their heel to their toe, we collected the data shown in figure 2 which allowed us to create thresholds which we classified as "too much weight on toes" and "too much weight on heels." When these cases were detected, we sent a signal to the runner via the vibration motors in the heel of the shoe to correct these biomechanics.

III. FUTURE WORK

A. Future Development

A key limitation of the current iteration of our device is a lack of automatic calibration of sensing and feedback to each user's biophysical configuration (i.e. weight, height, strike force etc); The amount of force each user generates while running differs based on their physical characteristics. It is pertinent to be able to easily calibrate the sensing thresholds to each user to accurately detect their running form and produce appropriate haptic feedback. In our prototype's current state, some users were not able to apply enough force to actuate the vibration motors due to having a lower body weight than the user which the shoe was calibrated to.

We will also like to minimize the form factor of our haptic shoe by using a smaller Arduino and thus a smaller haptic case. We would also like to experiment with a pressure sensor array as opposed to only two pressure sensors to optimize pressure detection; Similarly, we would like to experiment with different vibration frequencies and amplitudes to optimize the feedback.

B. User Study Protocol

In order to evaluate our haptic shoe, we will conduct a within-participants performance study with 20 total participants. We will compare two conditions (our haptic shoe vs a non-haptic shoe) and measure the impact on the participants' running form. All participants will be ages 18-40 and run recreationally 10-20 miles each week.

Each participant will establish a baseline running form by running 800 m lap the Hopkins recreational center's indoor track using provided running shoes with no haptic feedback while they are filmed. We choose the indoor track to ensure environmental conditions do not hinder our results. Then, after a 5-minute break, each participant will run another 800m using the haptic shoe. Video from both trials with and without the haptic shoe will be analyzed by a physical therapist. After running, each participant will be interviewed about the comfort and experience of using the haptic shoes for about 15 minutes. Each participant will be compensated at the rate of 10$ per hour.

C. Evaluation Metrics

We will measure the following quantitative metrics collected through data recorded by the device:

- Frequency of front-foot strikes
- Frequency of mid-foot strikes
- Frequency of rear-foot strikes
- Frequency of foot overpronation
- Frequency of front underpronation

We will measure the following qualitative metrics as indicated by an interview:

- Feedback preference
- Feedback intuitiveness
- Perceived task difficulty
- Running confidence
- Perceived annoyance of charging and calibration
- Overall thoughts/comments

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