Design Project 3

A low-cost wearable device to improve the performance and technique of a running athlete

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Approval

The project titled "A low-cost wearable device to improve the performance and technique of a running athlete" by Enlin Quental, is approved for partial fulfillment of the requirement for the degree of 'Master of Design' in Interaction Design.

Guide:

Chairperson:

Internal Examiner:

External Examiner :

Declaration

I declare that the written document represents my ideas in my own words and where others ideas or words have been included, I have adequately cited and referenced the original sources.

I also declare that I have adhered to all principles of academic honesty and integrity and have not misinterpreted or fabricated or falsified any idea/fact/source in my submission.

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Abstract

Advancement of technology has reduced sizes of the electronic components, which made possible in creating smaller devices, especially wearable devices. The best examples of wearable devices are fitbands and smart watches. These devices became popular because of the demand in sports and fitness tracking, and communicating with the connected smartphone. These devices have Inertial Measurement Unit (IMU) embedded inside the product, for tracking the exercise and sleep. IMUs are also used for gait analysis and it is a cheap, reliable and portable sensor when compared to other devices for capturing gait data. Fitness trackers are not using this potential, and they are not improving the performance and technique of a running athlete through gait parameters. Calculation of steps according to gait analysis is calculated from foot and not from wrist, which otherwise renders the related fitness parameters inaccurate. Therefore, we develop a low-cost wearable for the foot to improve the performance and technique of a running athlete through the runner's kinematic features. In this project, we also discusses about the unique features—integration of a running technique and fatigue alertness—that are not present in existing fitness trackers, design exploration of our product and our evaluation on the product.

Literature Review

Research papers

Running is a popular sport and one of the method's of getting fit. It is a means to burn calories, reduce weight, improve stamina and breathing, rejuvinate, becoming active through out the day, and reducing stress. Running is done as a passion or as a competitive sport. It is also a common source of injuries. Advanced and novice runners alike develop ailments that are often caused by improper shoe choice or deficient running technique [1]. Poor running technique and fatigue increase the risk of injury. Both are reflected in the runner's kinematics which is traditionally monitored and analyzed using optical motion capture systems [2].

Monitoring of foot and gait analysis of walking and running helps to prevent injury and improves performance in sports [3]. Gait analysis could also detect the potential diseases or abnormalities in advance [4] [5]. Table 1 shows area of application of gait analysis and how much of the related parameters are used in each application [5]. In the area of running sports, studies have shown us that "independent of the skill level, heel lift decreased during the course of the run due to progressive muscle fatigue [6]". As these gait parameters are useful for doctors, trainers, rehabilitation centres and people concerned about health, they could be detected using several gait capturing methods. So we explored the different methods of capturing gait.

Table 1: Overview of gait parameters and applications [5]

Gait Parameter	Application		
	Clinical	Sports	Recognition
Stride velocity	X	X	X
Step length	X	X	X
Stride length	X	X	X
Cadence	X	X	X
Step Width	X	X	X
Step Angle	X	X	X
Step time	X		
Swing time	X		
Stance time	X		
Traversed distance	X	X	
Gait autonomy	X		
Stop duration	X		
Existence of tremors	X		
Fall	X		
Accumulated altitude	X	X	
Route	X	X	
Gait phases	X	X	X
Body segment orientation	X	X	
Ground Reaction Forces	X	X	
Joint angles	X	X	
Muscle force	X	X	
Momentum	X	X	
Body posture (inclination, symmetry)	X	X	X
Long-term monitoring of gait	X	X	

There are different methods for capturing gait— gait video, clinical examination, kinematics, kinetics, markerless gait capture, Electromyography (EMG), foot pressure data and energy consumption [5][7][8]. Figure 1 to figure 8 shows the popular sensors and technique to capture gait pattern and gait parameters [5].

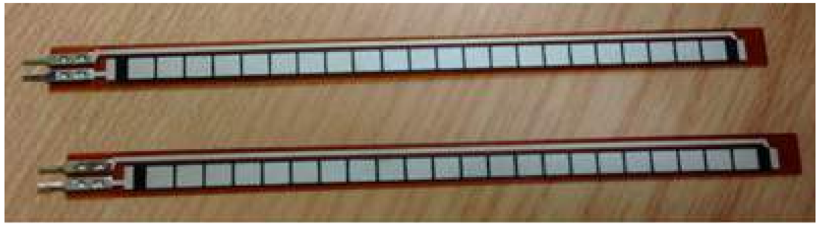


Figure 1: Flexible goniometer [5]

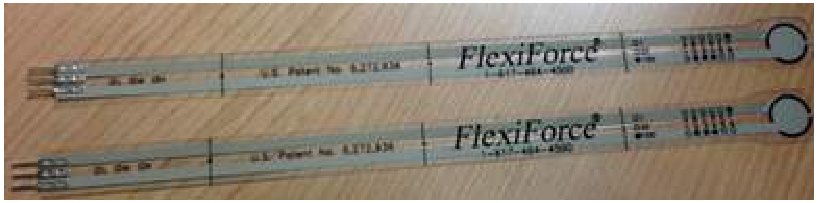


Figure 2: FlexiForce peizoresistive pressure sensor [5]

Figure 3: Instrumented shoe from Smartxa Project: (a) inertial measurement unit; (b) flexible goniometer; and (c) pressure sensors which are situated inside the insole [5].

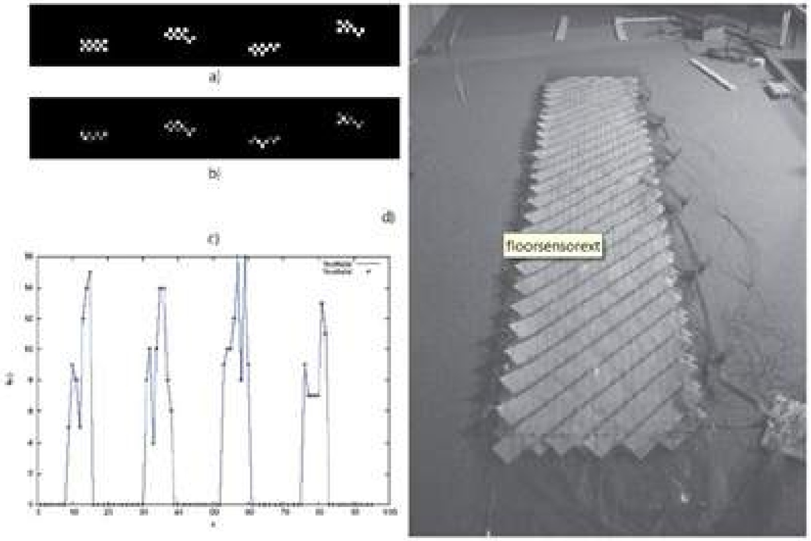


Figure 4: Gait analysis using floor sensors. (a) Steps recognized; (b) time elapsed position; (c) profiles for heel and toe impact; and (d) image of the prototype mat on the floor. [5]

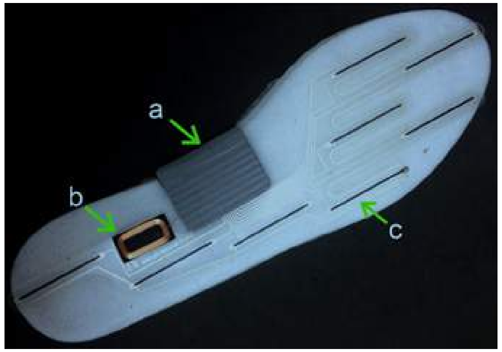


Figure 5: Instrumented insole: (a) inertial sensor, Bluetooth, microcontroller and battery module; (b) coil for inductive recharging; and (c) pressure sensors [5].

Figure 6: Example of NWS system: BTS GaitLab configuration. (1) Infrared video cameras; (2) inertial sensor; (3) GRF measurement walkway; (4) wireless EMG; (5) workstation; (6) video recording system; (7) TV screen; (8) control station [5].

The miniature sensing technology has advanced in such a way that they are used as body-mounted inertial sensors [9]. This was widely considered as a reliable and mobile alternative for gait monitoring [9]. Among these sensors, gyroscope sensors gained greater popularity in gait event detection [9]. They had a mean error below 7% and the inter-joint angle error of less than 1.1 or 1 degree [10]. Analyzing gait data using professional camera dedicated for gait detection is expensive and limited to laboratory setup [11]. IMUs having the combination of gyro and accelerometer had become an alternative to optical systems and they were low-cost, safe, low powered, and give continuous,

Figure 7: WS system based on (a) inertial sensors; and (b) wearable force plates [5].

Figure 8: Brainquiry Wireless EMG/EEG/ECG system [5].

online and offline unobstructed assessment of gait analysis, replacing piezoelectric crystal based accelerometers, which are considered to be large and clumsy [2][11][12][13] and without needing a special treadmill or foot pressure sensing floor or mat [5][14]. The usual positions of the sensor on human body were—shank, thigh, pelvis, foot and trunk of one or both legs [10] and among these shank was the preferred position to fix the sensor. Studies have recommended that any sensor that was to be attached to the body "should be small, light-weight, energy efficient and no wires should be needed in order to be worn comfortably and be cosmetically accepted [6][10] ."

Fitbands and smart watches includes IMUs. Jensen and Mueller point out that "these technologies focus primarily on performance metrics, such as time, distance and pace, and to some extent neglects the runner's technique. Furthermore, these technologies often falls short of utilizing data for assisting the runner to improve running style. Nevertheless, a proper running technique (or running style) is important for runners, as it affects their risk of getting injured, their performance results and their running economy, i.e. the energy spend on each stride. For example, the runner's bipedal gait cycle, also known as strides, inevitably impacts the overall running performance, and the runners' respiratory system, which provides the body with oxygen for metabolism, is a paramount part of doing exercise [15]."

In this project, we developed a low-cost wearable device for foot to improve the performance and technique of a running athlete through capturing the athlete's kinematic features.

Problem Statement

Fitness bands and smart watches measure incorrect step count as they are worn on the wrist. These devices as well as smart shoe and smart insole devices have Inertial Measurement Unit (IMU) sensor, which is capable of measuring gait parameters [16–18][19][20]. Gait parameters can inform the sports activity performance and fatigue level for early prevention of injury [18] [19][20][21]; but these fitness trakers are not using this potential. Hence, they are not improving the runner's running technique [15].

Therefore, there is a opportunity to develop a low-cost foot-mounted wearable device, which measures gait parameters, and displays performance and fatigue levels.

Goals

- A wearable product to improve performance of a running athlete by using the technique—Fartlek.
- Alerting fatigue level of a running athlete, to prevent injury.
- Display physical activity, fitness, and fatigue level in human readable form.

Objectives

- Develop a foot-mounted wearable device to capture gait parameters.
- Analyze the gait parameters from the prototype for performance and fatigue levels.
- Visualize the gait parameters with numerical values, so athletes can understand the their performance and fatigue level.
- Display the time lapse of the athlete's performance and fatigue level to check his/her daily progress.

Scope

- Users—joggers, running athletes seeking to improve their skill in running or preparing for marathon.

Secondary Research

We decided to explore on existing fitness trackers to study their features—similarity and differences, study on the existing smartphone applications that perform smartphone to behave as fitness tracking device, and to list down their pros and cons, which will help in development of our initial prototype.

Fitness Bands — Features

Fitness bands ,shown in figure 9, uses Bluetooth Low Energy(BLE) connectivity with smartphones. The popular bands comes with OLED or AMOLED display to show physical activity in numerals. These products have primary features of date, clock, alarm, and they are waterproof. Their secondary features includes Live step counter, distance, speed, heart rate monitor, calories burnt, sleep tracking, phone notifications, two-way finder, self notifications, view and reject calls, read messages, and weather forecast. Expensive product have inbuilt GPS, and live stream music. Fitness trackers without GPS and display, are light weight, and therfore doesnot interfere with the physical activity.

Figure 9: Smart watches and fitness bands [22]

Fitness Bands — Flaws

- Fitness band is worn on one wrist and preferred to wear on non-dominant hand. Therefore results of physical activity are not accurate.
- Steps are measured by movement of hand. Actually steps are counted from foot movements.
- Sleep tracking works in the night (Mi band) and are measured by movement of hands.
- They do not measure performance, or alert fatigue level, which can prevent early injuries due to sports acitivity.
- They do not inform the angular range of the foot or foot strike events, which help athletes to improve their speed.
- Results are shown at the end of an activity [15].

Smart Shoes

Smart shoes—for example: Nike Adapt as shown in figure 10—uses Bluetooth Low Energy(BLE) to connect with smartphones. They have unique feature of auto-lacing, and therefore they are laceless shoes. Other features includes 6–axis accelerometer and gyro sensor, pressure sensors, RGB leds, and companion app.

The cons of this product are that they are very expensive, any external or internal damage can cause wear and tear of the auto-lacing, and therefore they are not popular among athletes.

Figure 10: Nike Adapt [23][24]

Fitness Tracking Application

Fitness tracking applications—for example: Nike Run Club as shown in figure 11— for smartphones renders them to behave as fitness trackers as all smartphones comes with IMU sensors, which can detect physical activity, and display results similar to a physical tracker. They have features of distance travelled, pace, duration, heart-rate, mile splits, GPS route, offline saving, audio guided runs with nike coaches and athletes, personalized coaching plans, compare and compete with leaderboards.

The cons of using smartphone as fitness tracker are the athlete has to wear the smartphone on his body, which interefere his physical activity as they are adding weight to the body. Most of these applications does not come with offline maps. Therefore internet will be required during the physcial activity.

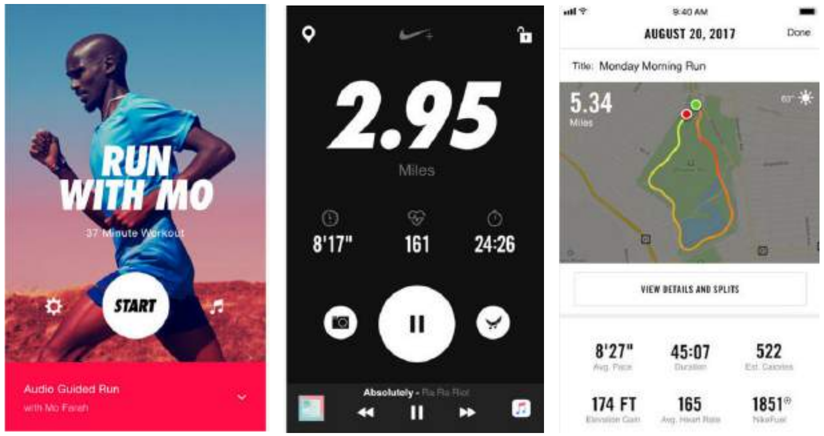


Figure 11: Nike Run Club [25][26]

Primary Research

For our primary research, we developed our initial prototype which includes IMU sensor, MPU 6050, which is an accelerometer and gyro sensor; to capture and visualize gait patterns while walking in barefoot and footwear. This was done to test whether this sensor is good enough to be used for our pre-final prototype; to know different possible error that could happen in capturing the gait patterns due to communication lag of the protoype, location of the prototype on the foot, disturbances caused during walking, and to check whether people can understand their gait patterns from graph plots, and the colors used in the plots.

Prototyping

Our prototype had the hardware and software part. The hardware part consists of two modules—foot sensor module and shank sensor module, for each foot of an individual. The foot sensor has eight piezoelectric sensors glued to a 0.5mm thickness styrene sheet. The styrene sheet was cutout from an actual shape of both —left and right—foot of an individual of size 10cm. The eight piezoelectric sensors are glued on each cutout such a way that the sensors covered the area touched by the foot on the ground. One layer of 3mm sponge, for left and right foot, was glued on top of the sensor and the styrene cutout and was cut in the same shape. Wires from the piezoelectric sensors were extended to come out of the foot cutout, which

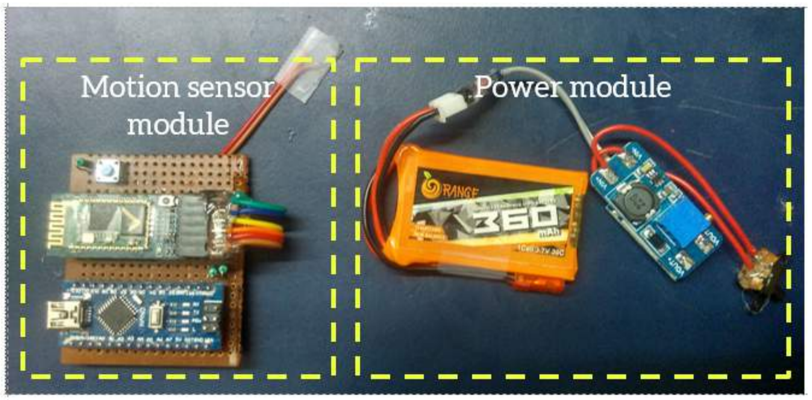


Figure 12: The motion sensor module and the power module.

would be connected to the extended wires from the shank sensor module.

The shank sensor module consists of the power and motion sensor module. The power module had 360mAh LiPo battery, charger and booster circuit board. The motion sensor module consists of MPU6050 accelerometer and gyro sensor, Arduino Nano, and HC05 Bluetooth module. The shank sensor module had extended wires to connect to foot sensor module, to read the values of piezoelectric sensors.

For software part, other than for coding the sensor to capture values and sending the data to the laptop/pc, we used Python script for saving the gait data—time; yaw, pitch and roll angles, acceleration on x, y and z axis of the IMU, and digital reading of the eight piezo crystal sensors of both legs —in a csv file. Python script wrote the readings in the csv files for every 40ms. The saved csv file was later opened in Tableau to plot the gait data. In Tableau, we plotted dual axis area chart of pitch vs time graph of both shanks and acceleration on x axis vs time of both shanks. The reason for choosing pitch angle and acceleration on x axis was that the values were better than rest of the axis.

To use the prototype, first the foot sensor module was attached to each legs by Velcro. The shank sensor module—in OFF state—was then attached to each shank by Velcro.
Now the extended wires from the foot and shank sensor module were connected together as shown in figure 16. Sensors on both legs were turned ON and the Python script was executed, which automatically connects both the sensors through Bluetooth and then creates a csv file. After the csv file was created, the script

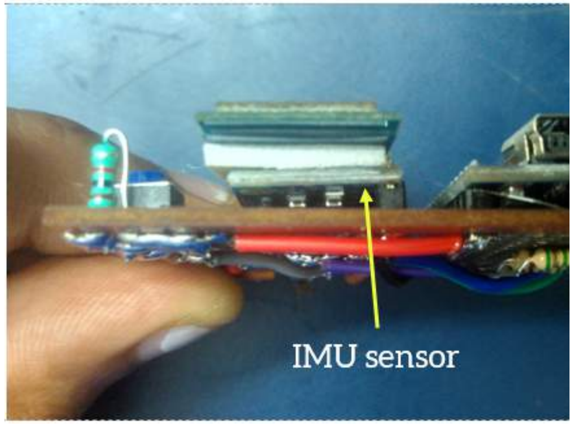


Figure 13: The IMU sensor, MPU6050, was kept under the Bluetooth module to reduce the size of the motion sensor module.

Figure 14: Image shows the finished prototype of the foot sensor module. Black was the Velcro and the white sheet was the sponge layer glued on top of the styrene sheet and piezoelectric sensors.

starts writing the gait data continuously in the csv file till the script was stopped. The csv file would be automatically saved after the script stopped. The saved csv file was later opened in Tableau to visualize the gait data.

Figure 16: Image shows connecting the wires.

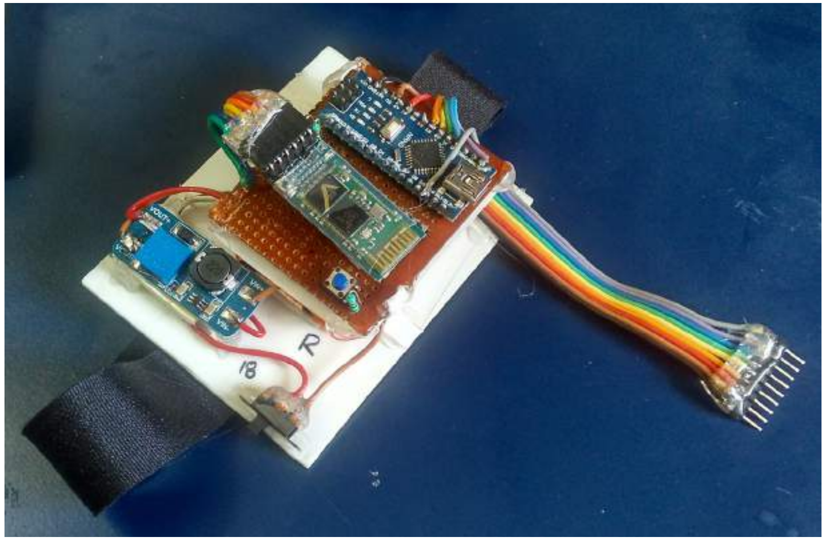


Figure 15: Finished prototype of the shank sensor

Figure 17: Overall size and look after attaching to both legs.

Gait Data Visualization

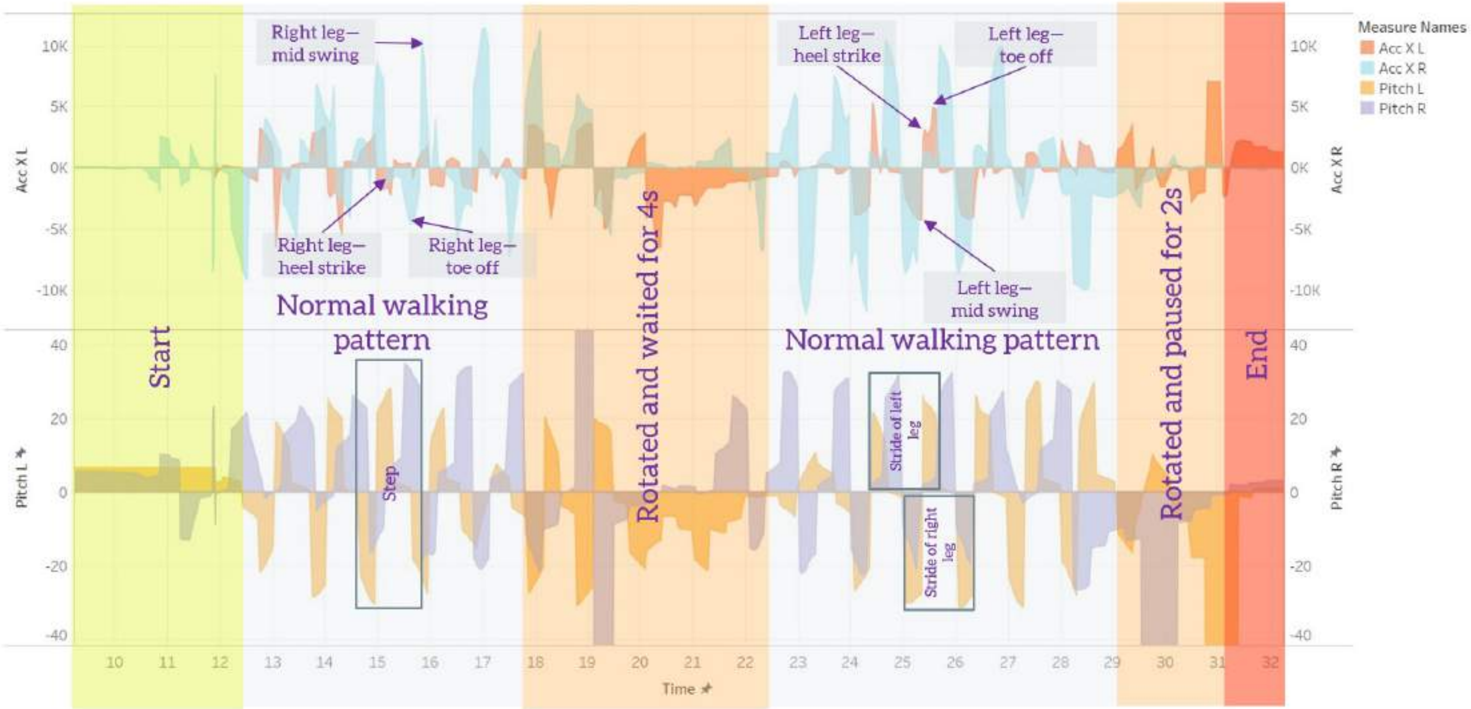


Figure 18: Data visualization of gait pattern from one of the users wearing a customised shoe.

The dual axis on acceleration of left and right shank vs time was plotted above the dual axis of angular position of left and right shank vs time as shown in the figure 18. We considered using dual axis to visualize the actions happening on both legs simultaneously so that plotting the acceleration and angular position against time will convey unique patterns. The reason for plotting acceleration above angular position of the shank was there are more chances the acceleration will be varied more than angular position of the legs when different footwear was used to walk.

In the plots, we chose warm colors for indicating left leg and cool colors for right leg. This color palette was inspired from the navigation lights for aircraft and vessel, where they use red indicator light on left side (port side) and green indicator light for right side (starboard side). Area chart was visually appealing than a line chart and it was easy to identify each leg through colors.

Feedback from Indian Doctors

Doctors were Impressed by the fact that prototype cost less than Rs.1500. They told us that the advantage of this system were, it was a small setup, and applicable for multiple situations—ortho, physiotherapy, sports, developing customised shoe, showing a patient about her altered gait pattern against a normal gait pattern. They said that for a normal person to understand, display the parameters through visuals of foot than displaying plots. The system is beneficial for bowlers, and athletes, who are looking for improving performance and technique.

Cost of a gold standard gait analysing equipment is around 20–30 lakhs, and it is expensive for patients to spend money on gait analysis. They don't encourage their patient to go to gait lab for gait testing as it is expensive and on speding extra money for the travelling cost. Their hospital did not have gait lab and the number of gait analysing labs are less in India. They told us to increase the accuracy and validate against a gold standard gait analysing equipment. After validation on accuracy, develop the prototype into a product, and sell in Indian market because, such low cost gait analysing devices are required currently. Therefore the product will be bought by athletes, doctors and hospitals. They warned us to not sell this product for identifying pathology gaits, because eyes of the doctors are trained to find the pathology gait and the causes of it.

Lastly they encouraged us to target the product for sports.

Conclusion

We developed a low cost IMU sensor based device to capture and visualize the changes occurring in walking gait pattern, when different type of footwear was worn. We evaluated our initial prototype by nine participants. Participants positively agreed that wearing their footwear changed their gait patterns from their barefoot gait pattern. They responded that the information shown from gait patterns from their footwear as well as from others was informative and will be considering to wear comfortable footwear so as to maintain their normal barefoot walking gait pattern. Future work includes implementing algorithms or machine learning to the device for auto detection of gait parameters, visualization of foot and its related comparison as suggested by the participants, so that people can understand without assist. We also evaluated our initial prototype with doctors and from their feedback, we decided to focus our initial prototype towards running sports, and integrating a running technique and fatigue alert for running athlete. In future, IMUs, especially the accelerometer based sensors, have a “promising ambulatory monitoring technique that could be used for the assessment of mobility in routine clinical practice.” [15]

Proposed Product Unique Features

The following are our proposed unique features, which are gait parameters, that comes with the final product. These features are not shown in existing fitness trackers and they will be combined with the running technique, Fartlek.

- Contact Time (duration of the contact between the foot and the ground)
- Step Rate, Stride Length, Footstrike Type (part of the foot that strikes the ground first: heel, midfoot or forefoot), Heel lift,
- Max Pronation Velocity (maximum angular rate at which the foot pronates between footstrike and the point of maximum pronation),
- Pronation Excursion (total angular range the foot rolls inwards) and
- Stance Excursion (total range of pitch angular movement between footstrike and toe off).

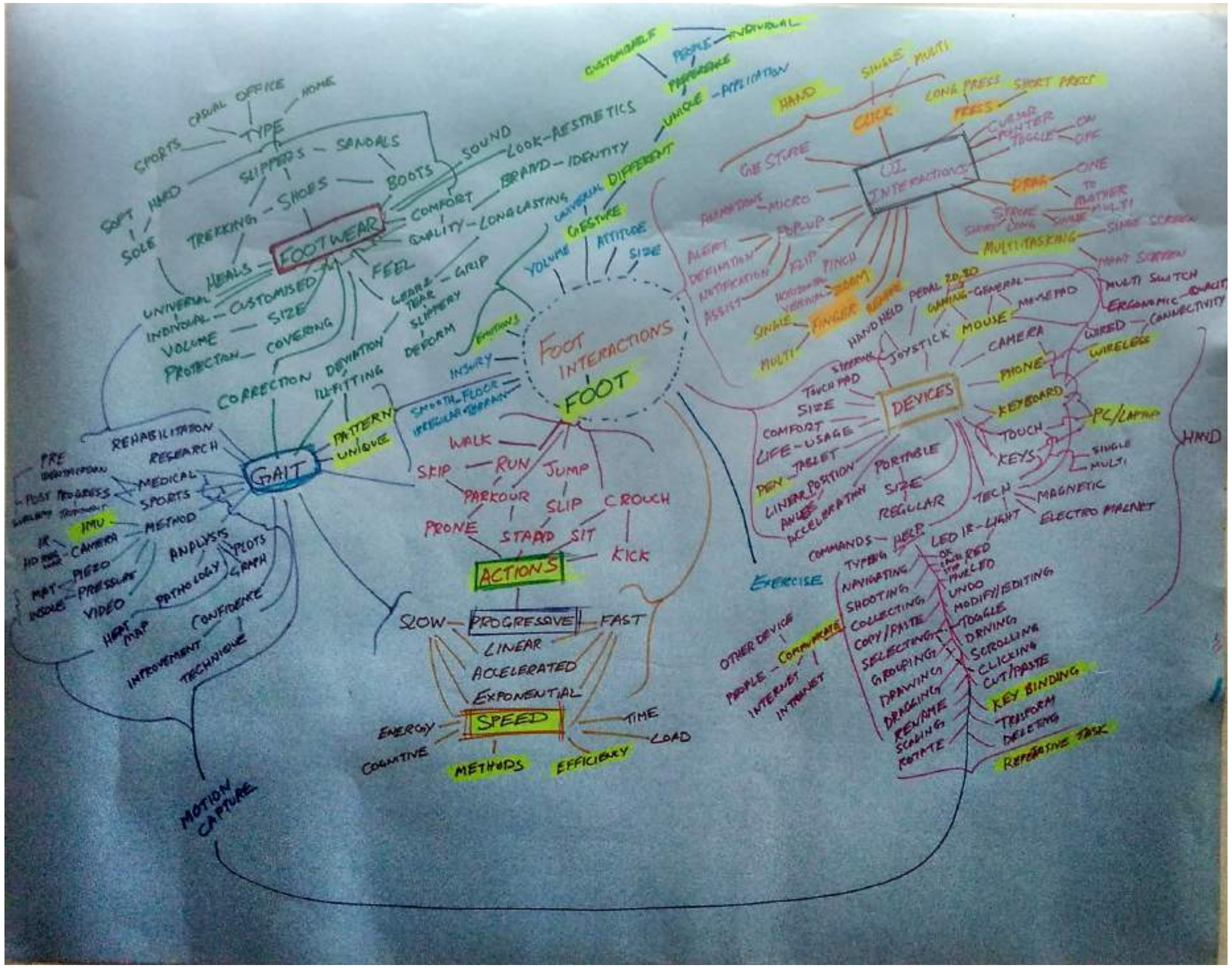
"The foot contact of an expert is shorter. Heel strikers have less stress on their calves and Achilles tendon but are slowed down. As the knee is not bent during the strike it experiences high impact stresses, which promotes injuries over time. Midfoot runners experience more stress on the calves and Achilles tendon but absorb shock better since the knee is bent. Most long distance runners are midfoot runners. Toe striking contributes to a better form and faster running but it keeps calf muscles contracted contributing to various injuries. However, toe strikers experience less stress on knees and ankles.[24]"

Ideations and Concepts

Mind map

Next we did mind map on foot interactions. It was done for generating ideas and concepts. Keywords that we focused were on:

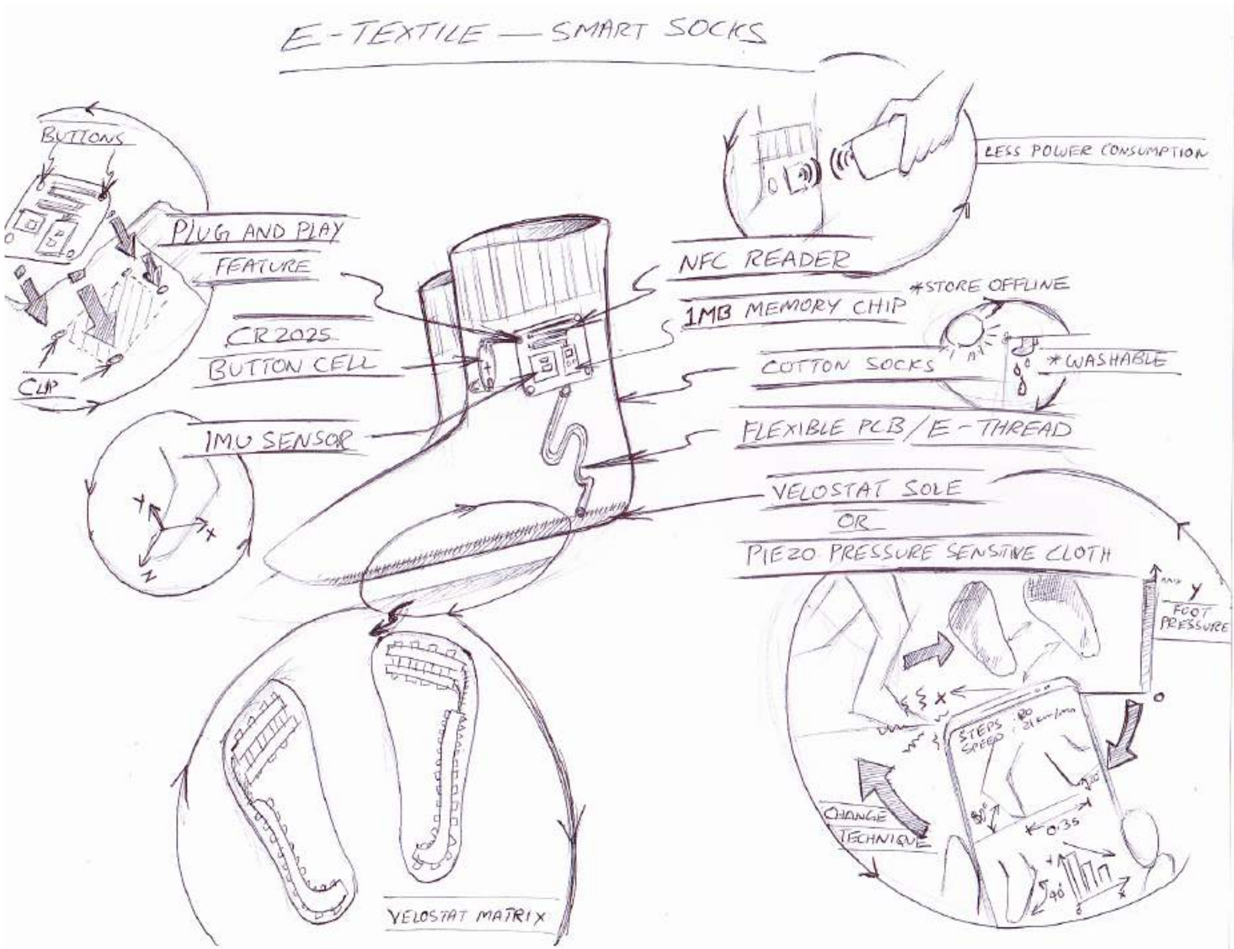
- Foot actions
- Foot gestures
- Speed of actions
- Gait analysis through IMU
- Running comfort



1. E-textile—Smart Socks

Features

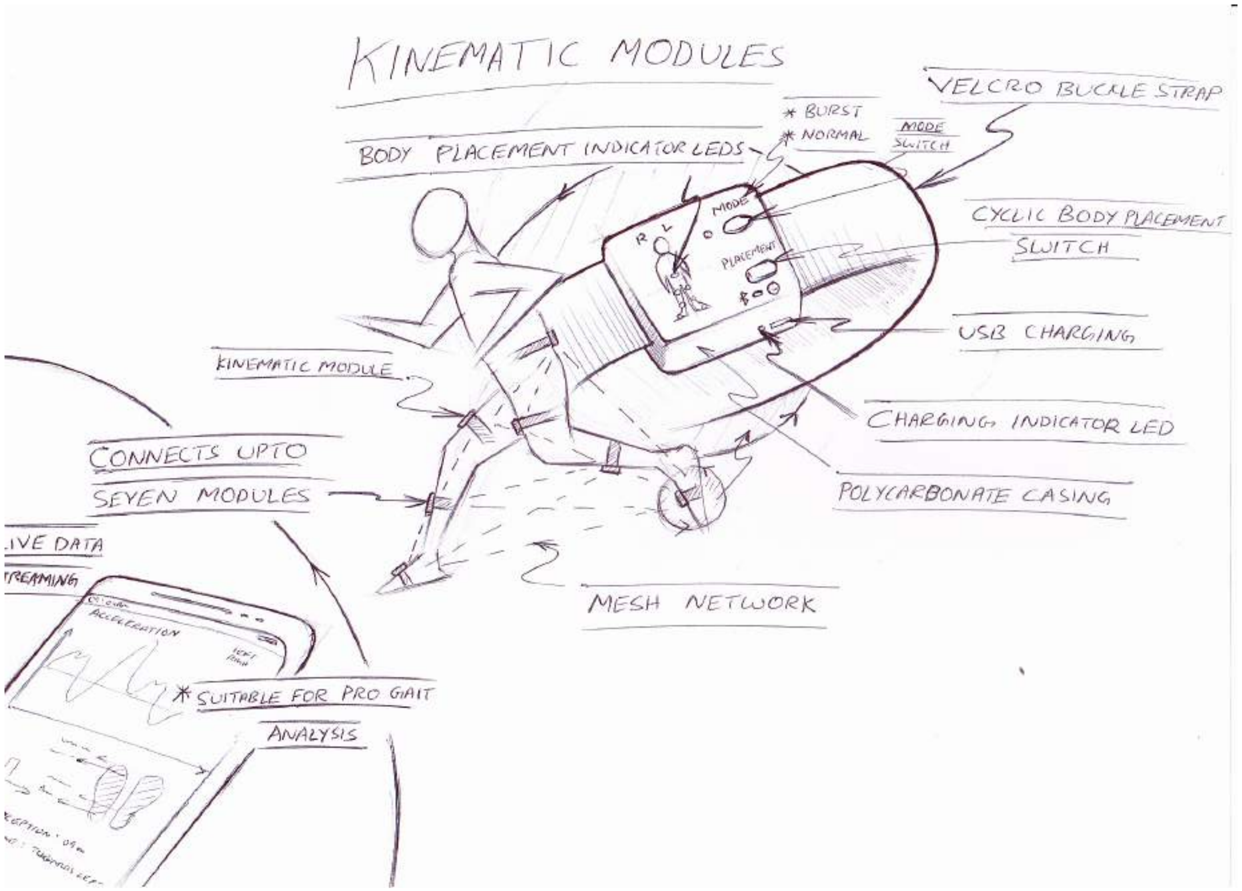
- It is washable.
- Plug and play sensor module.
- Pressure sensitive velostat sole for identifying foot pressure points.
- Flexible PCB.
- NFC communication.
- 4 MB internal storage.
- Powered by CR2025 button cell.



2. Kinematic modules

Features

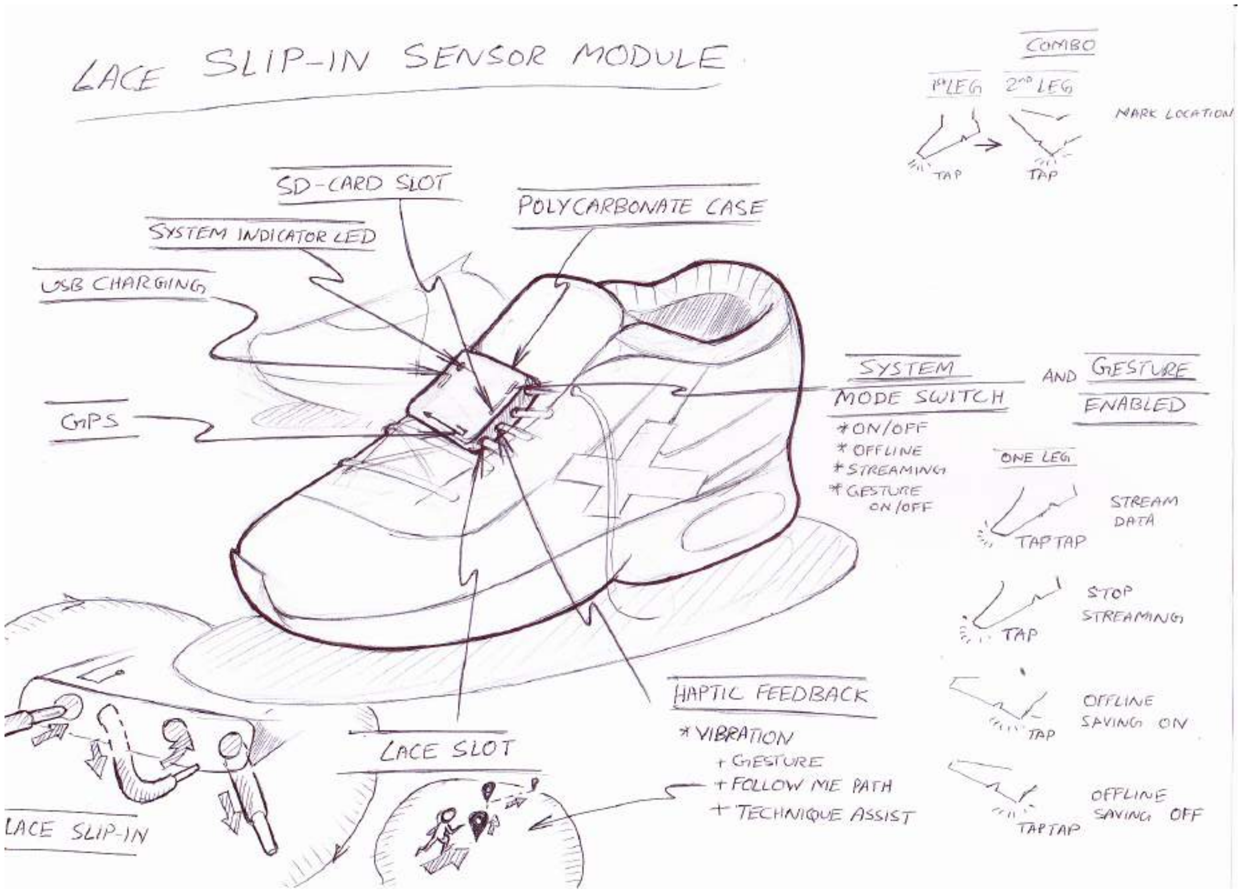
- Bluetooth Low Energy (BLE) connections upto 7 modules.
- Live data streaming.
- Cyclic body placement mode.
- Polycarbonate casing.
- USB charging.
- Velcro buckle strap



3. Lace Slip-In Sensor Module

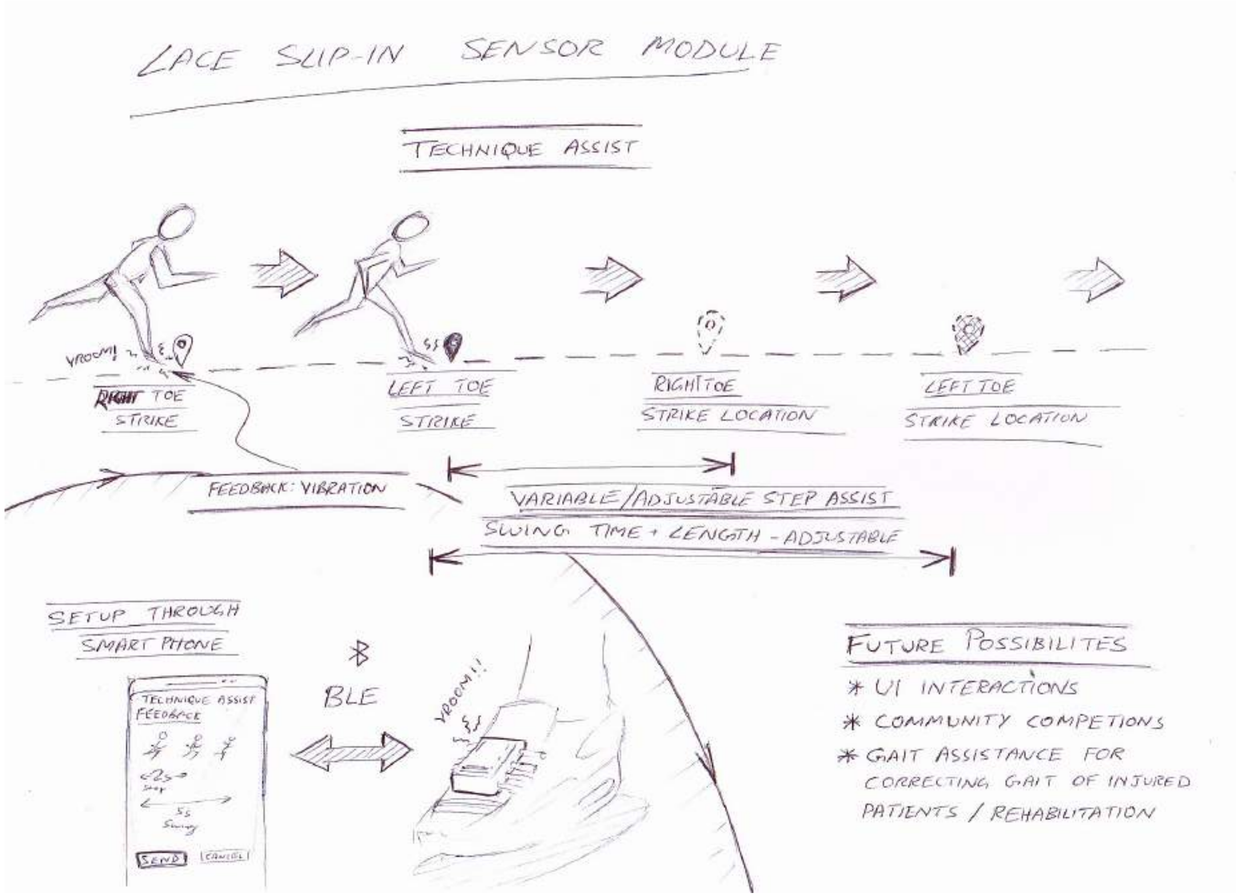
Features

- Bluetooth connectivity.
- GPS tracking.
- Polycarbonate casing.
- Gesture enabled.
- SD-card data storage.
- Haptic Feedback—vibration.
- Technique assist.



Future Possibilities

- UI interactions.
- Correcting altered gait.
- Community sharing competition.

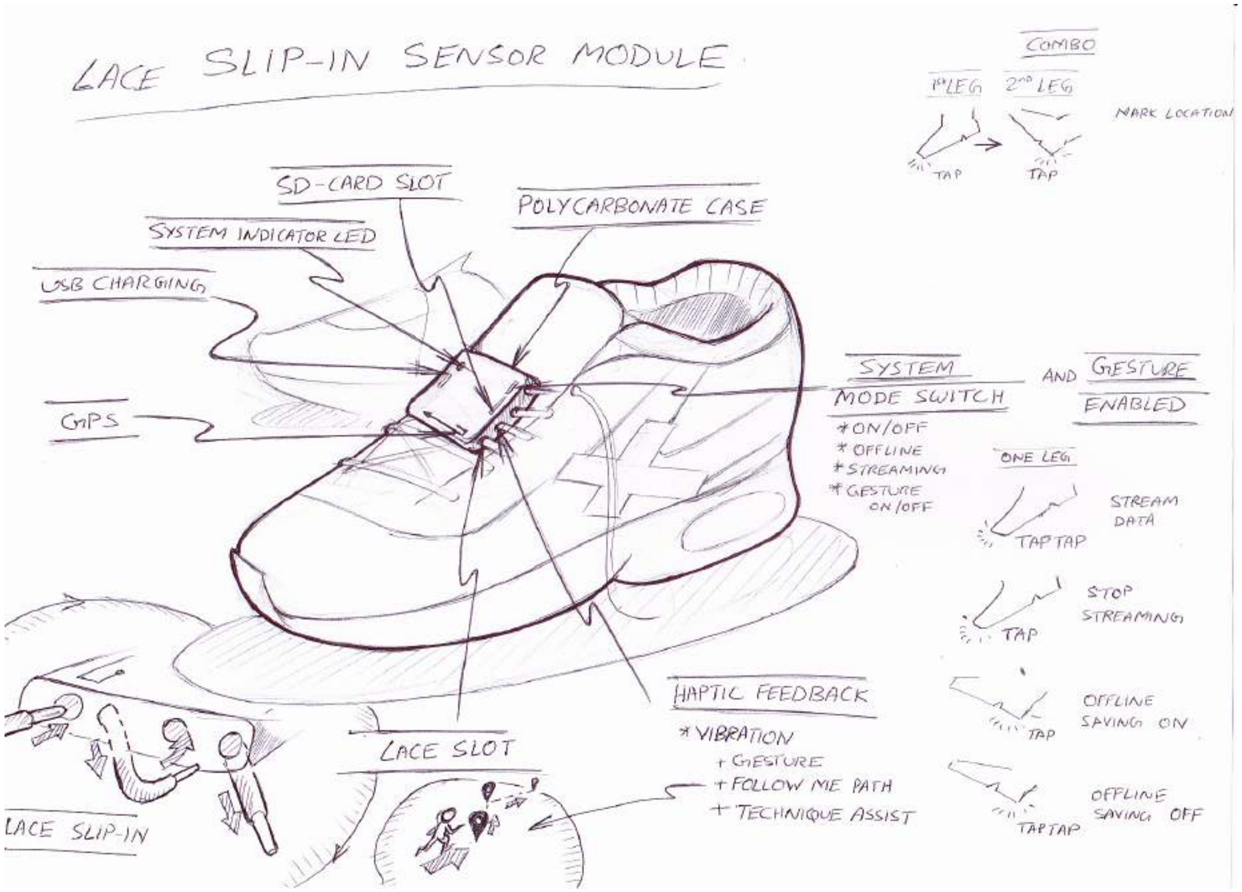


Final concept

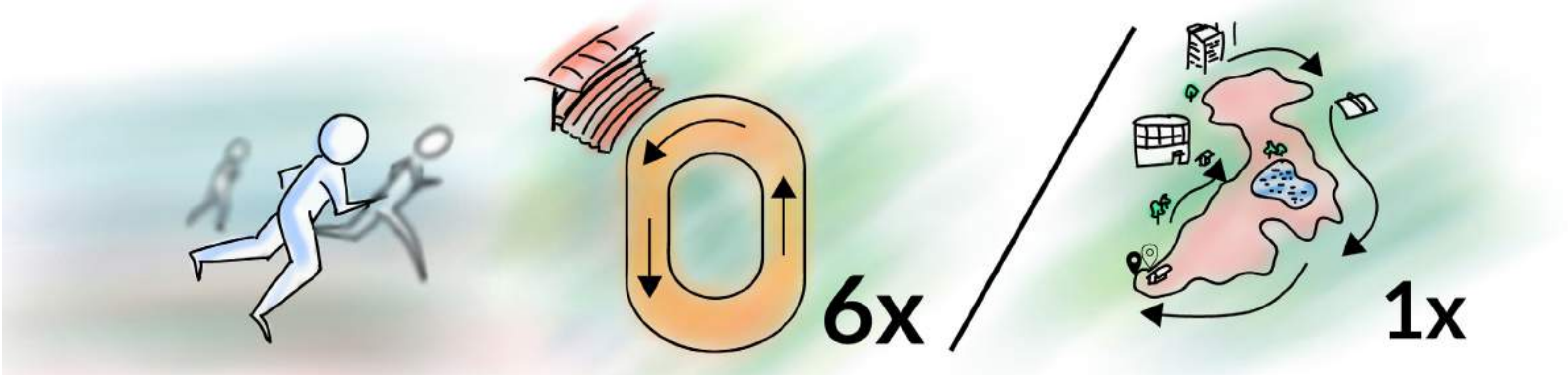
Lace Slip-In Sensor Module

Advantages

- Tied firm to the shoes.
- Requires 2 modules.
- GPS tracking.
- Offline and live data streaming capability.
- More useful for running athlete



Product Story

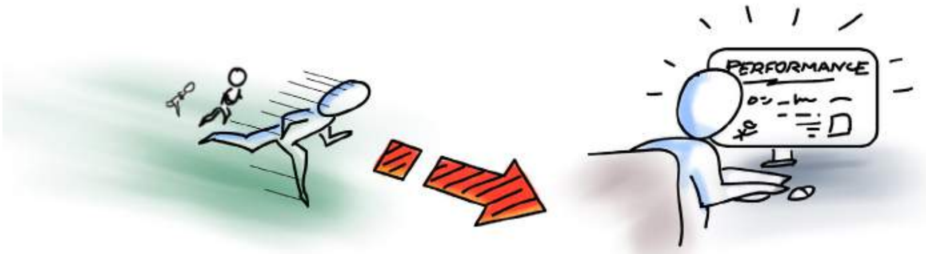


Uzi runs daily for **6 rounds** in a stadium/**1 round** in a circuit.

Uzi's smart watch shows his steps, distance travelled, pace, heart rate and time.
In the month of may, his steps was **90**, pace **2 steps/s**, and time taken **1 hour**.

Month passes to june.

His steps increased to **150**, pace to **4 steps/s**, and time decreased to **50 min.**

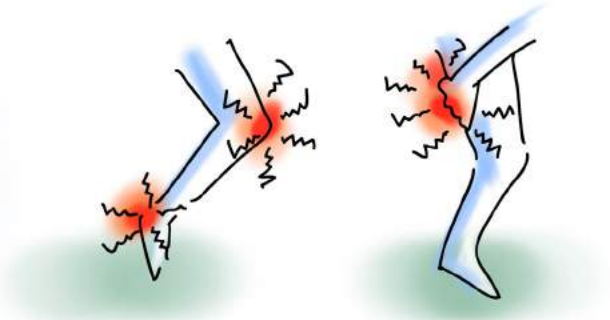


Uzi wants to increase his speed. He go through the methods written in the performance sites.

His mind is filled with increasing his performance and run faster.

Month flies to july.

His steps increased to **160**, pace to **4.5 steps/s**, and time decreased to **49 min**.

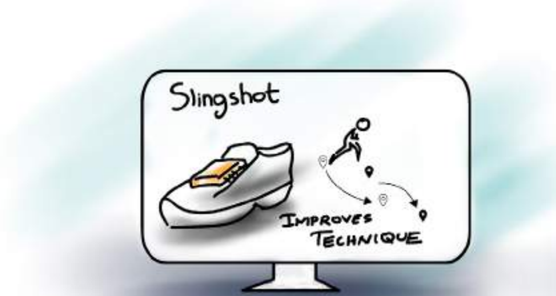


He started aching his leg muscles and joints.

Uzi goes through injury prevention techniques.

He came across a product ***Slingshot***.

Slingshot can increase the performance, prevent injury by alerting fatigue levels.

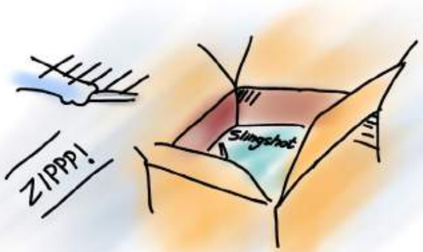


Slingshot can also improve the technique.

Uzi is wowed.

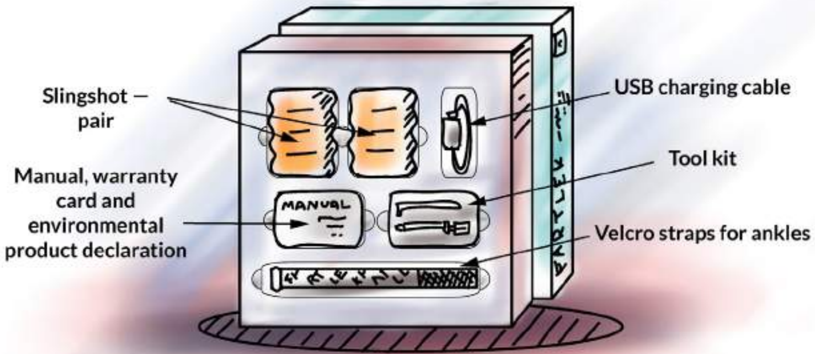
He orders ***Slingshot***.

Slingshot gets delivered to him.



He cuts the package with a cutting knife.

He opens ***Slingshot***.



Slingshot device is palm sized.

Uzi reads the manual and attaches ***Slingshot*** to his shoes.

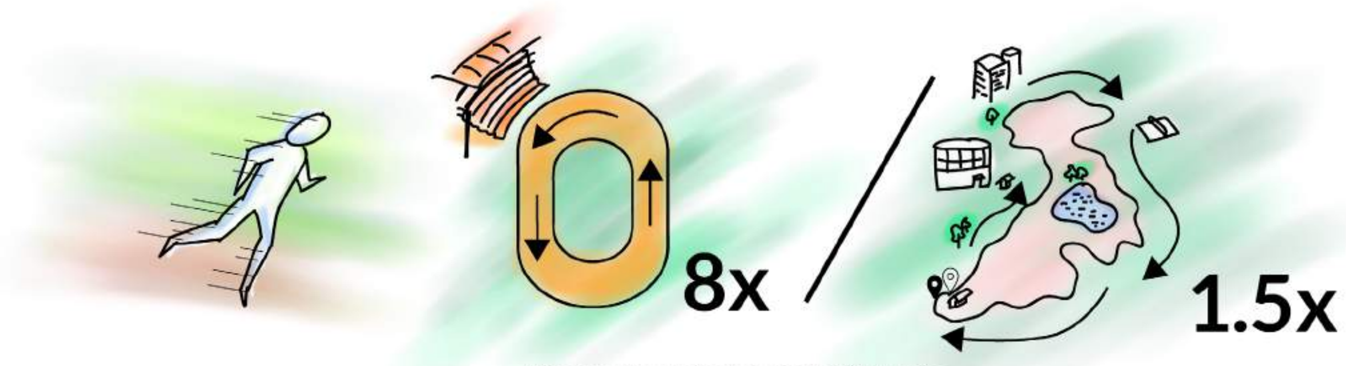
Distinguishing Features

- Contact Time
  **For an expert, contact time is less*
- Step Rate
- Stride Length`
- Foot Strike
  -Heal
  -Mid foot
  -Forefoot
  } *Determines Fatigue Levels*
- Heel Lift
- Max Pronation Velocity
- Pronation Excursion
- Using Gait Parameters
- Accurate Step Counting

Similarity in Technology

- IMU sensors
- Bluetooth connectivity

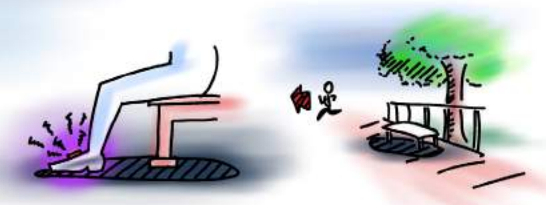
- Live Step Counter
- Distance
- Speed
- Heart Rate
- Notifications
- View/Reject/Accept Calls
- Message
- Weather Forecast
- GPS Tracking
- Music Streaming



Uzi wears ***Slingshot*** and starts his daily running.

By the time he covers 8 rounds in the stadium or 1.5 rounds of the circuit, ***Slingshot*** alerts his fatigue level by vibrational feedback—1.

He drinks liquids and takes rest.



After a specific time, ***Slingshot*** alerts him to continue his routine by vibrational feedback—2.

Uzi completes the circuit to 2 rounds.

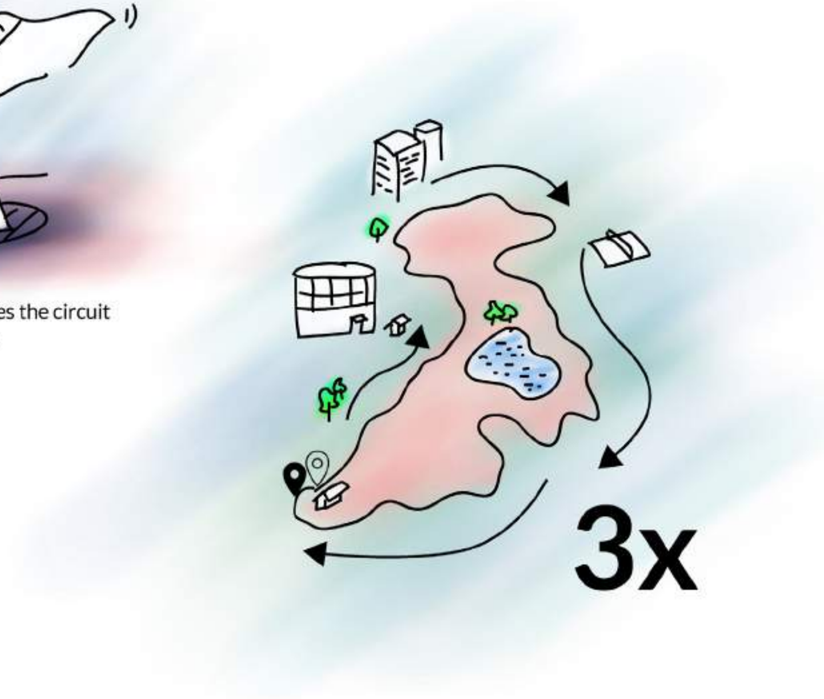
After reaching home, he links ***Slingshot*** to his smartphone through Bluetooth and retrieves the data from ***Slingshot*** .

The product's application showed the altered angle made by his foot by time and the time at which he came to his fatigue stage.

He enables technique assistance of ***Slingshot***, for his running, so that he can run by rhythmic steps.

Month passes to august.

By september, Uzi completes the circuit with **3 rounds.**



Slingshot and Fartlek

About Fartlek

In 1937, Gösta Holmér, Swedish coach, developed fartlek, and Fartlek means “speed play”. It is a continuous training with interval training. They are very simple form of a long distance run. Fartlek training “is simply defined as periods of fast running intermixed with periods of slower running.” A typical example of a runner doing a fartlek run is “sprint all out from one light pole to the next, jog to the corner, give a medium effort for a couple of blocks, jog between four light poles and sprint to a stop sign, and so on, for a set total time or distance.”[27]

Advantages of Fartlek [28][29]

- Highly adaptable
- Effective for endurance training
- Effective for speed training
- Improve race tactics
- Improves fast twitch muscle responses
- Improves slow twitch muscle responses
- Great for group training
- Easy for individual training
- Improve mental strength.
- Fartlek provides a lot of flexibility, so you can do a high intensity session to push your limits or a low intensity session if

you are tapering for a race or easing back into running post-injury.
• Fartlek is playful and it is playing with speed

Disadvantages of Fartlek [28]

• If improperly performed, an injury can occur
• Difficult to keep detailed metrics
• Can be more painful to perform
• Requires a little creativity

Need of the Product — *Slingshot*

As mentioned earlier in the proposed unique features of kinematic extraction, showing the parameters of contact time of the foot on the ground; the foot strike events—toe, mid, and heel; and alerting pre fatigue levels from the heel lift data through graphics and numerals will improve the overall Fartlek training. Through switching vibration levels on either foot—informing the athlete when to place the foot on the ground—each level for specific interval of time and maintaining the athlete's foot strike with vibrational rythm, will again increase the challenge of doing Fartlek run. The means of keeping rythm with vibrational levels will also add to the examples of Fartlek training. Therefore this also becomes an example for how wearable technology can also be designed to improve the technique and performance of a sport.

Figure 19: Slingshot logo. Logo inspired from the posture of a running athlete beginning to sprint.

Product Placement Exploration

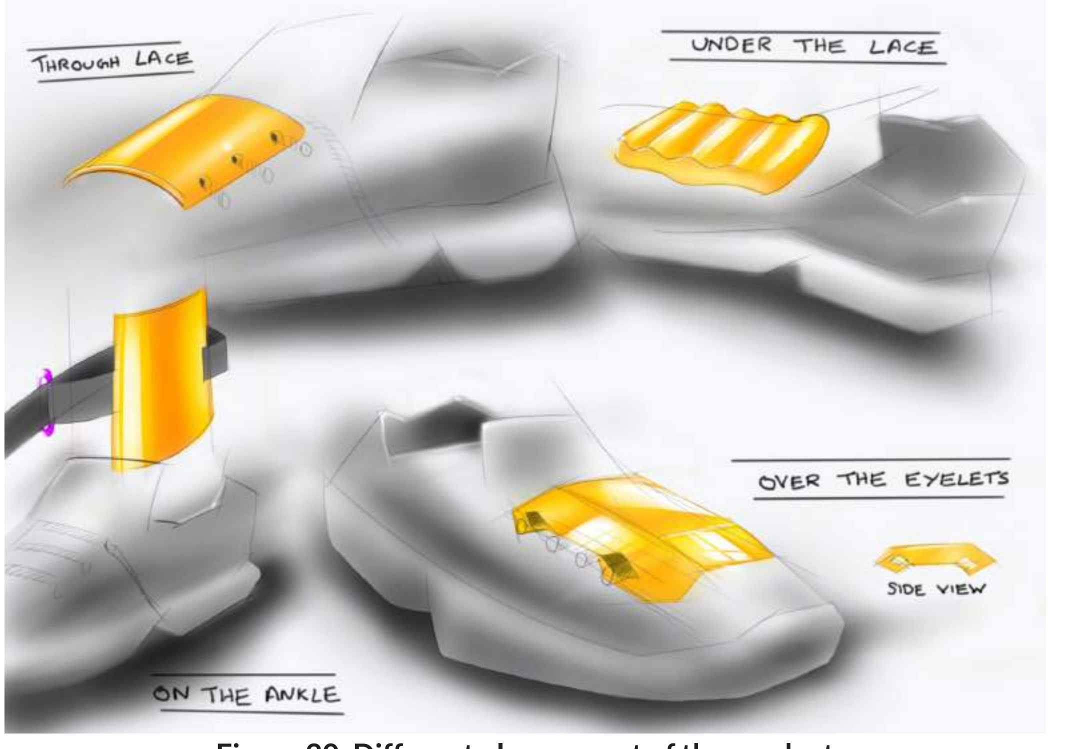


Figure 20: Different placmement of the product

We came up with four placment explorations of the product:
1. Through lace
2. Under the lace
3. On the ankle
4. Over the eyelets

Figure 20, shows the the visuals of the product and how the product can be placed on the shoe and on the ankle. Figures 21–24, shows non-photorealistic rendering of placement explorations of the product on the shoe and foot.

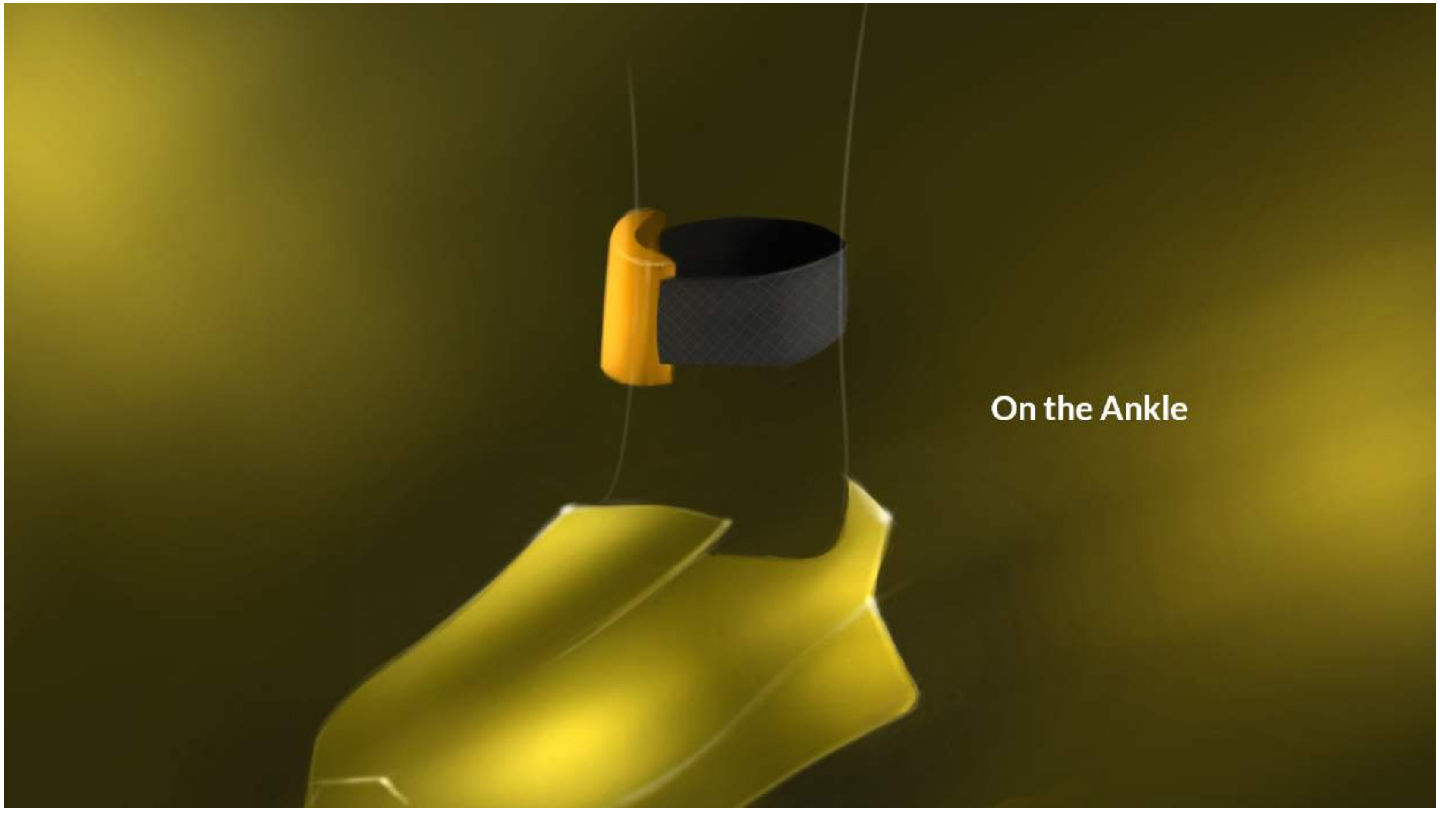


Figure 21: Non-photorealistic rendering of the product(orange colored) tied on the ankle of the foot, using velcro(textured grey colored).

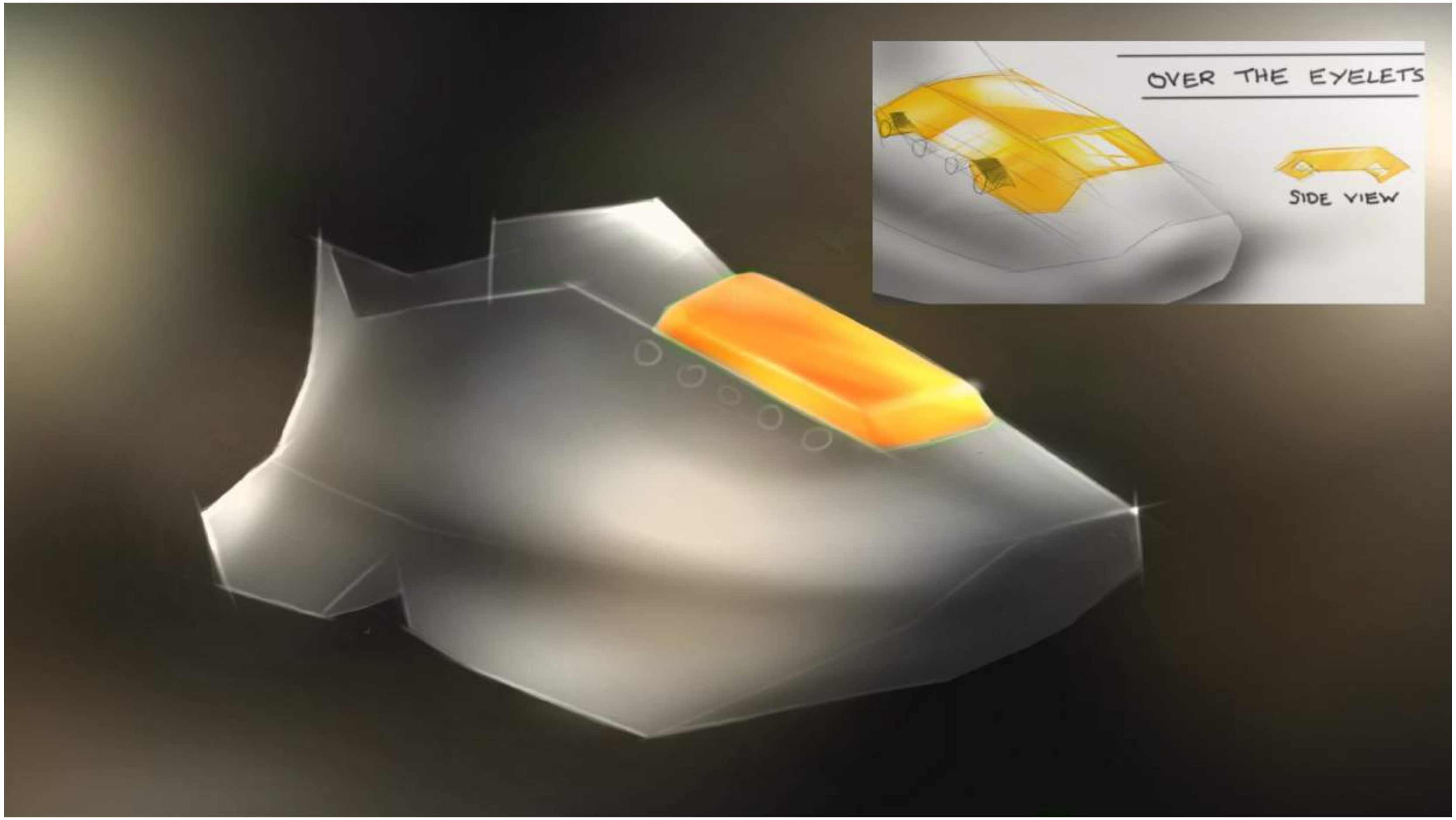


Figure 22: Non-photorealistic rendering of the product(orange colored) placed over the eyelets of the shoe. The image on the top-right shows the overall look the product and how it is fitted to the laces of the shoe.

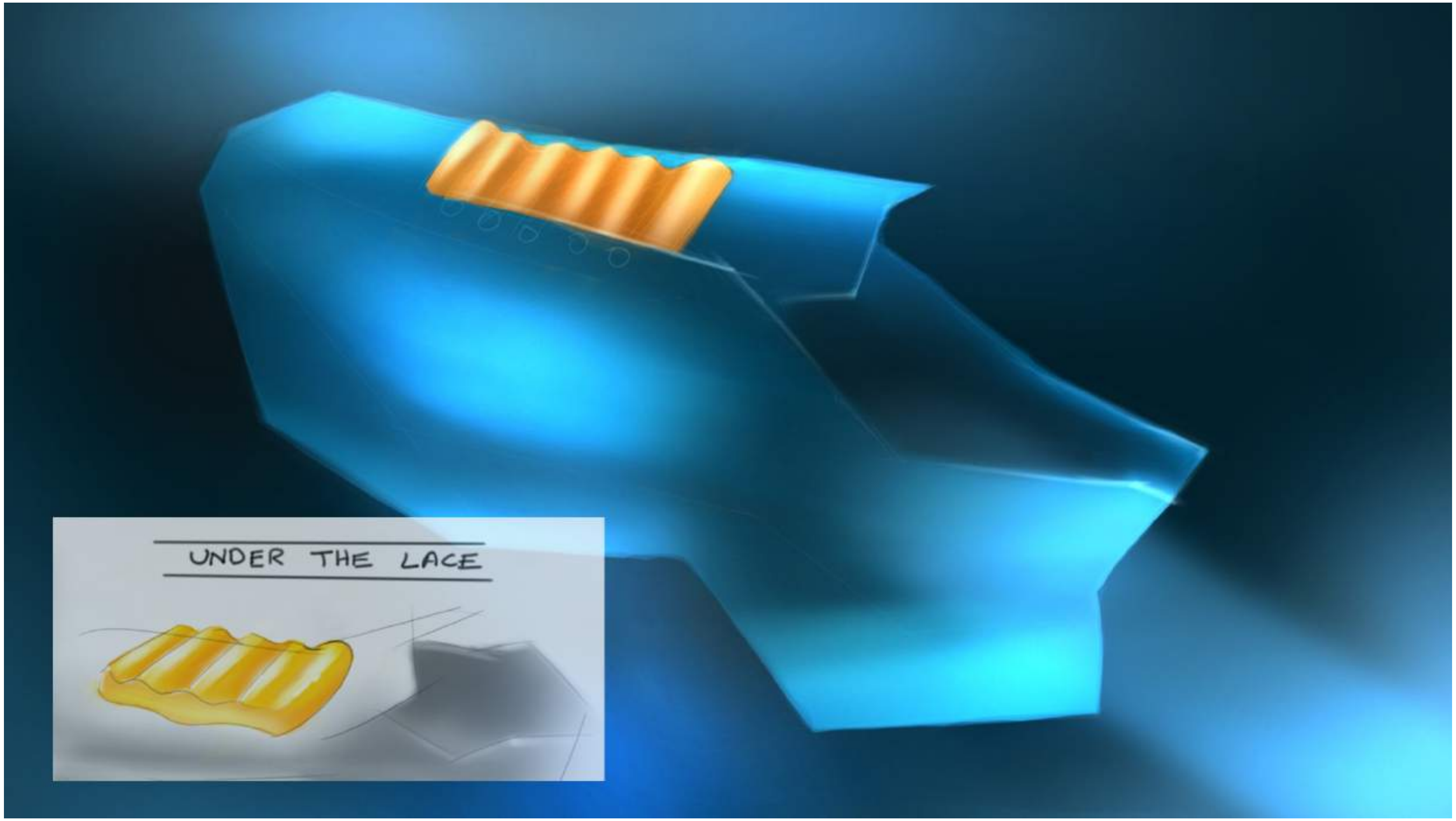


Figure 23: Non-photorealistic rendering of the product(orange colored) placed under the lace of the shoe. The image on the bottom-left shows the waved shape of the product that allows the product to be tightly fit under the laces of the shoe.

Figure 24: Non-photorealistic rendering of the product(orange colored) tied by the lace of the shoe.
The image on the top-left shows the visible holes near to the base of the product, that allows it to lace with the shoe.

Product — Shoe locking Explorations

We explored four different ways to lock the product on to the shoe:

1. Locking the product to the shoe by passing a single rod through the laces of the shoe, as shown in left part of figure 25

2. Locking the product to the shoe by passing double rods through the laces of the shoe, as shown in right part of figure 25

3. Through lace by lacing, as shown in left part of figure 28

4. Locking over the eyelets, by clipping on the edge of shoe laces, as shown in right part of figure 28

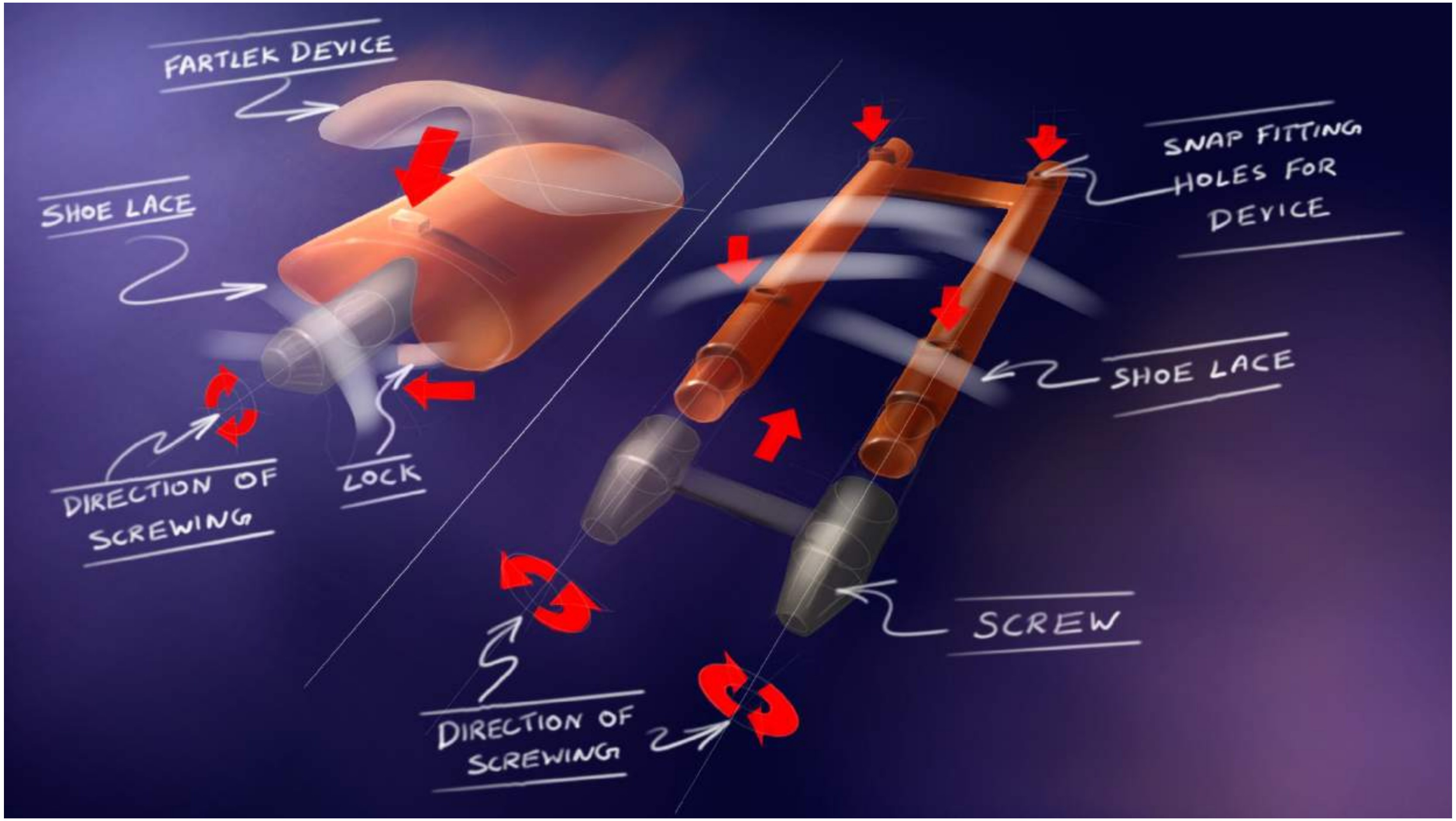


Figure 25: Non-photorealistic rendering of the product lock fitting mechanism on the shoe, through shoe laces. Left of the image shows how single lacing rod and double lacing rod(brown colored) fits through the lace of the shoe. Single rod styled locking mechanism has the product attached on it while the double styled locking mechanism allows a product module to fit on it by snap fitting holes of the rods.

Figure 26: Image shows how the single rod—shown here by a pen—style locking mechanim fits through the lace of the shoe. Stablity is the main problem faced by this style of locking of the product to the shoe.

Figure 27: Image shows how the double rod—shown here by two pens—style locking mechanim fits through the lace of the shoe. This type of locking to the shoe is more stable as compared to single rod styled product locking to the shoe.

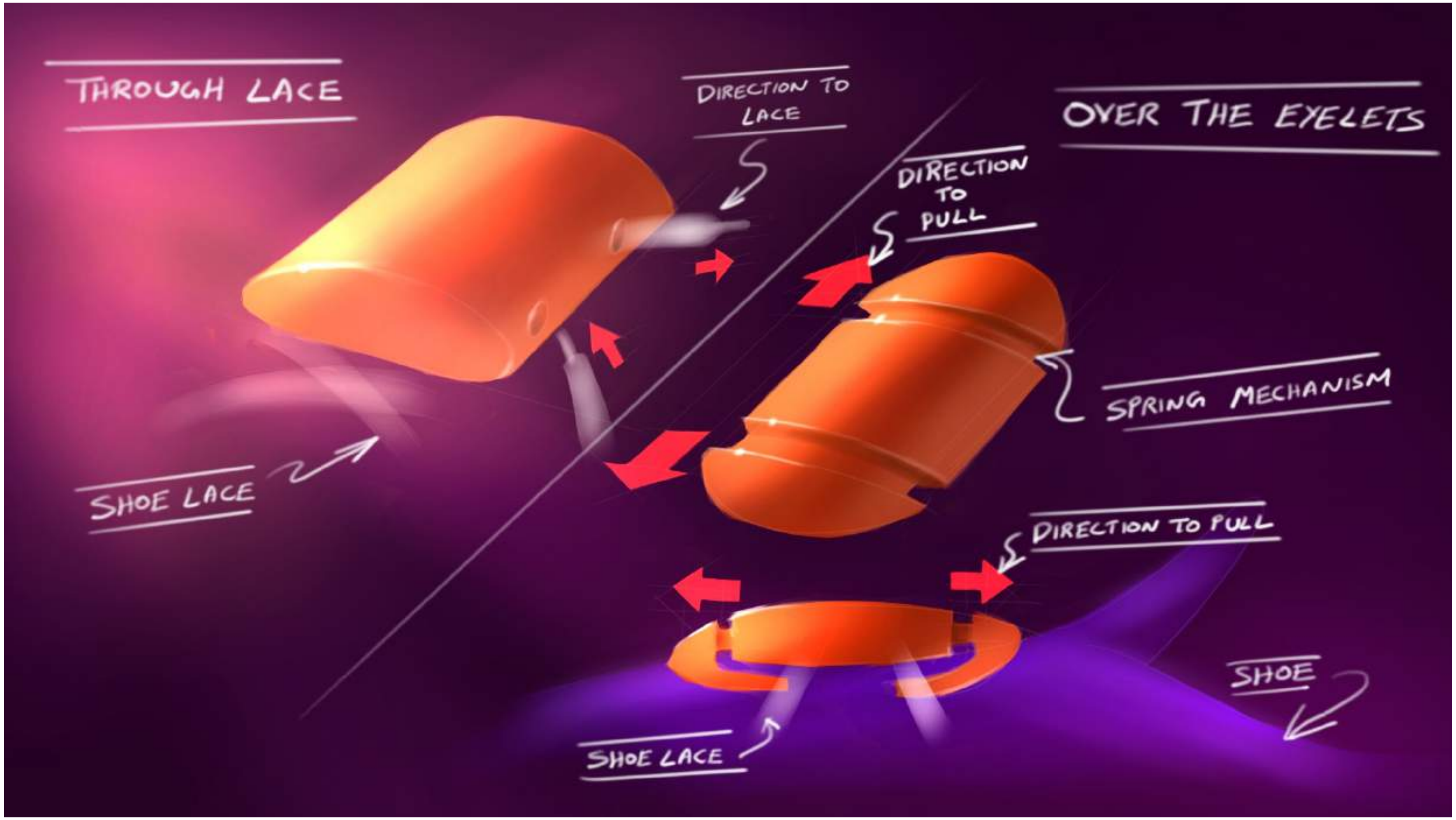


Figure 28: Image on the left part shows the how the product is locked to the shoe by lacing. Image on the right part shows locking the product over the eyelets of the shoe—the product has clips on either of the edges with internal spring locking mechanism,. So it works like, pull the clips to their extreme sides, place the product over the laces and release the clip to lock the product in place over the laces of the shoe.

Product Form Explorations

Figure 29: Form explorations for the product. A total of six different forms for the product were made.

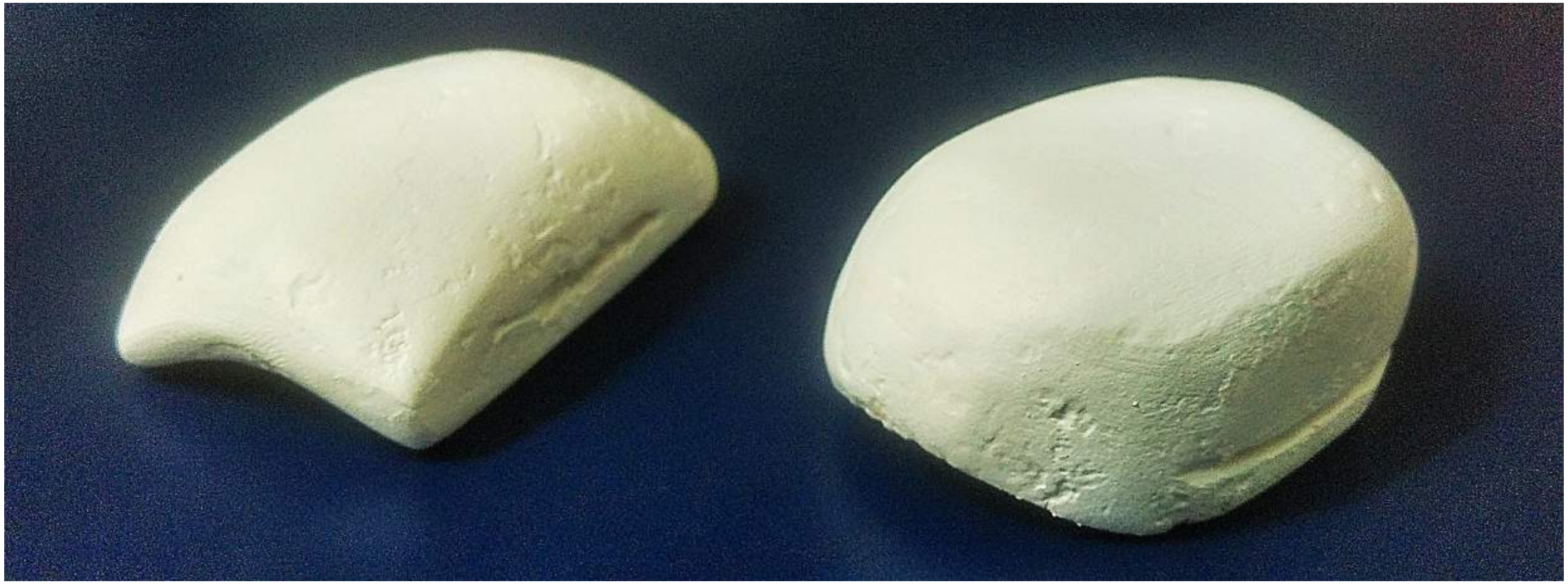


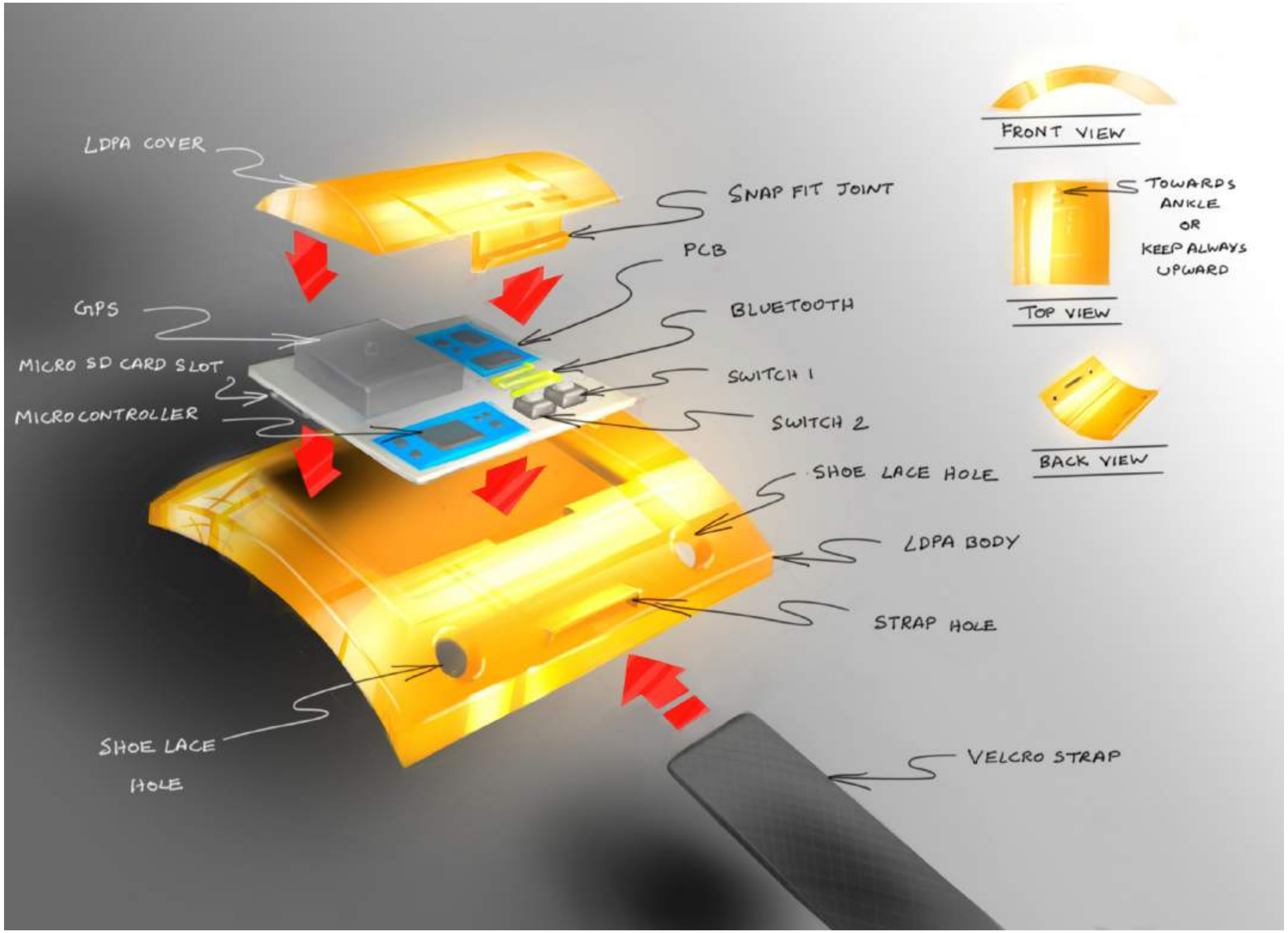
Figure 30: Two product form explorations for the ankle of the foot. The side groWove is slot for passing velcro.

Figure 31: Three product form explorations for lacing. The side holes allows shoe lace to pass in and out allowing product locking to the shoe by lacing.

Figure 32: Product form explorations for product locking under the lace of the shoe. The cross marks allows space for shoe lace to pass through.

Figure 33: Overall size of the product with respect to shoe.

Proposed Product



Wireframes—High Fidelity

Figure 34: Smartphone home page with Fartlek app is installed.

Figure 35: Fartlek loading screen.

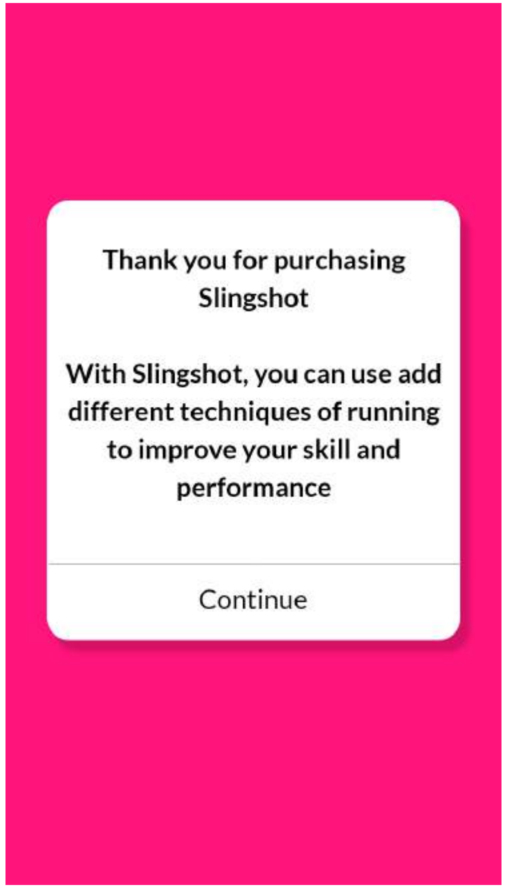


Figure 36: Welcome screen

Figure 37: Information screen 1

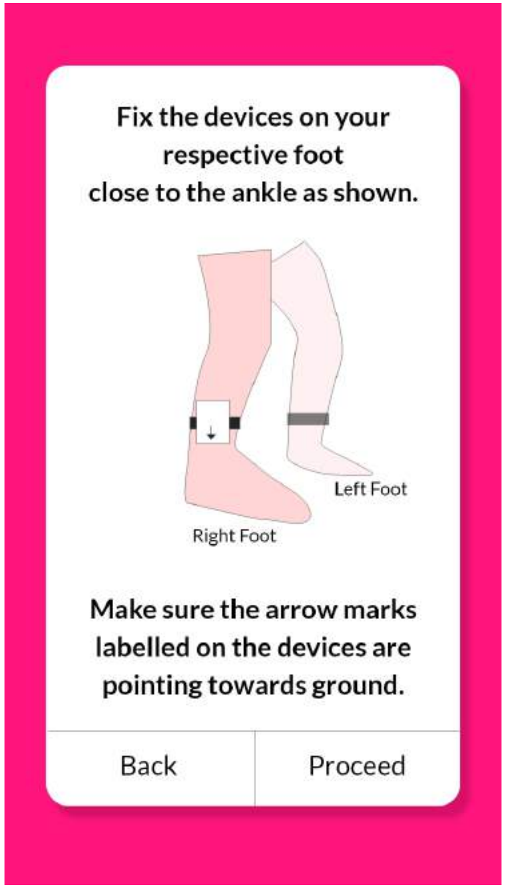


Figure 38: Information screen 2

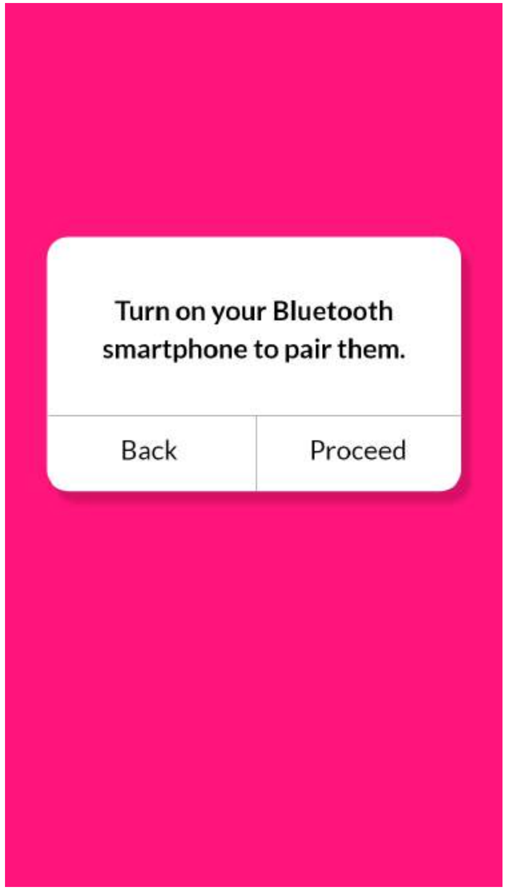


Figure 39: Information screen 3

Figure 40: Permission to turn on phone's bluetooth.

Figure 41: Searching for Fartlek devices.

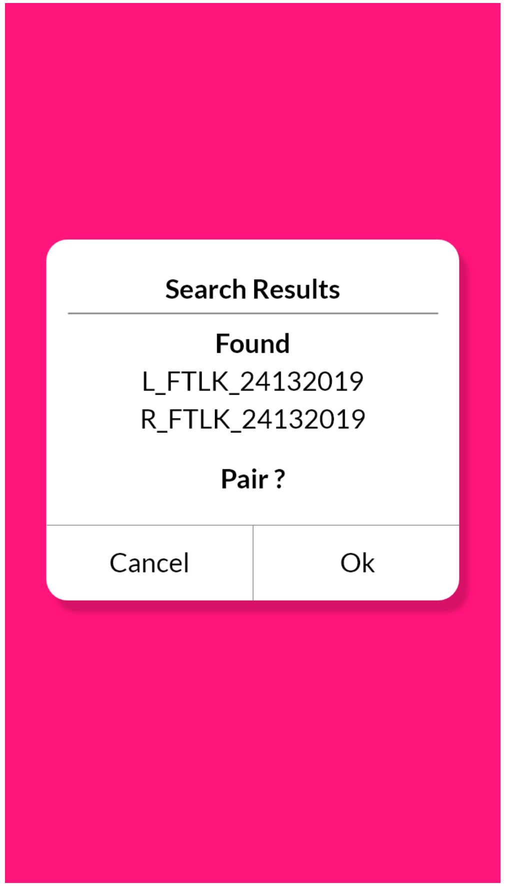


Figure 42: Search results screen.

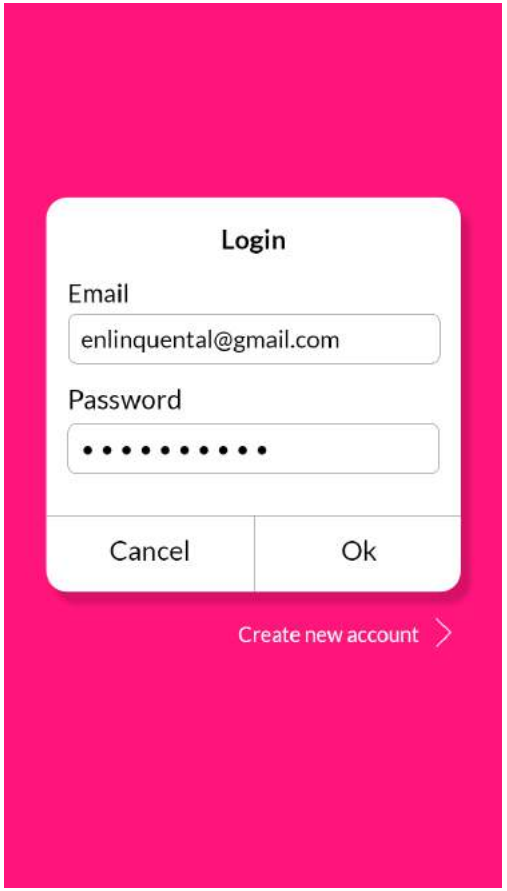


Figure 43: Login screen.

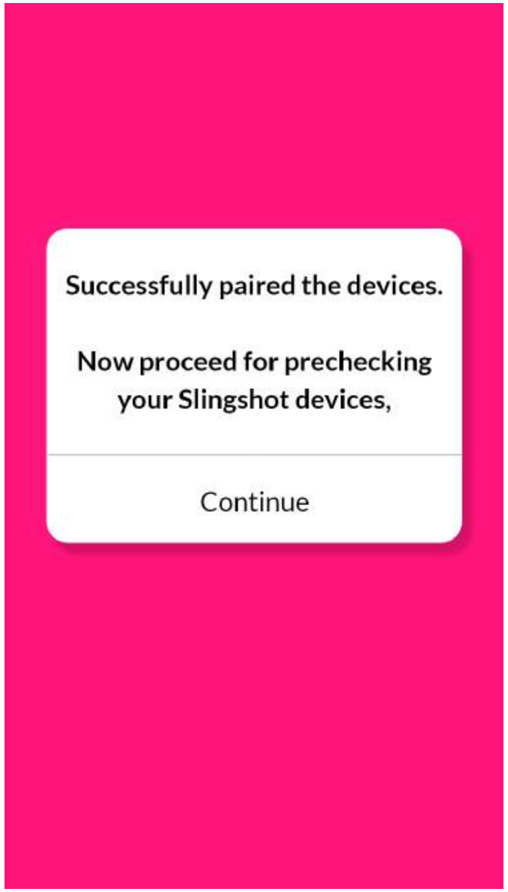


Figure 44: Information screen 4

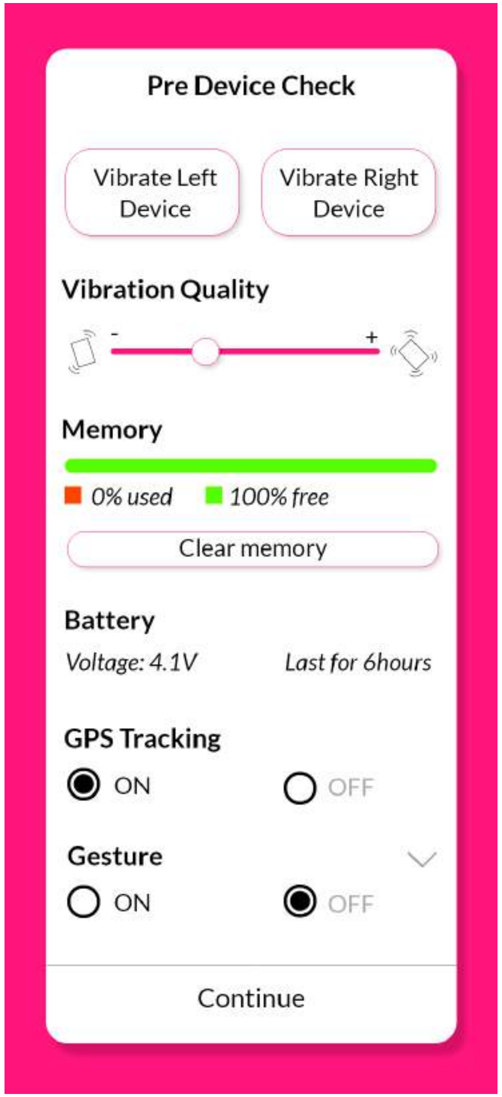


Figure 45: Checklist, status and settings of the device.

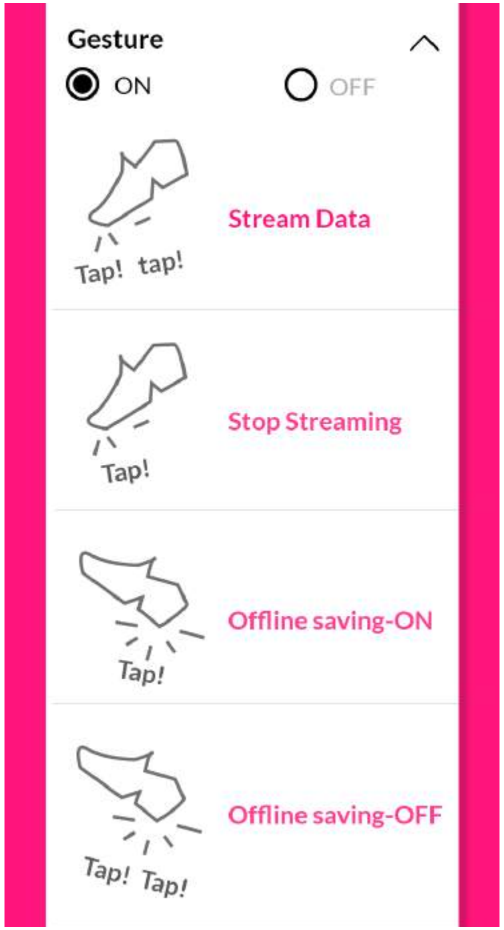


Figure 46: The drop down menu of gesture, if enabled

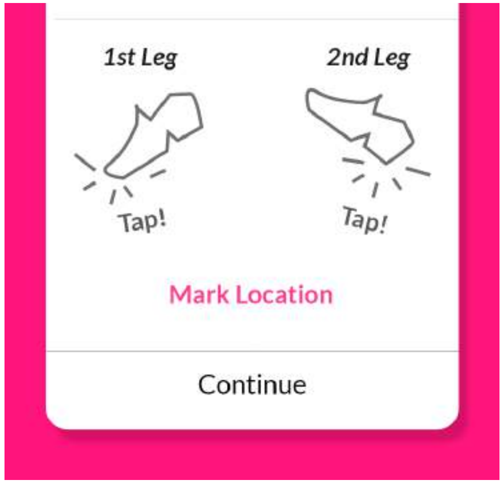


Figure 47: Continuation of figure 46

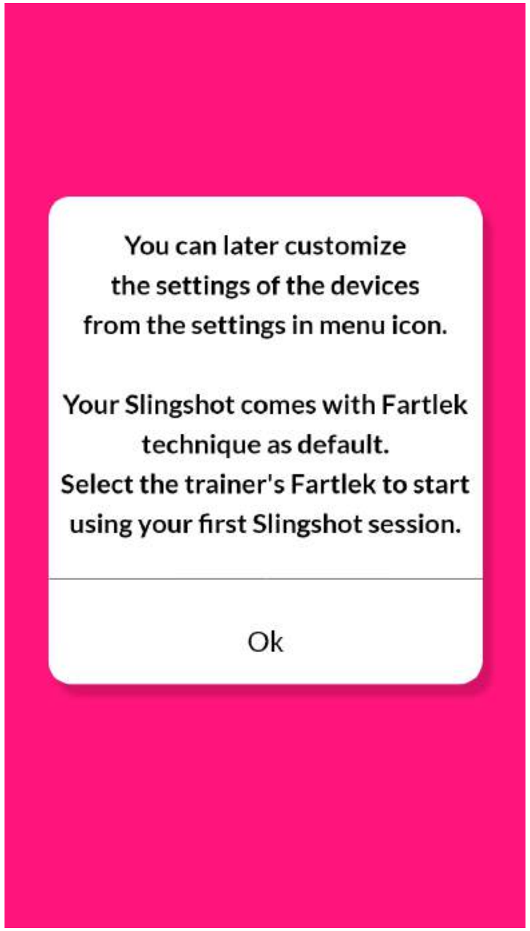


Figure 48: Information screen 5

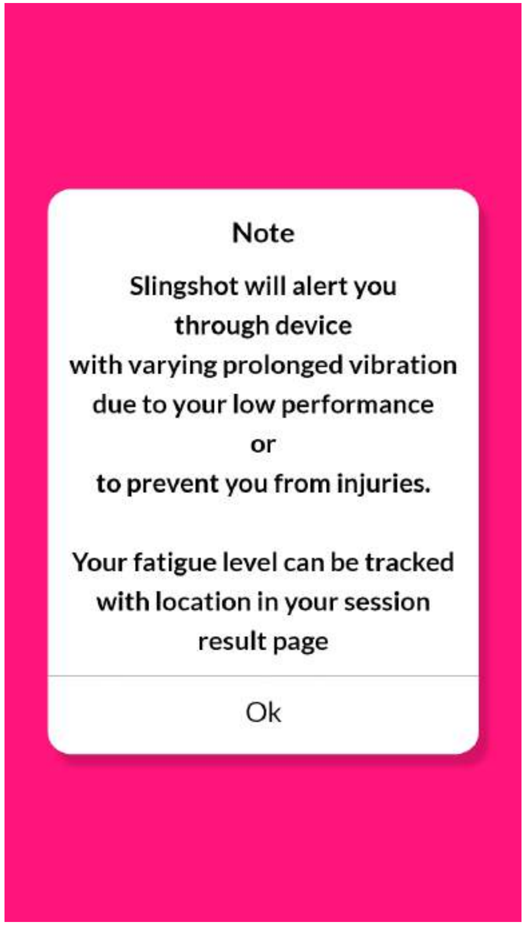


Figure 49: Information to the user about what the device does incase the athlete starts to experience fatigue.

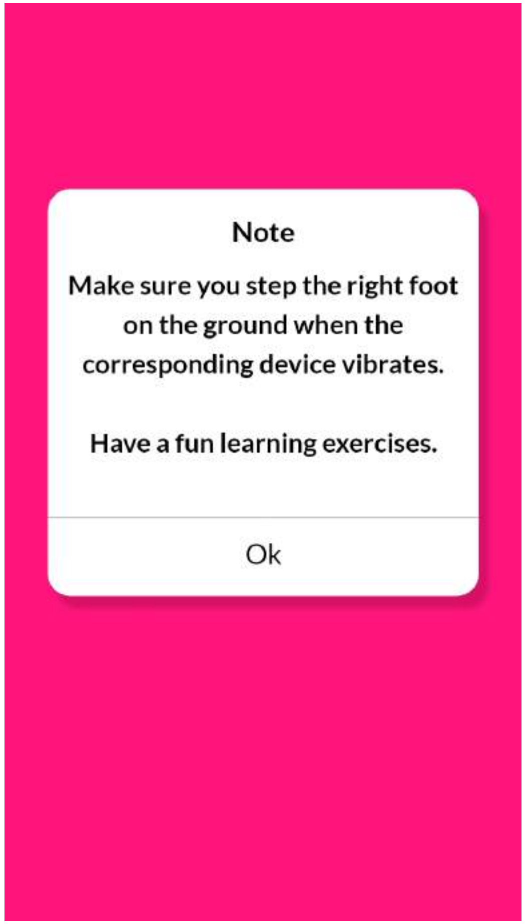


Figure 50: Information screen 7

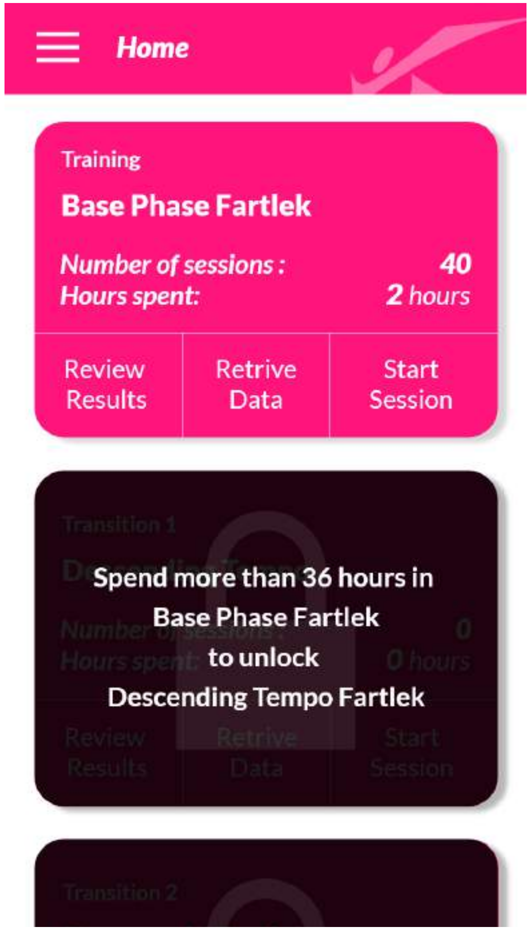


Figure 51: Home screen of the app.

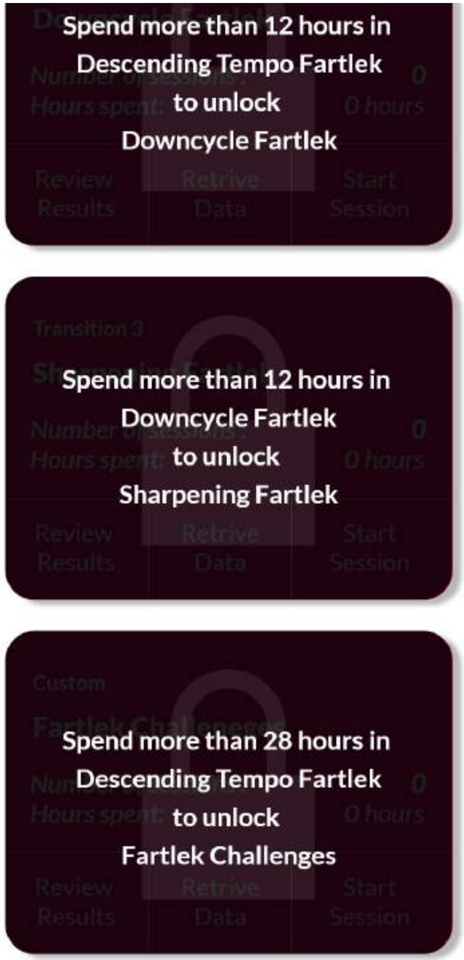


Figure 52: Continuation of figure 29.

Figure 53: Smartphone connects to the device to send information about the type of Fartlek training, chosen by the athelete, and prepare for the athlete.

Figure 54: Screen after the device got ready.

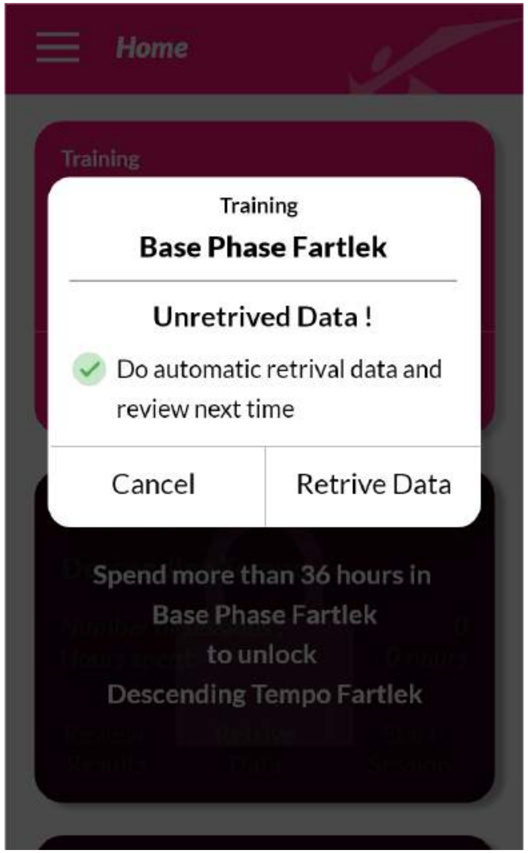


Figure 55: Screen of the Fartlek app, incase it didnot receive the new data collected by the device, after the athlete performed his training.

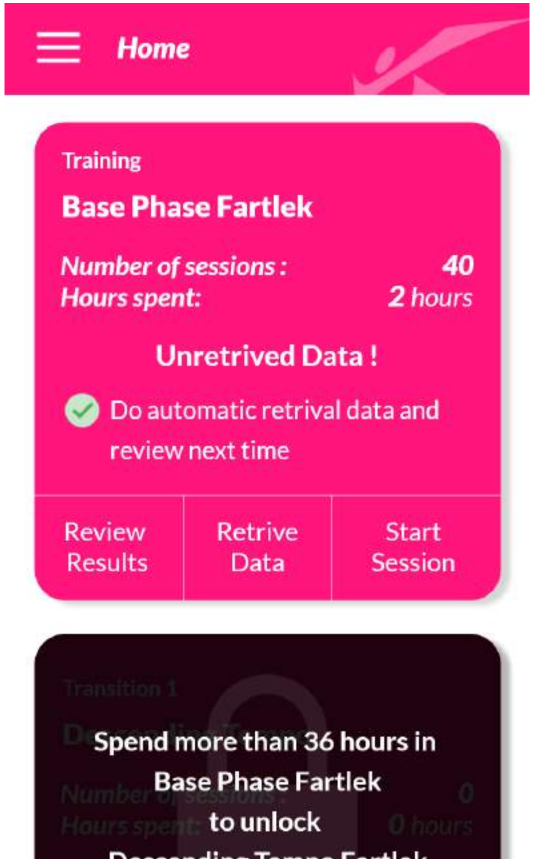


Figure 56: Home screen of the app, if the athlete didnot allow his smartphone to retrive the new data collected by the device.

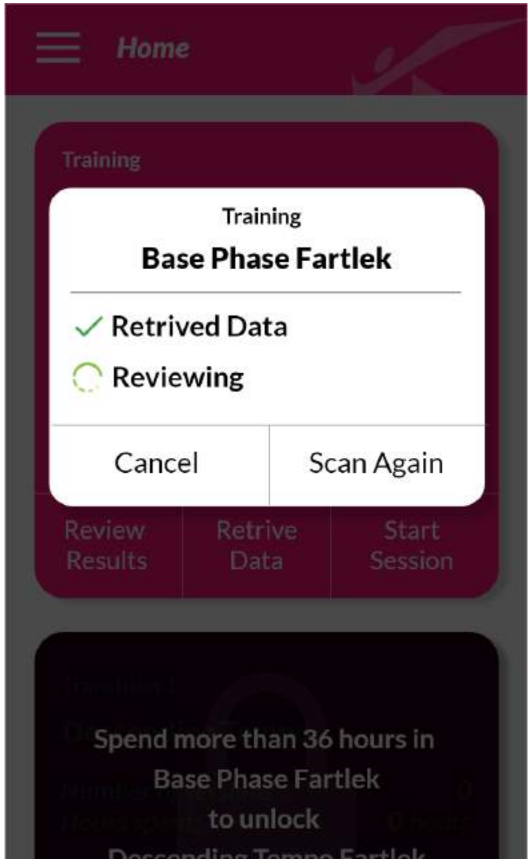


Figure 57: Data retriving process and the review progress screen.

Figure 58: Review screen of the last session performed by the athlete.

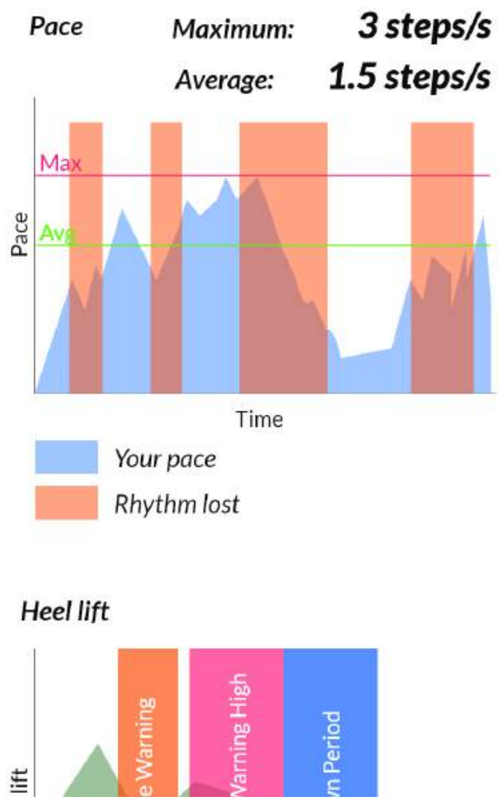


Figure 59: Continuation of figure 36.

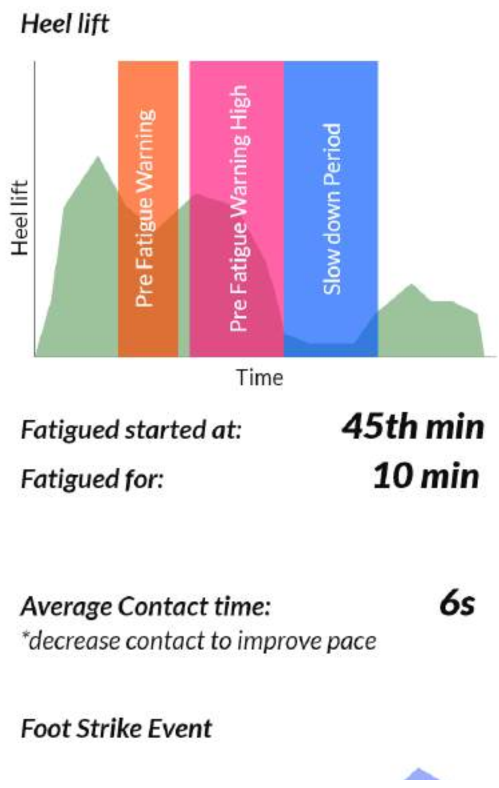


Figure 60: Continuation of figure 36.

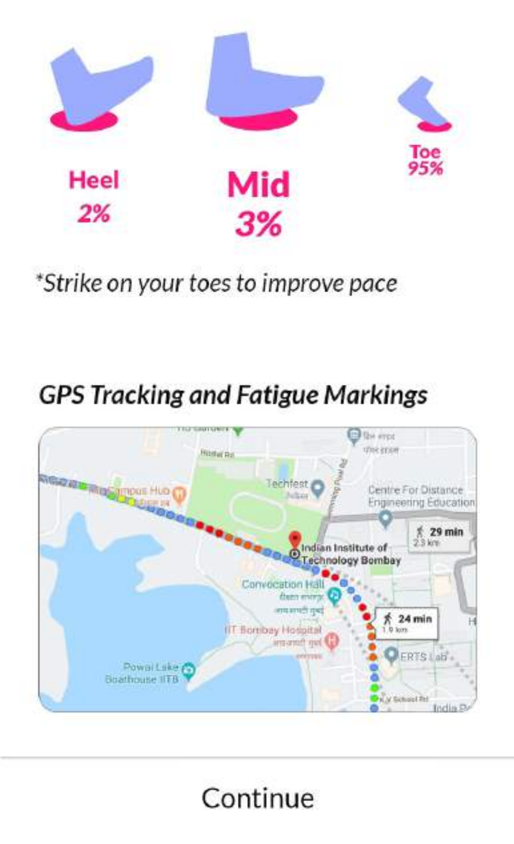


Figure 61: Continuation of figure 36.

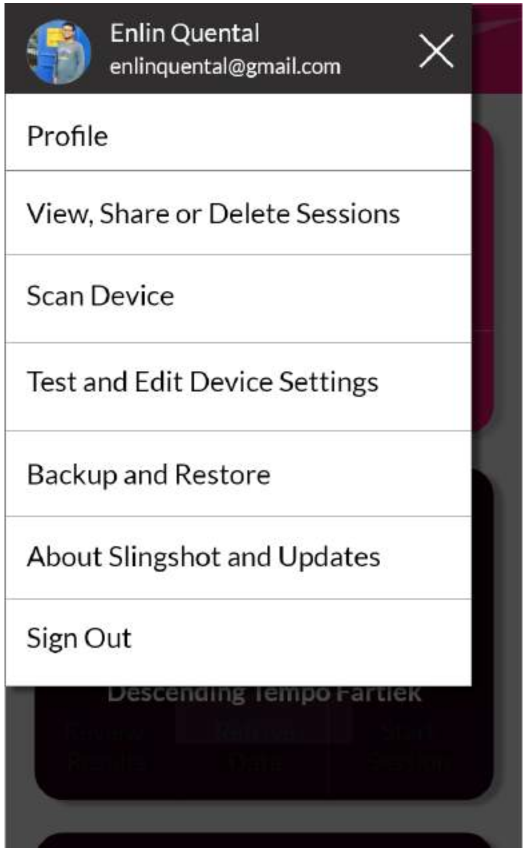


Figure 62: Menu screen.

Figure 63: Screen showing the list of recorded sessions.

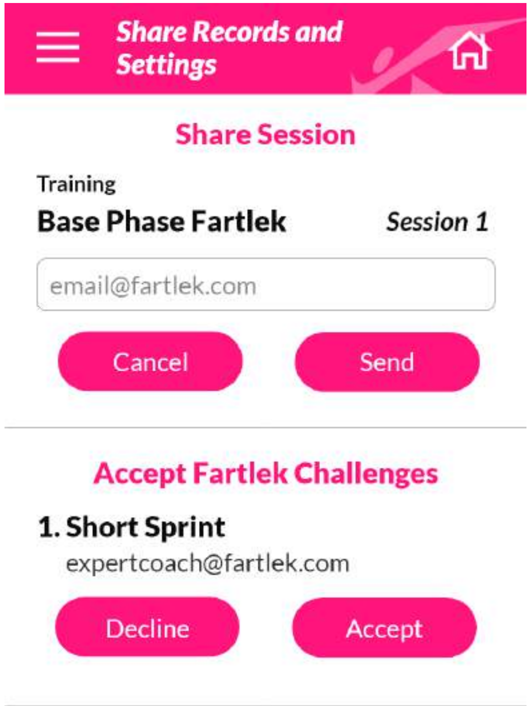


Figure 64: Sharing and accepting Fartlek challenges screen.

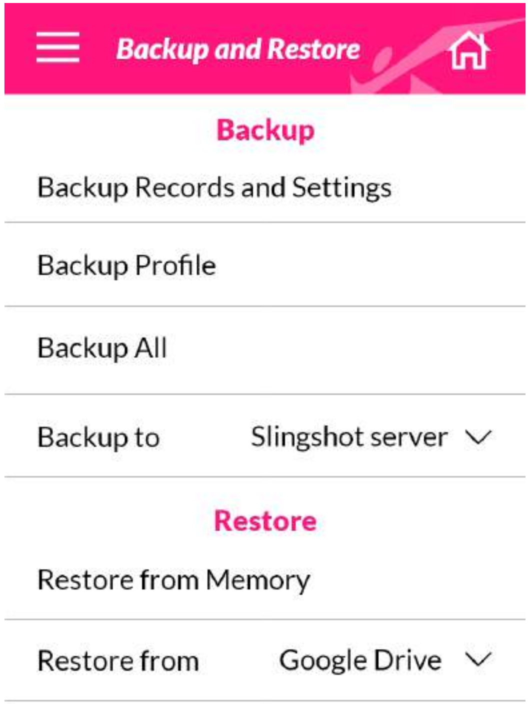


Figure 65: Backup and restore screen.

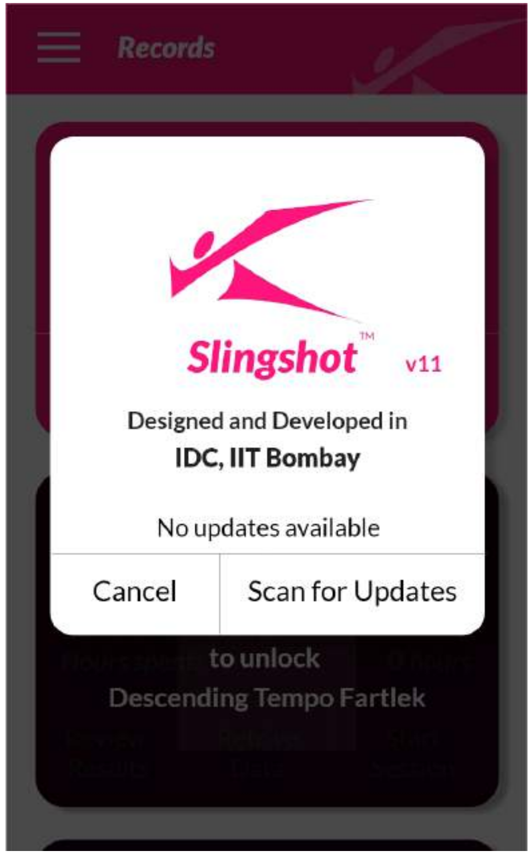
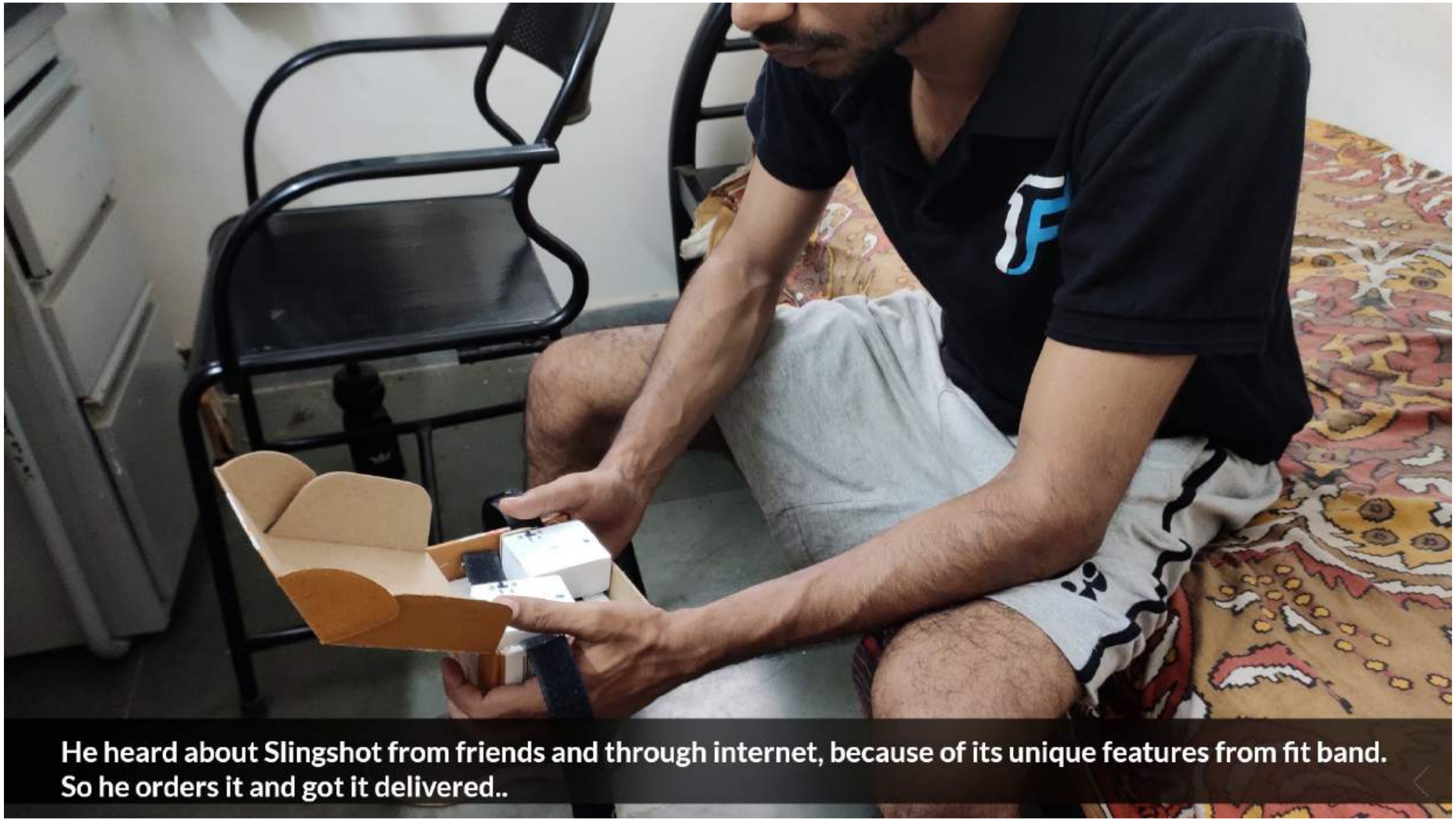
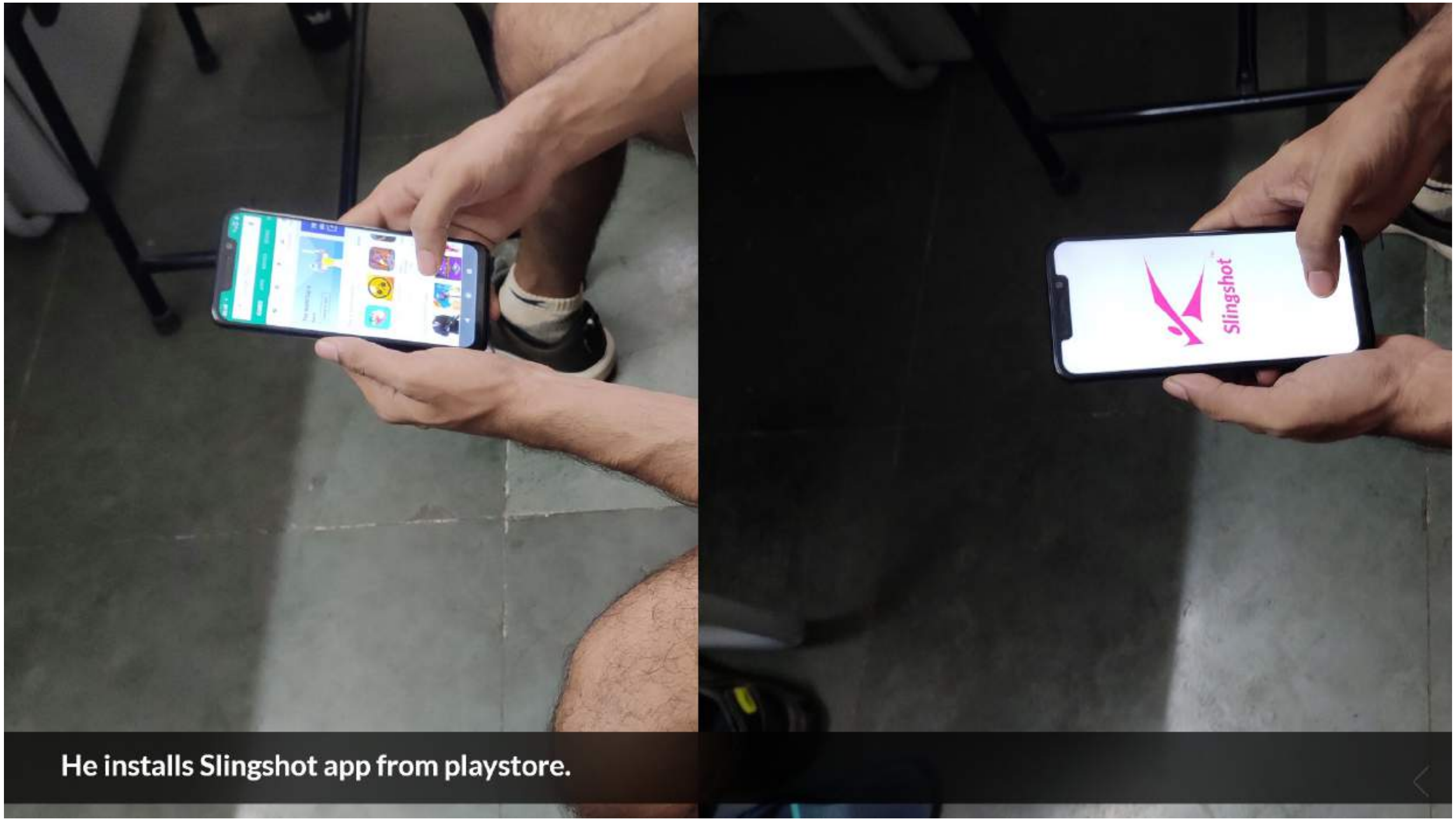


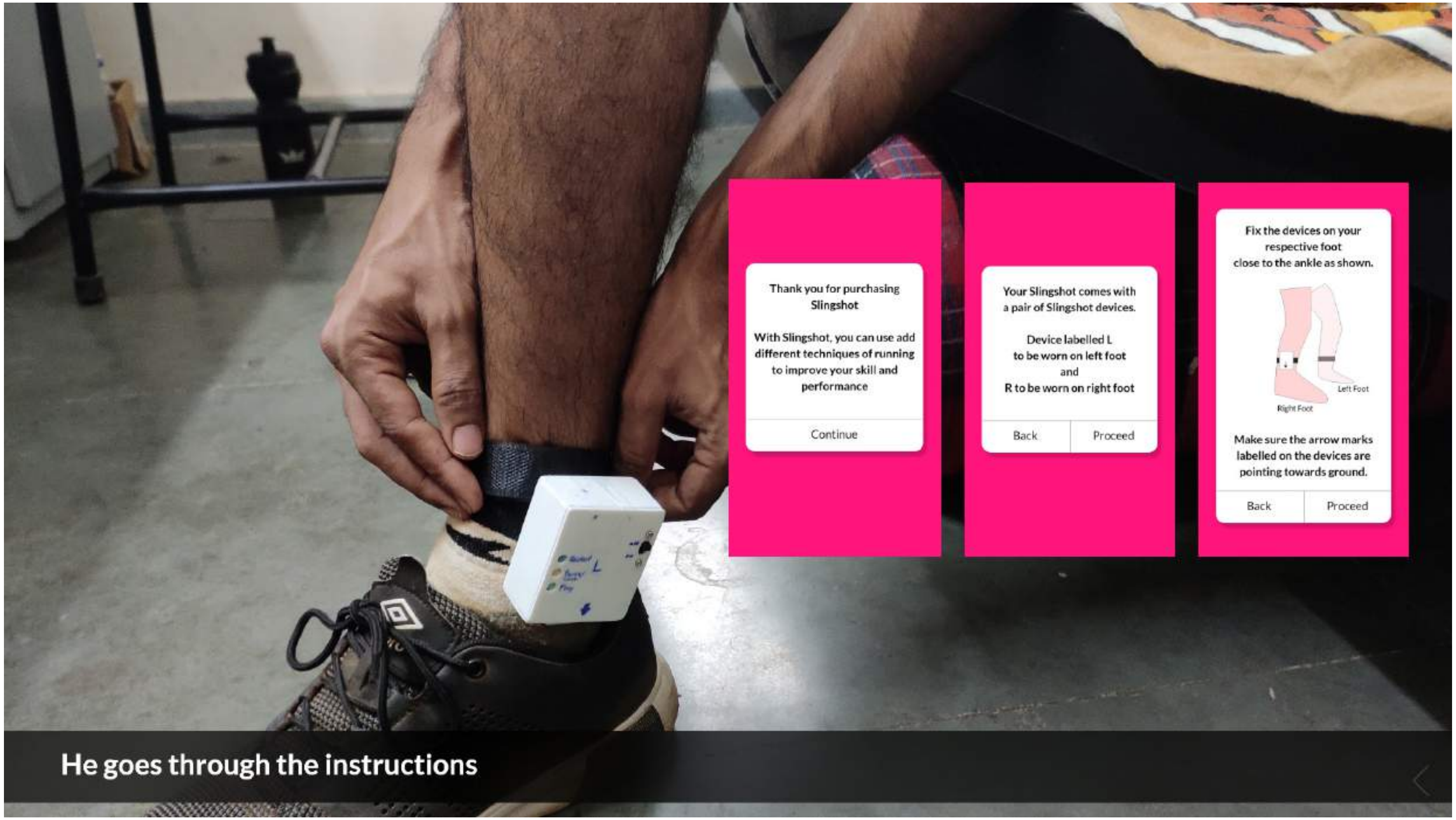
Figure 66: About Fartlek and update screen.

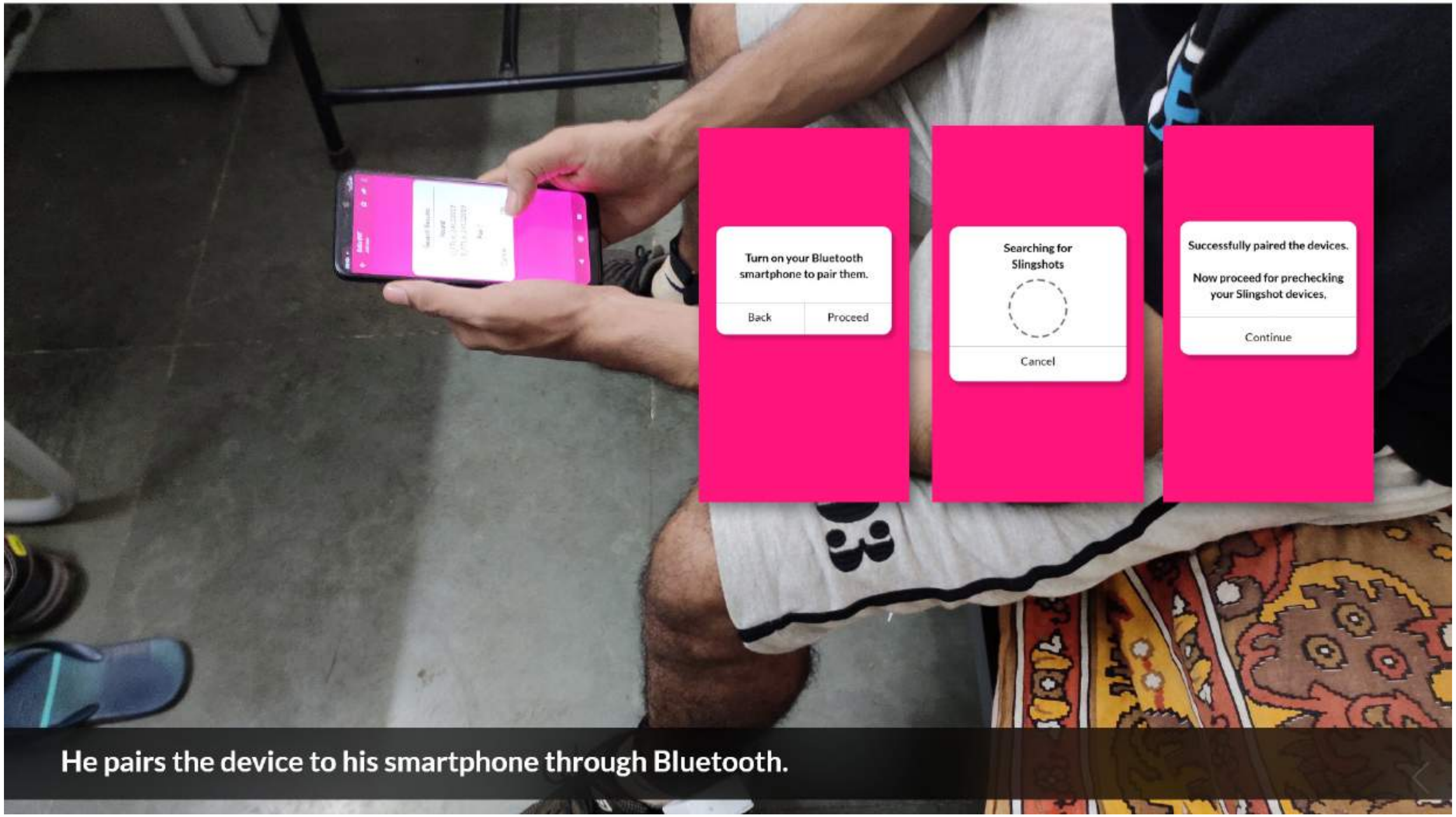
Real World Concept

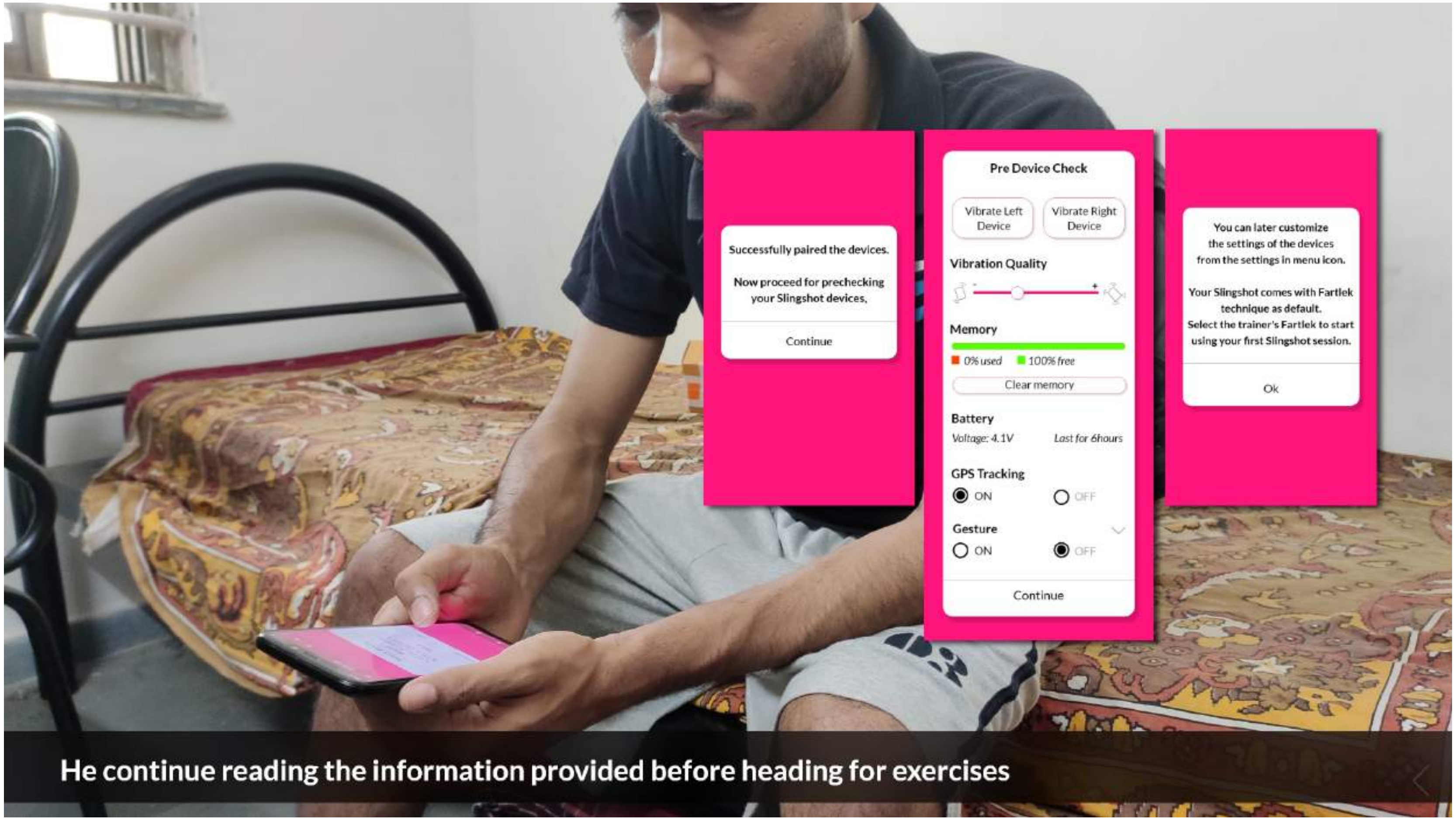

He heard about Slingshot from friends and through internet, because of its unique features from fit band.
So he orders it and got it delivered..

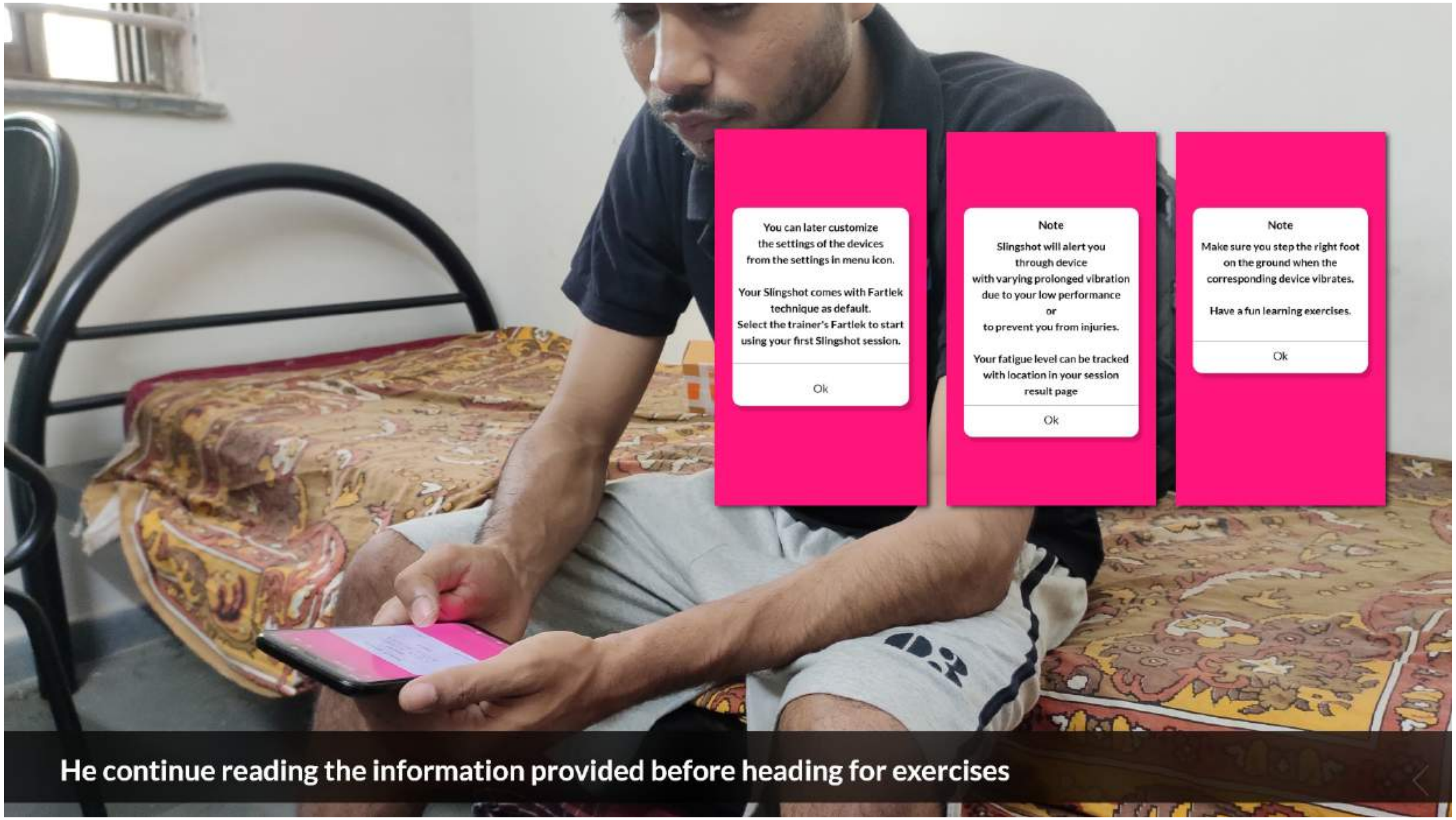


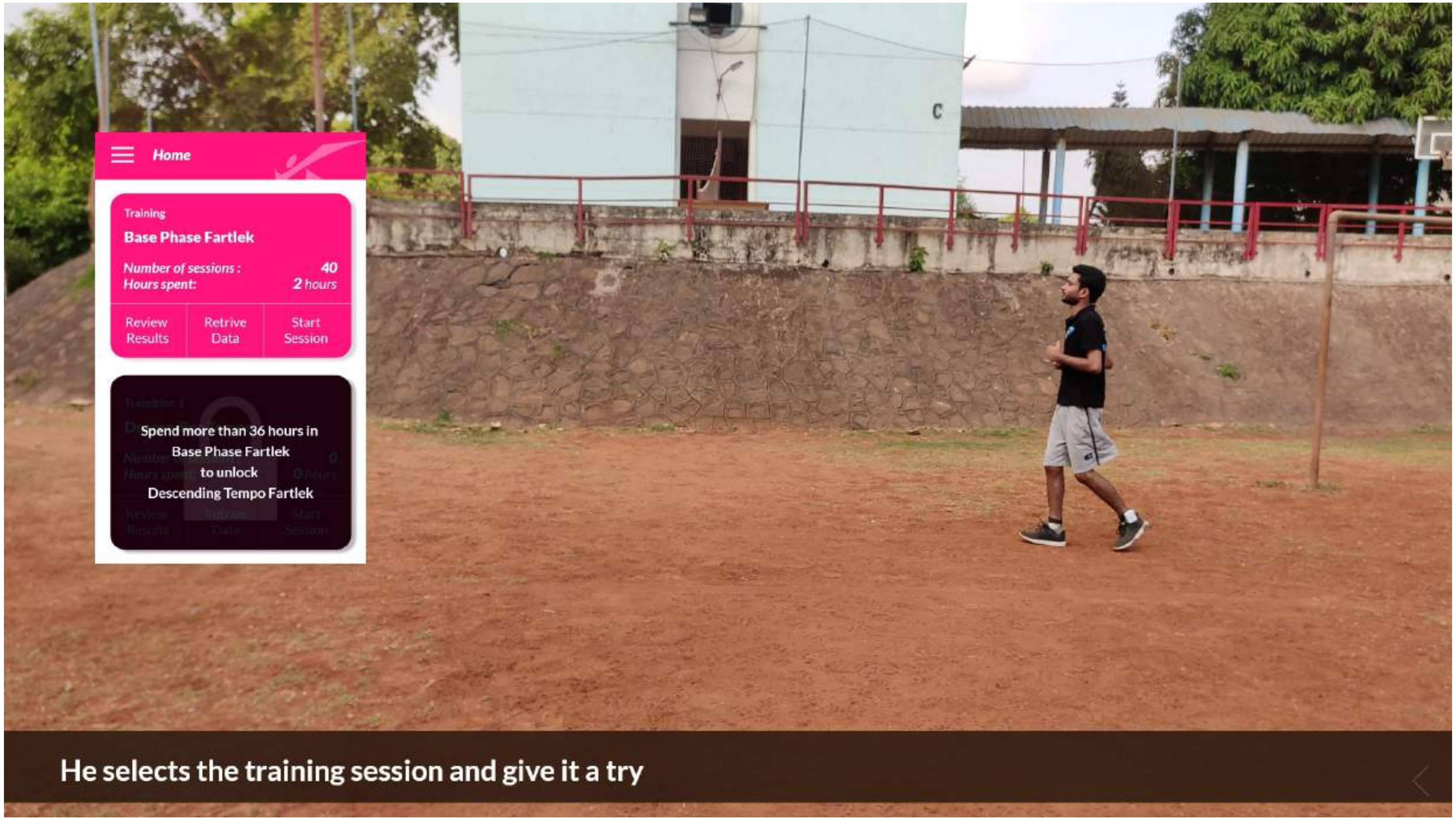
He installs Slingshot app from playstore.


Thank you for purchasing Slingshot
With Slingshot, you can use add different techniques of running to improve your skill and performance
Continue
Your Slingshot comes with a pair of Slingshot devices.
Device labelled L to be worn on left foot and R to be worn on right foot
Back
Proceed
Fix the devices on your respective foot close to the ankle as shown.
Left Foot
Right Foot
Make sure the arrow marks labelled on the devices are pointing towards ground.
Back
Proceed
He goes through the instructions

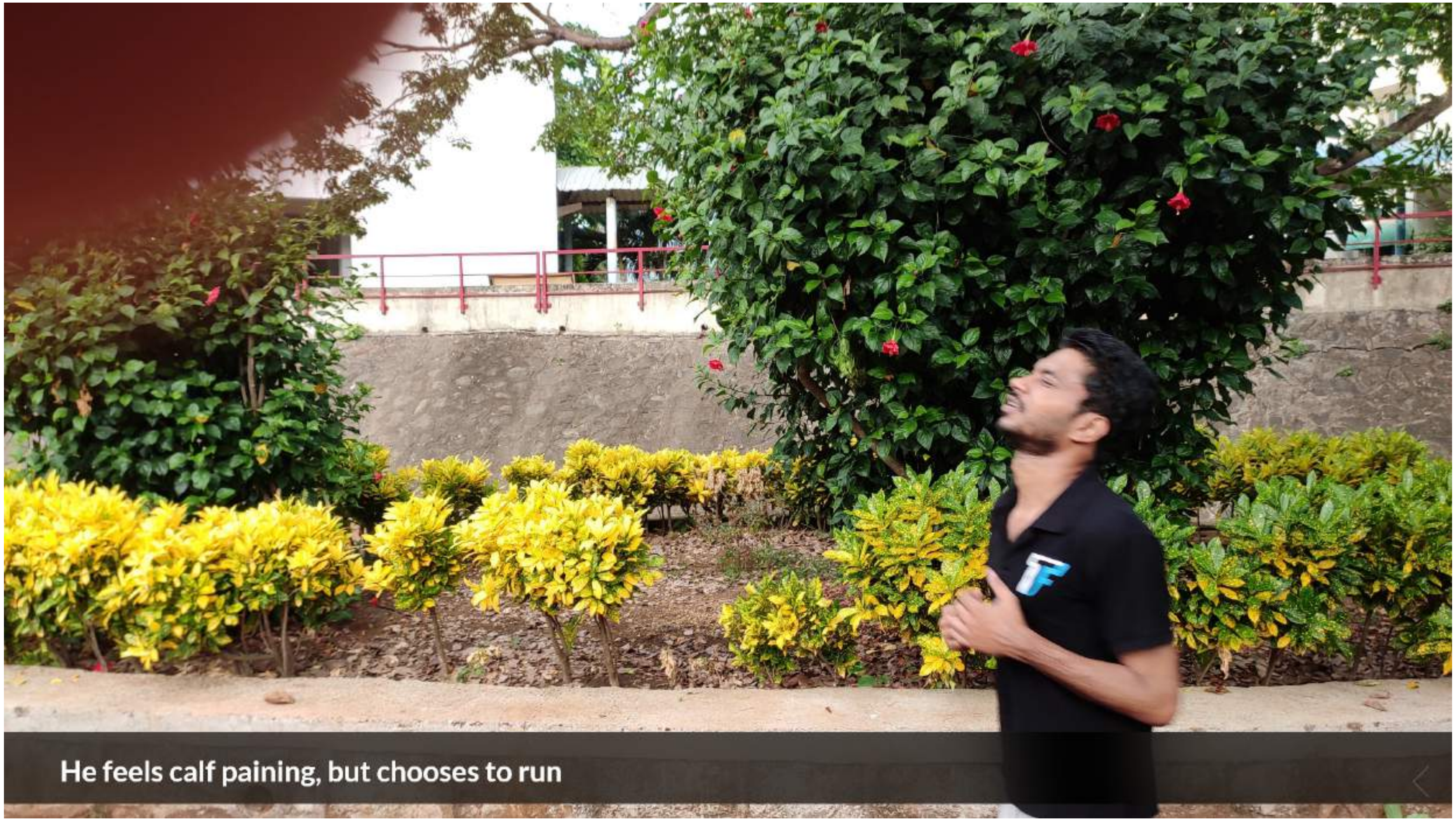

Turn on your Bluetooth smartphone to pair them.
Back
Proceed
Searching for Slingshots
Cancel
Successfully paired the devices.
Now proceed for prechecking your Slingshot devices.
Continue
He pairs the device to his smartphone through Bluetooth.


Successfully paired the devices.
Now proceed for prechecking your Slingshot devices,
Continue
Pre Device Check
Vibrate Left Device
Vibrate Right Device
Vibration Quality
Memory
0% used
100% free
Clear memory
Battery
Voltage: 4.1V
Last for 6hours
GPS Tracking
ON
OFF
Gesture
ON
OFF
Continue
You can later customize the settings of the devices from the settings in menu icon.
Your Slingshot comes with Fartlek technique as default.
Select the trainer's Fartlek to start using your first Slingshot session.
Ok
He continue reading the information provided before heading for exercises

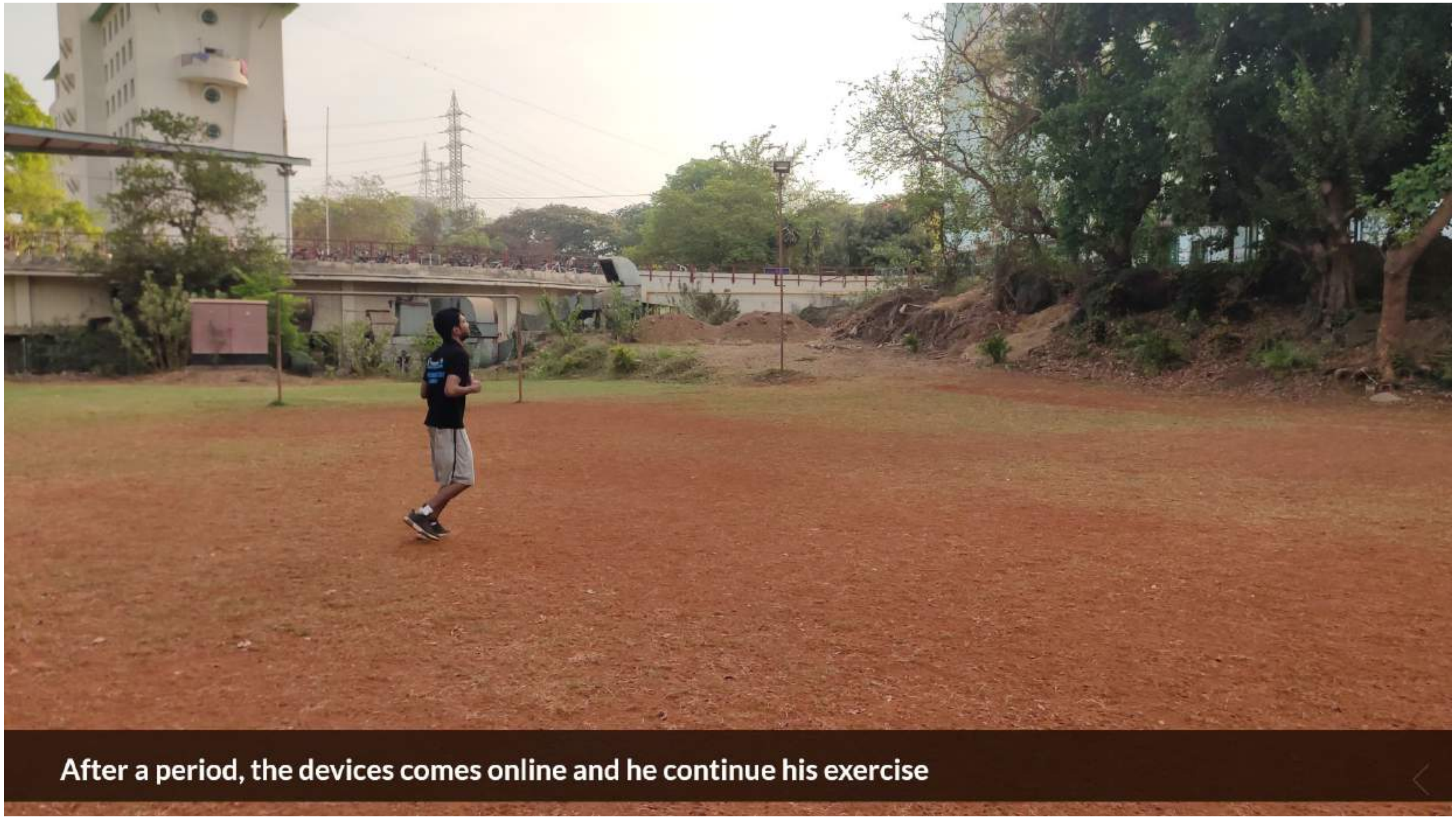

You can later customize the settings of the devices from the settings in menu icon.
Your Slingshot comes with Fartlek technique as default. Select the trainer's Fartlek to start using your first Slingshot session.
Ok
Note
Slingshot will alert you through device with varying prolonged vibration due to your low performance or to prevent you from injuries.
Your fatigue level can be tracked with location in your session result page
Ok
Note
Make sure you step the right foot on the ground when the corresponding device vibrates.
Have a fun learning exercises.
Ok
He continue reading the information provided before heading for exercises

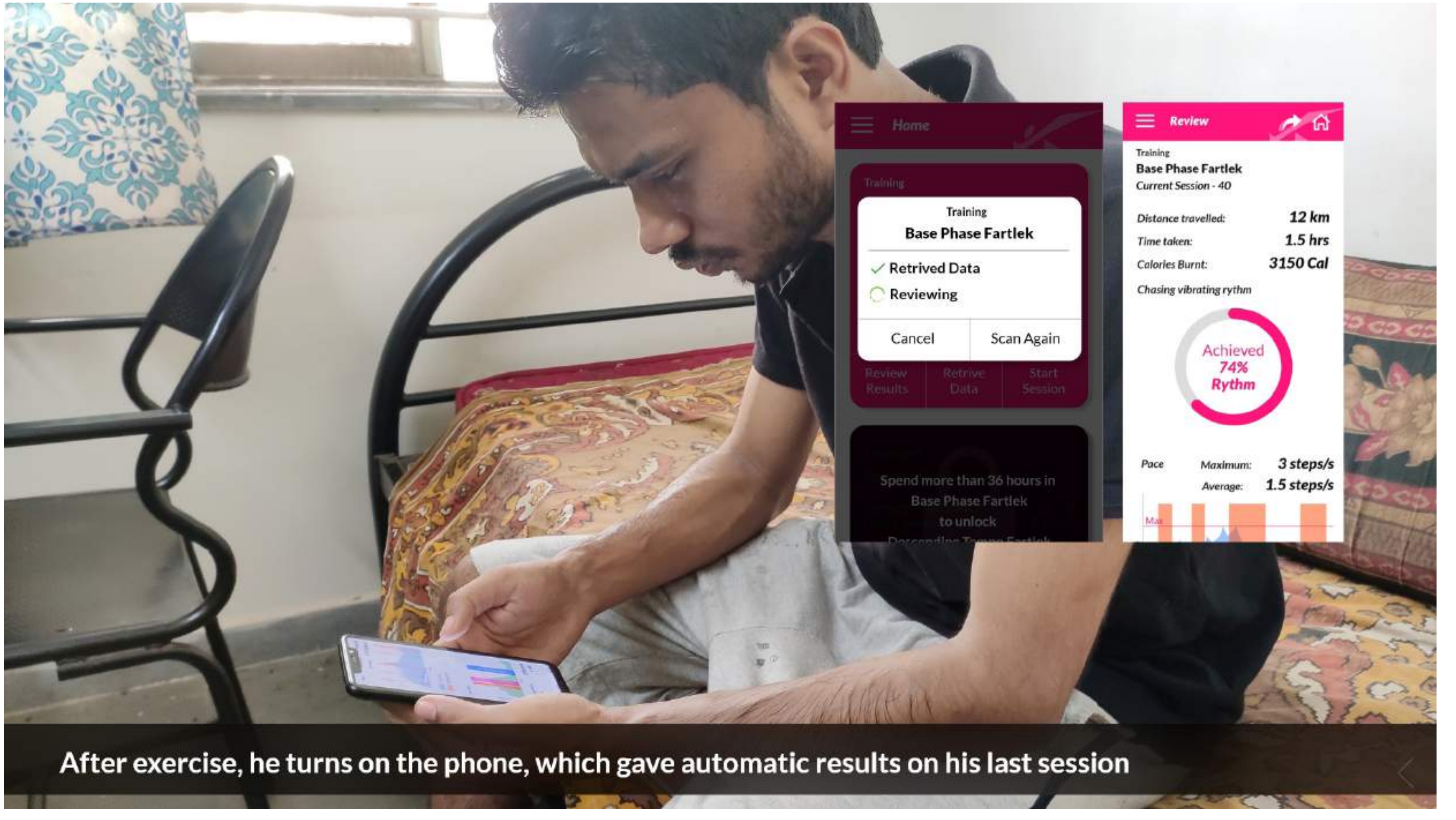

Home
Training
Base Phase Fartlek
Number of sessions : 40
Hours spent: 2 hours
Review Results
Retrive Data
Start Session
Spend more than 36 hours in
Base Phase Fartlek
to unlock
Descending Tempo Fartlek
He selects the training session and give it a try

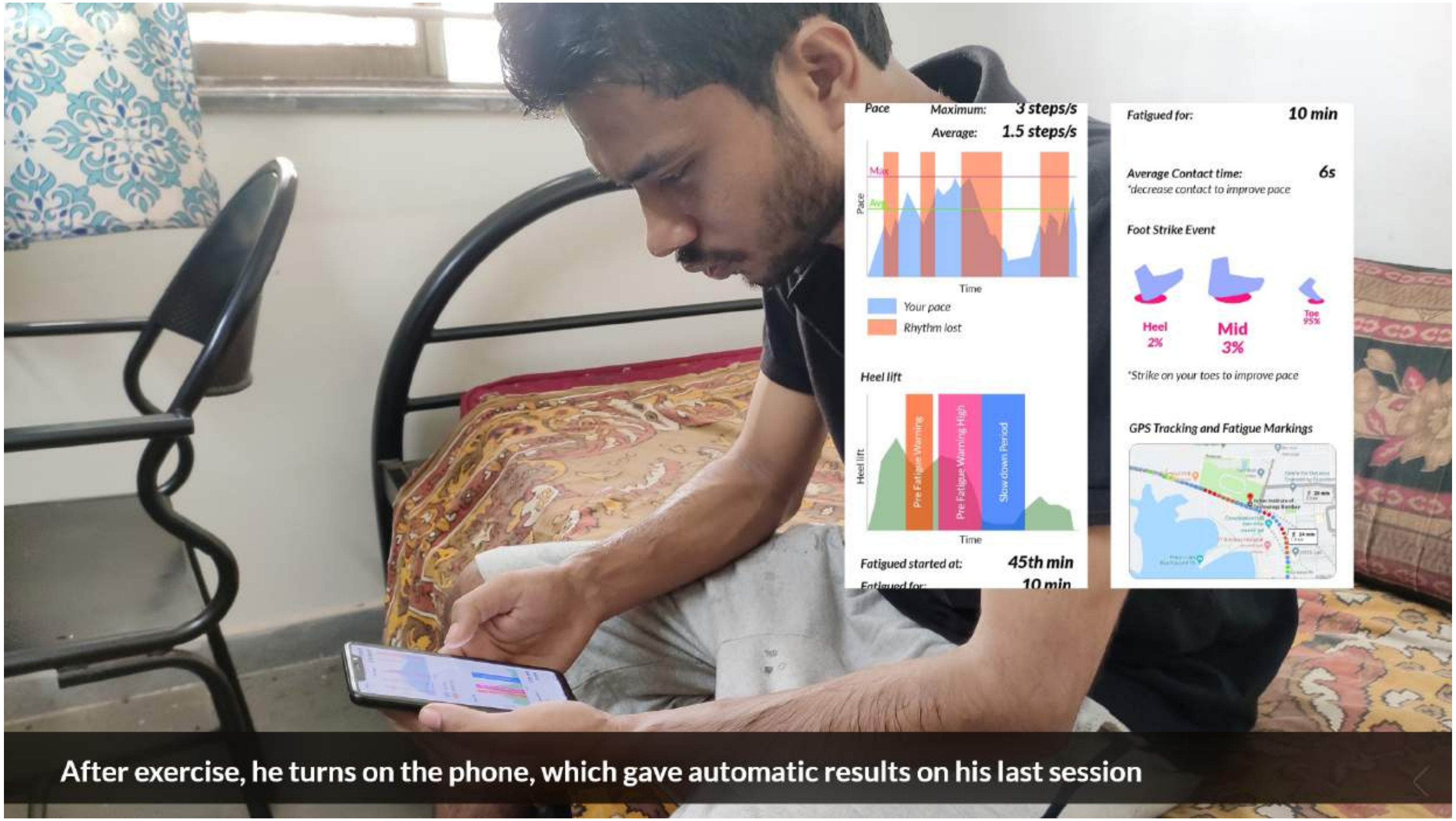

C
He tries to maintain the rhythm of running given through vibration of the devices


He feels calf paining, but chooses to run

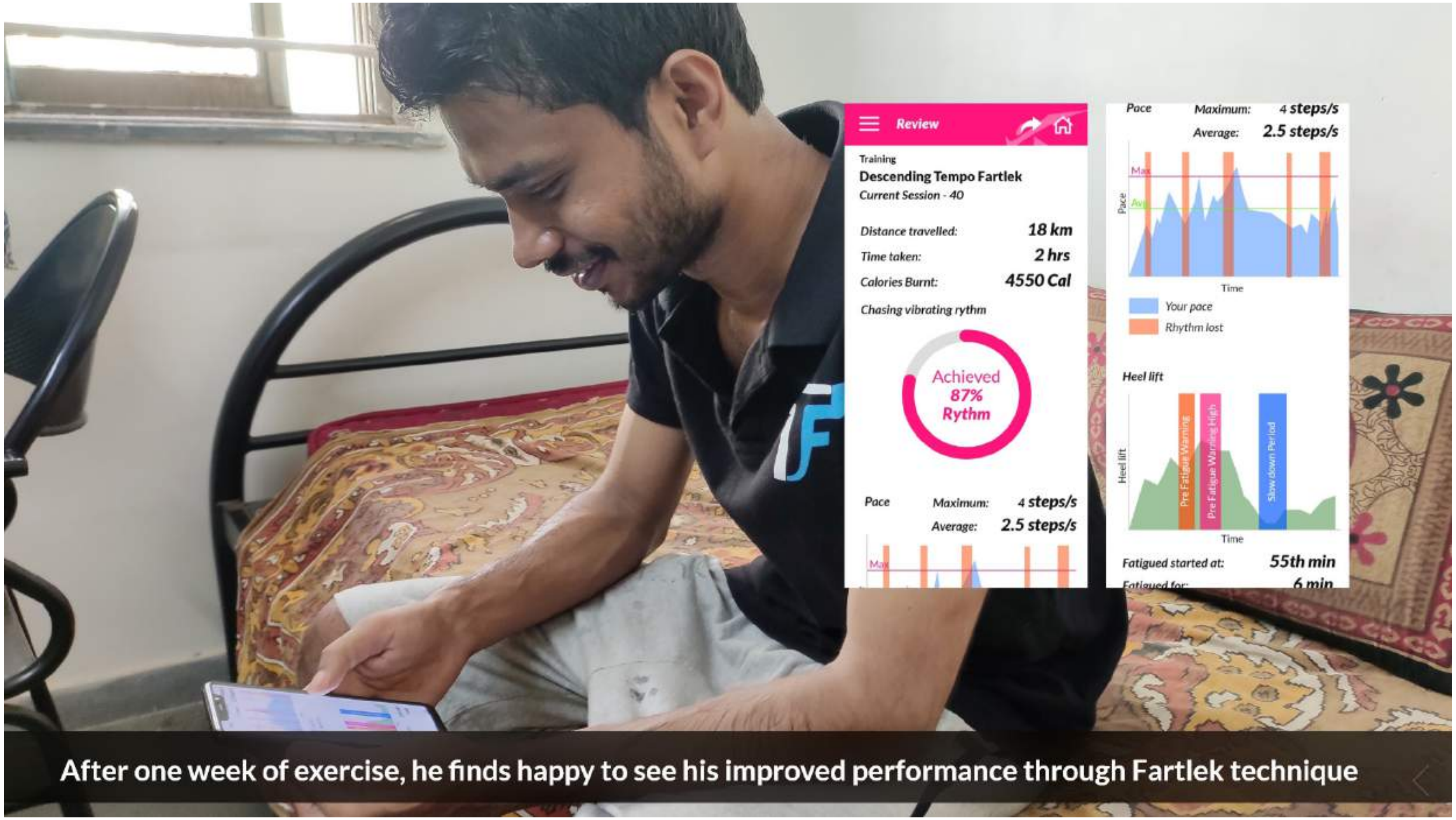
His devices alert him of possible fatigue through varying vibrations and pauses for sometime to give him rest


After a period, the devices comes online and he continue his exercise


Home
Training
Training
Base Phase Fartlek
Retrived Data
Reviewing
Cancel
Scan Again
Spend more than 36 hours in
Base Phase Fartlek
to unlock
Review
Training
Base Phase Fartlek
Current Session - 40
Distance travelled:
12 km
Time taken:
1.5 hrs
Calories Burnt:
3150 Cal
Chasing vibrating rythm
Achieved
74%
Rythm
Pace
Maximum:
3 steps/s
Average:
1.5 steps/s
After exercise, he turns on the phone, which gave automatic results on his last session



After exercise, he turns on the phone, which gave automatic results on his last session



After one week of exercise, he finds happy to see his improved performance through Fartlek technique

Prototype—Physical Challenges

When we started doing the pre-final prototype, and the casing for the prototype according to our proposed product dimension, the dimension went beyond our proposed product dimension. Therefore we did a research on some of the popular fit bands—MI band and Samsung Gear Sport, explored their specifications, how do they look when fixed to a shoe and tied on a foot, near to the ankle. The following details shows how much similar are there in the usage of our product components with existing fitband components, and the variation in dimensions.

Proposed Product—Specifications

Outer case material: Polycarbonate or HDPE
Dimensions: 60 x 38 x 23 mm
Weight: 50g
Display: none
Connectivity: Bluetooth 4.0
GPS: yes
Storage: 2 GB
Feedback: vibration
Battery: 3.7v 360mAh lipo battery

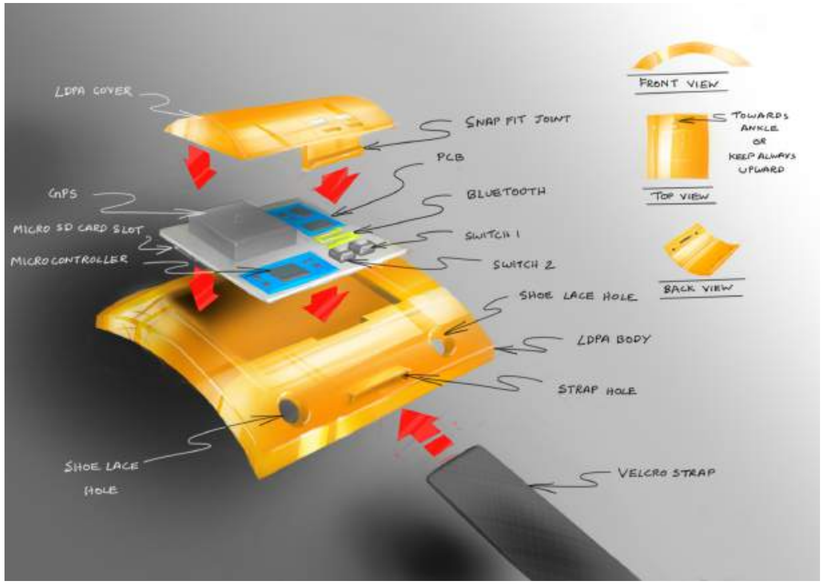


Figure 67: Proposed product

Existing Products

Samsung Gear Sport—Specifications

Dimensions: 42.9 x 44.6 x 11.6 mm
Weight: 50g
Display: AMOLED
Connectivity: Bluetooth 4.2
GPS and GLONASS
Storage: 4GB
Battery: 3.7v 300mAh Lipo

Figure 68: Samsung Gear Sport

MI Band v1—Specifications

Outer case material: Aluminum, Polycarbonate
Dimensions: 36 x 14 x 9 mm
Weight: 5g
Display: none
Connectivity: Bluetooth 4.0
GPS: none
Storage: -- GB
Battery: 3.7v 41mAh Lipo

Figure 69: MI Band v1

Pre-final Product—Specifications

Outer case material: Styrene
Dimensions: 60 x **50** x **30** mm
Weight: 50g
Display: none
Connectivity: Bluetooth 2.0
GPS: yes
Storage: 2 GB
Battery: 3.7v 360mAh Lipo

Therefore, if the components of our pre-final prototype were done in a PCB (Printed Circuit Board) and manufactured, the dimensions and the weight should be **within 60 x 44.6 x 11.6 mm and less than 50g**, taking references from the Samsung Gear Sport and MI band.

Figure 70: Image shows the overshoot of dimensions of pre-final prototype from the proposed product.

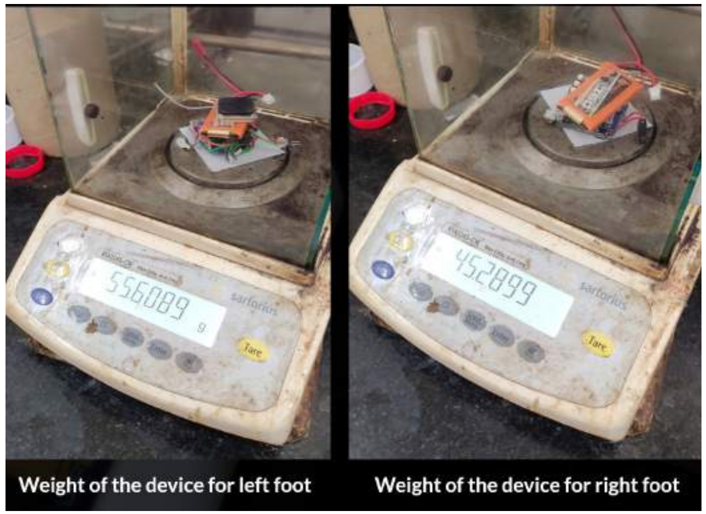
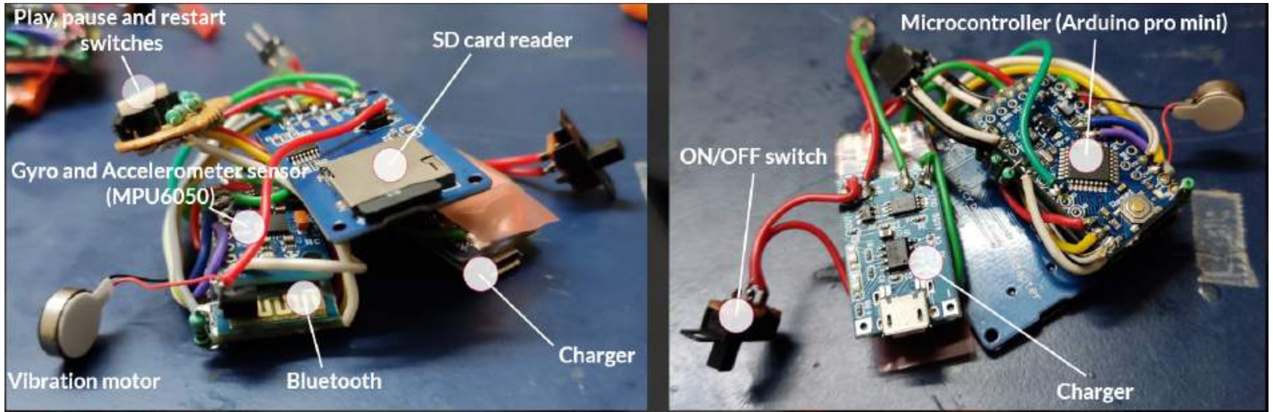
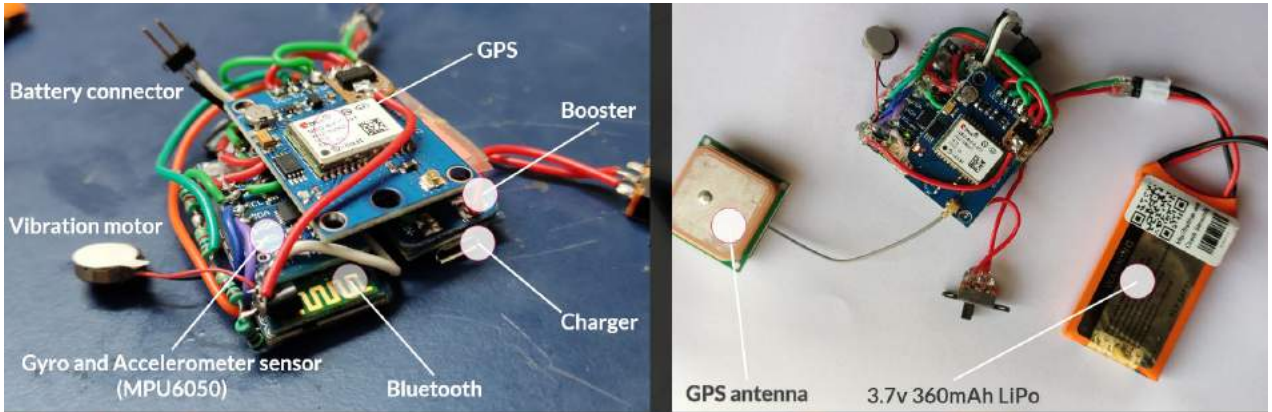


Figure 71: Weight of electronic components of pre-final prototype.

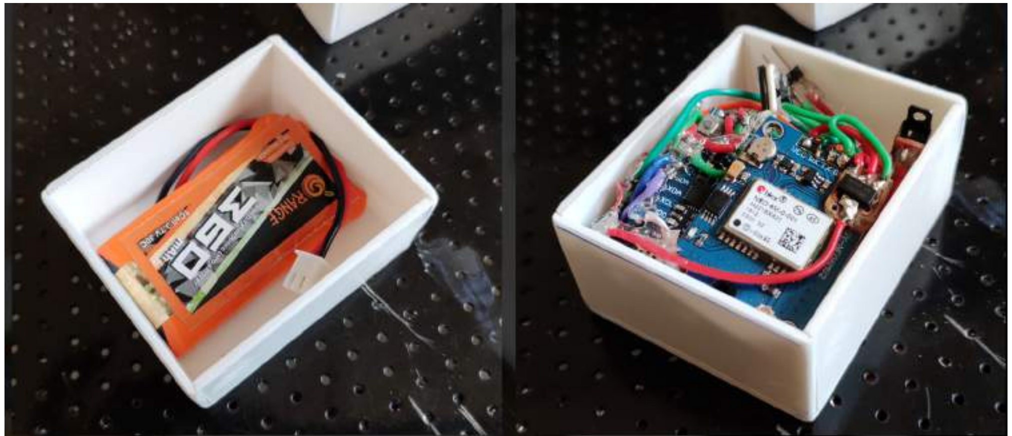
Prototype—Making



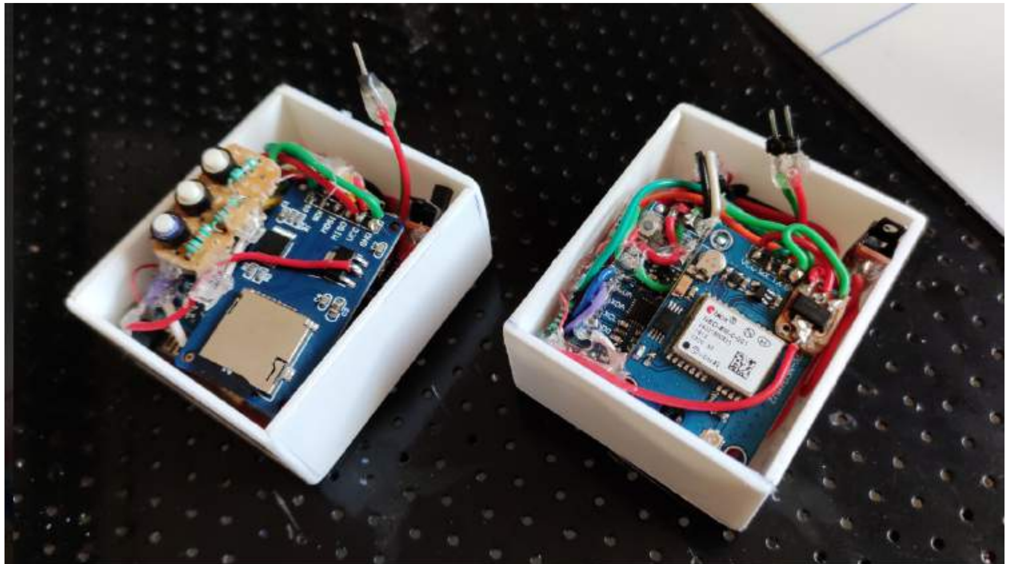
Internal components of the device for left foot



Internal components of the device for right foot



Casing—material: styrene—made for the prototype



Casing—material: styrene—made for the prototype

Evaluation Protocol

Users
2 users— a regular male athlete and a general female athlete.

Place
IITB campus

Time
20 minutes per user

Variables
Conceptual variable—performance, fatigue.
Measured variables—heel lift, foot strike event, contact time. These measures the pace and fatigue level(for injury prevention).
Control variables—path taken, weather, time of test, shoes and gears, number of participants.
Random variables—test order of participants.
Confounding variables—skill of participants.

Method

A regular running/jogging user is approached and a brief description on the project is given.

Details of the product and its usage is explained to the user.

He will be asked to wear the product if he hasn't started exercised on the same day. He will be helped in attaching and enabling the device to his shoes.

The user is asked to run for 10–20 minutes wearing the device and return to the original starting point.

The data stored in the product is then saved to smartphone or laptop. The results are showed to the user, explaining each parameter.

If the user is willing to continue his running with wearing the product, he may be asked to change his running style to improve his output.

The user's output will be shown and is compared with old data, for any possible improvements.

Questions

The questions for the evaluation were focused on the following:

- Did the system affect the jogging/running pattern?
- Comfortability of the product.
- How challenging it was to match the vibrational feedback given by the device?
- Understanding of the visualization.
- Effects of introducing a new running technique and the changes in performance.
- Potential of the device in the current stage and for future possibilities.
- Pros, cons, areas of improvement, adding/removing features, etc.

Feedback

After the evaluation, participants told us that the information on foot strike events—heel, mid and toe strike—, fatigue information, and the mapping of fatigue on a map were new and were good features of the product. While wearing the product, participants felt that the straps were not comfortable and recommended that strapping should be easy. They were comfortable with the weight of the product. It was not heavy when tied on the ankle, and they did not feel that the product was attached on their ankle during their exercise.

While walking, the vibration feedback was sensible to the participants otherwise on running it was not sensible. Therefore the product did not introduce the new technique, neither was challenging nor improved the performance of the participants from the device due to less skin sensitivity to the vibration feedback from the device, during running. The possible reason could be, on running the body itself is in vibration and this cancles out the vibrational feedback given from the device, which is attached on the ankle of the participants. Participant suggested us for skin friendly/sweat free pad which can increase the skin contact with the product, which increases skin senstivity on the vibration feedback from the device.

Participants feedback on visualizations used in the results page was that the missing dimension of the x-axis(time) was not intuitive. For the regular athlete, the application was understandable as he had tried out other fitness tracking devices and applications. For the general female athlete, graph and visualizations were not understandable as she hasn't used any fitness tracking devices and applications. Figure 72 shows an idea/suggestion she made for the visualisation of the results page.

Participants recommended that an indication of the live feedback on data collected by the product was necessary—an indication that product was functioning properly—, and the important results have to be displayed on the product.

Takeaway

From the feedback given the participants after their evaluation on the product, we decideded in improving the visualization used in the results page. As the participants could not feel the vibration feedback given by the product, which was tied on their ankle, it gave us an area to explore on different ways the rhythmic pattern can be given to the running athlete. Possible solutions can be giving the vibration feedback on the wrist/ arm of the user, which will require additional devices to be tied on the user; or sending sound beats instead of vibration to a wireless headphone, worn by the user, which also needs an additional usage of device—wireless headphone.

Displaying the important parameters and values on the product, and a strap free attachment or a user friendly easy

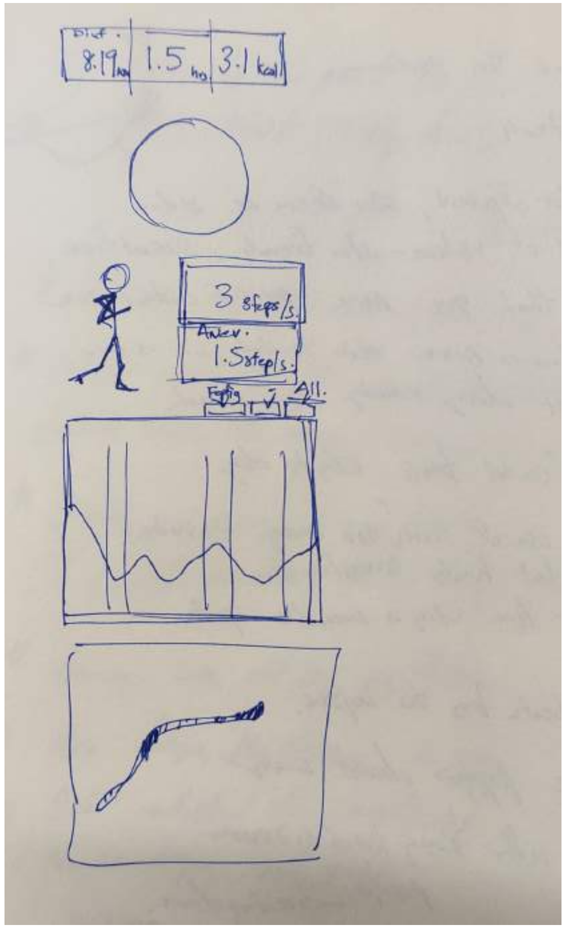


Figure 72: The picture shows the female participant's idea on visualization that could be used in the results page of the product, *Slingshot*.

strapping of the product with larger base coverage on the user's body, will be considered and implimented in the near future.

The novelty and the unique features of the product created interest in the participants for retesting the product again once the product clears out the existing problems, and they will be willing to use it for their exercise.

Conclusion

Inertial Measurement Unit (IMUs) have been used in fitness trackers for tracking the number of steps and sleep patterns of the user. IMUs have also been used for gait analysis as a cheap, reliable and portable sensor when compared to other techniques of capturing gait. Considering the popularity of wearable fitness trackers and their ease of use, we found an opportunity to extend the use of IMUs for improving the performance and technique of a running athlete through gait parameters tracked by IMU. Calculation of steps according to gait analysis is calculated from foot and not from wrist, which otherwise renders the related fitness parameters inaccurate.

We achieved in developing an IMU based, foot worn product, which successfully captured and visualized the gait patterns. The features are aimed at helping the user improve their running technique and avoid injuries due to over-exertion and fatigue. Our product gives more information on kinematics of the running athlete and there is no such fitness tracking device that displays these parameters. The product is a low-cost device compared to existing products for gait analysis and fitness tracking. More research has to be done in the technique, Fartlek and for the visualizations.

Users have found the features to be novel during evaluation. They have found the vibration cues of the tackers useful for maintaining the running pace and following the correct running technique. The prototype requires further technical development which will enhance the usability of the features. These include map visualisations in the app that show different points in time and space when the user experienced fatigue. We conclude that our design for foot-based wearable tracker can be useful for fitness enthusiasts to step up their running routine to a more efficient and professional running technique. The product will be improved and upgraded in the near future, to create a positive influence among joggers/running athlete.

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