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

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Literature Review

Literature Review

Running Sport

- Running is done as an exercise and 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].

Literature Review

Running Sport

- Gait analysis could also detect the potential diseases or abnormalities in advance [4] [5].

- Independent of the skill level, heel lift decreased during the course of the run due to progressive muscle fatigue [6]”.

Literature Review

Gait Analysis

Table 1. Overview of gait parameters and applications.

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	

Table from Reference[5]

Literature Review

Sensors

- 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].

- 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, online and offline unobstructed assessment of gait analysis[2][11][12][13].

Figure 6. FlexiForce piezoresistive pressure sensor.

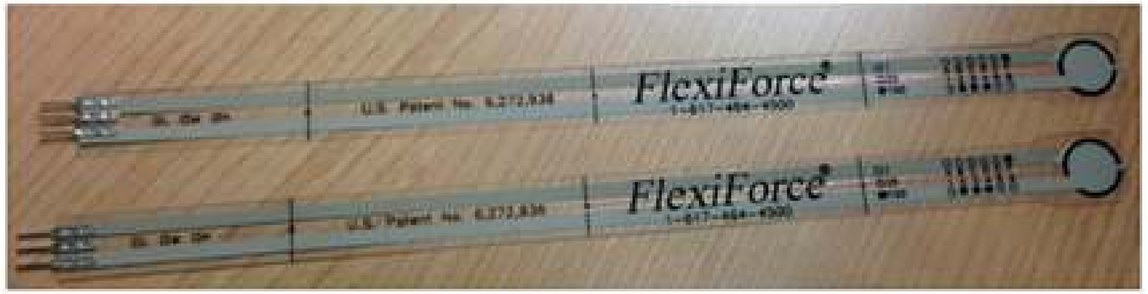


Figure 4. Gait analysis using floor sensors. (**a**) Steps recognized; (**b**) time elapsed in each position; (**c**) profiles for heel and toe impact; and finally (**d**) image of the prototype sensor mat on the floor. Reproduced with permission from University of Southampton.

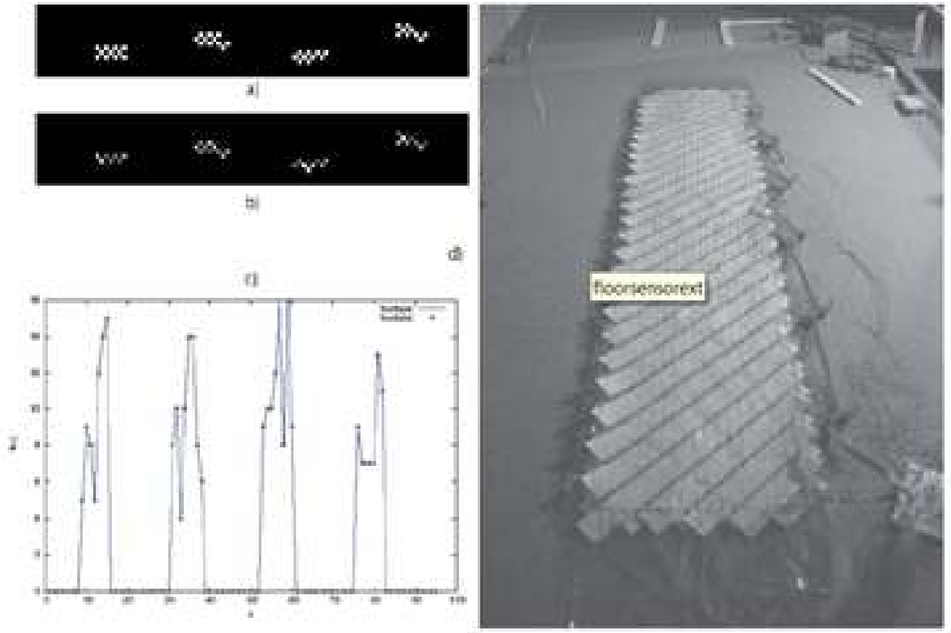


Figure 9. Flexible Goniometer.

Figure 10. Brainquiry Wireless EMG/EEG/ECG system.

Pictures from Reference[5]

Figure 11. Example of NWS system: BTS GaitLab configuration. (**1**) infrared videocameras; (**2**) inertial sensor; (**3**) GRF measurement walkway; (**4**) wireless EMG; (**5**) workstation; (**6**) video recording system; (**7**) TV screen; (**8**) control station. Reproduced with permission from BTS Bioingenieering.

Figure 13. WS system based on (**a**) inertial sensors and (**b**) wearable force plates. Reproduced with permission from Tec Gihan Co.

Pictures from Reference[5]

Literature Review

Sensors

- 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.

- 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] .”

Literature Review

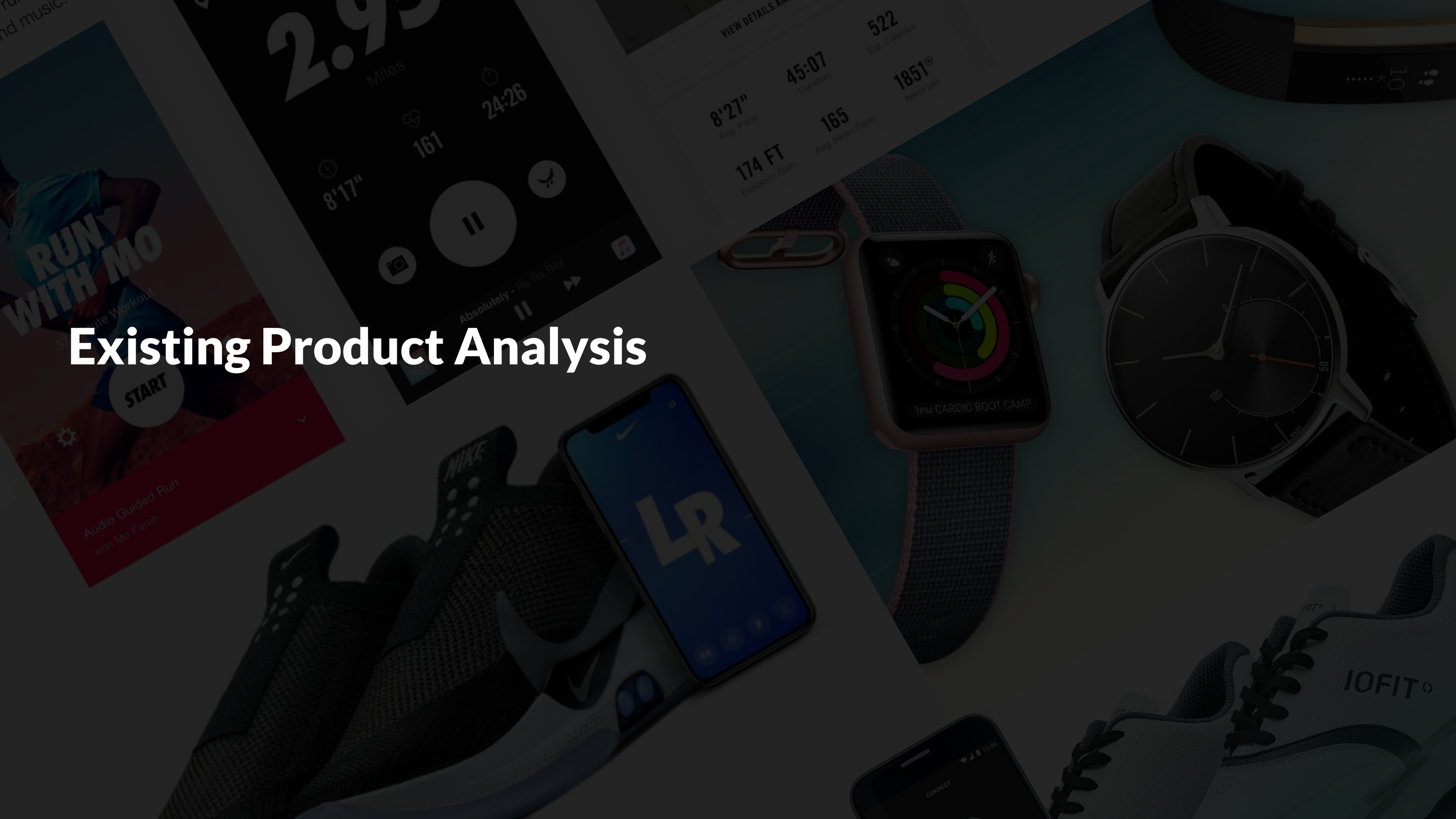
Sensors

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 spent 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].”

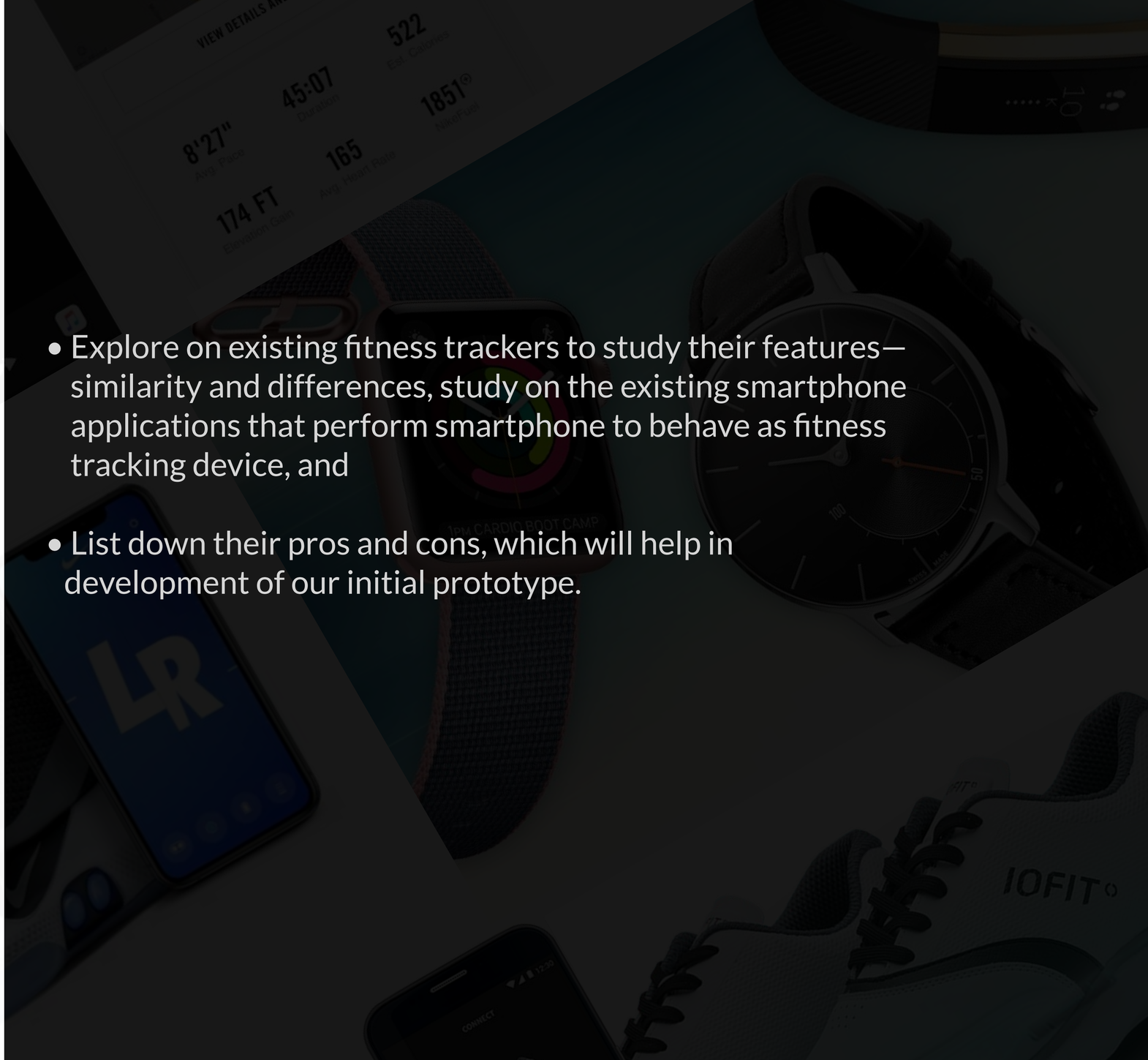
Existing Product Analysis



Existing Product Analysis

Goals

- 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
- List down their pros and cons, which will help in development of our initial prototype.



Existing Product Analysis

Fitness Bands — *Similar features*

Connectivity: Bluetooth Low Energy

Display: OLED or AMOLED

Primary features: Date, Clock, Waterproof

Secondary features:
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, weather forecast.

Advanced secondary features:
Auto activity detection, stream and listen music, GPS tracking, standalone device—offline mode.

Existing Product Analysis

Fitness Bands — *Flaws*

- Fitness band on one wrist — preferred to wear on non-dominant hand.
- Steps measured by movement of hand.
- Sleep tracking activates in the night (Mi band).
- Sleep tracking measured by hand movements.
- Do not measure performance, or alert fatigue level, which can prevent injury.
- Does not inform the angular range of the foot or foot strike events and results shown at the end of an activity [15].

Existing Product Analysis

Smart Shoes

Connectivity: Bluetooth Low Energy

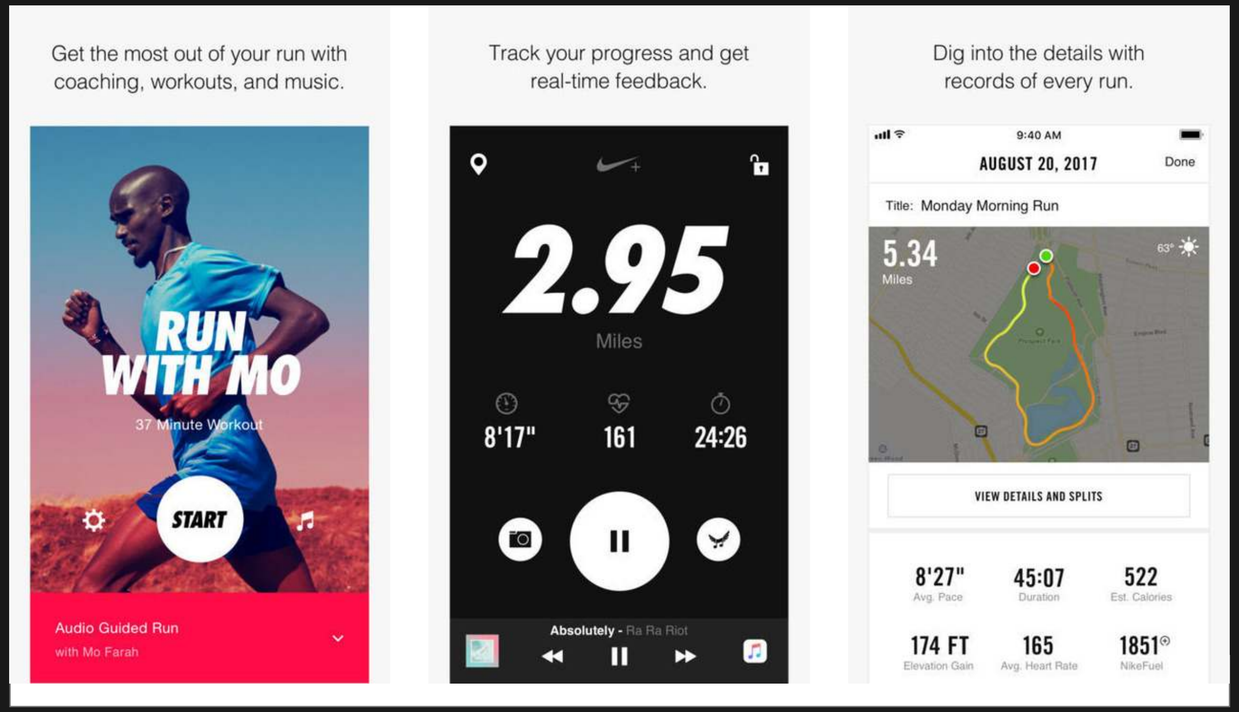
Features:
Smart lace, lace-less, 6–axis accelerometer and gyro sensor, pressure sensors, RGB LEDs, companion app.

Cons:
- Expensive
- Any external or internal damage can cause wear and tear of the auto-lacing

Existing Product Analysis
Fitness Tracking Application

Features:
Distance, 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.

Cons:
- Usage of phone during activities.
- No offline maps.



Problem Statement

Fitness bands and smart watches measure incorrect step count as they are worn on the wrist. These devices as well as smart shoes 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 trackers are not using this potential. Hence, they are not improving the runner's running technique [15].

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

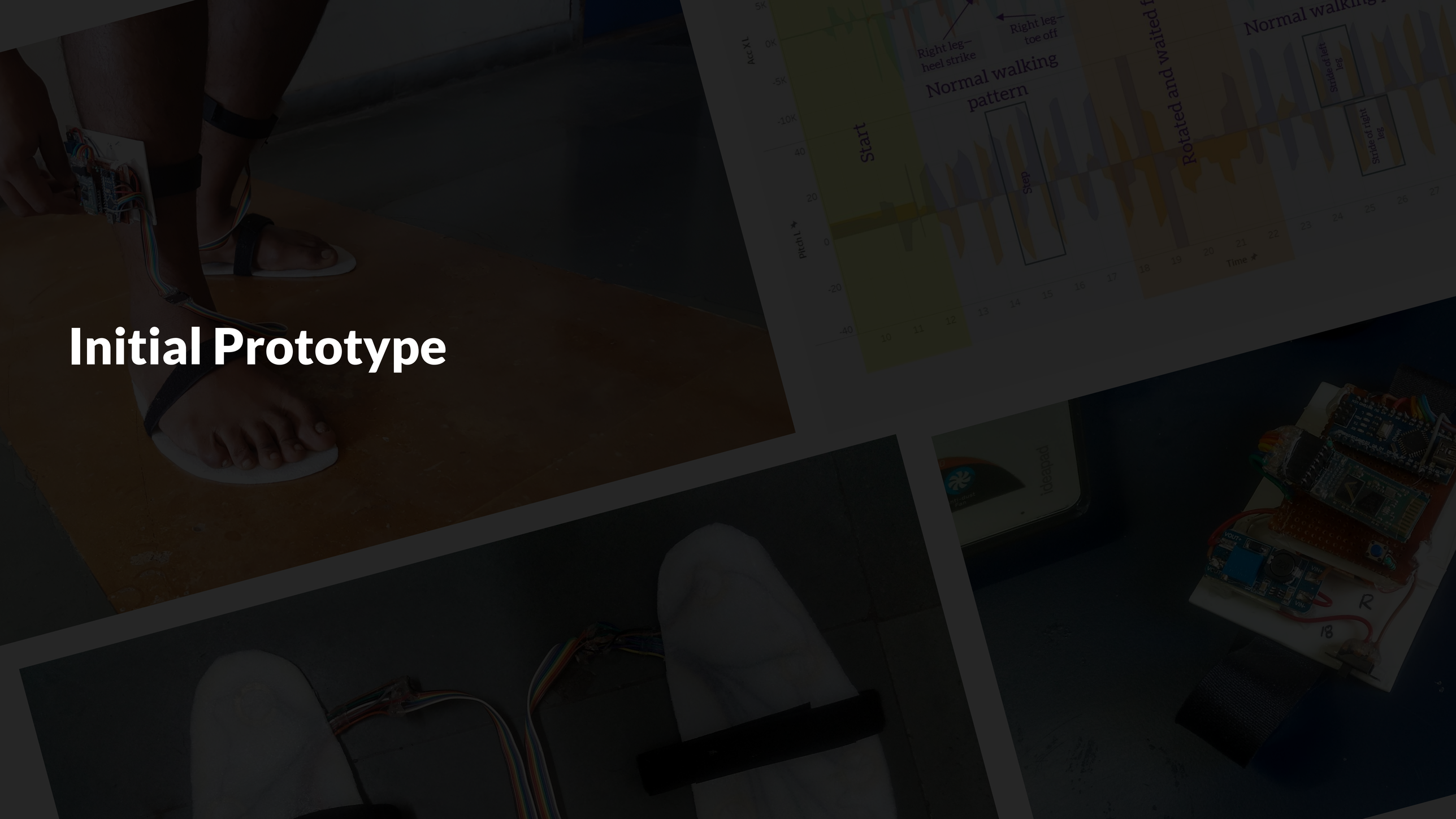
Goals

- A wearable product to improve performance of a running athlete by using a technique.
- 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 their performance and fatigue level.
- Display the time lapse of the athlete’s performance and fatigue level to check his/her daily progress.

Initial Prototype



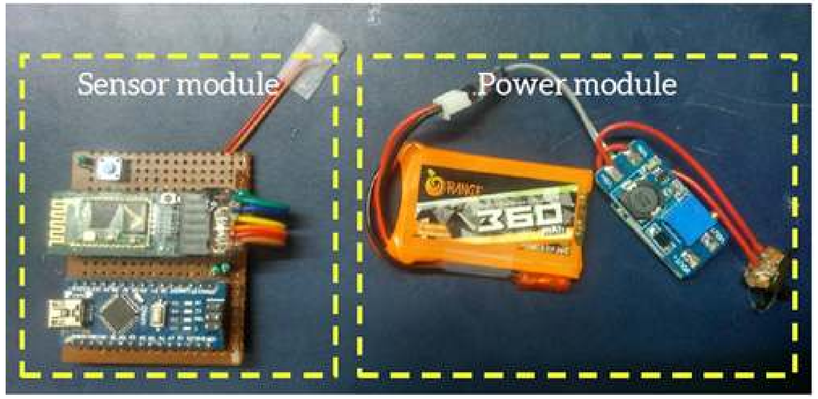
Initial Prototype

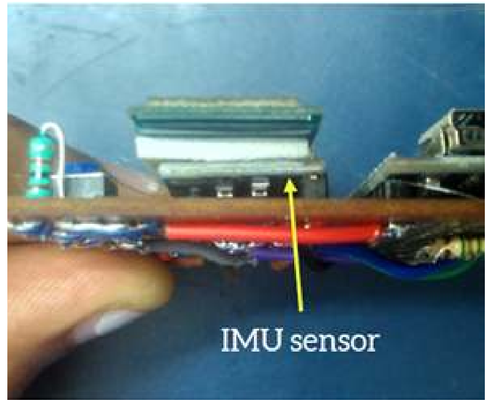
Goals

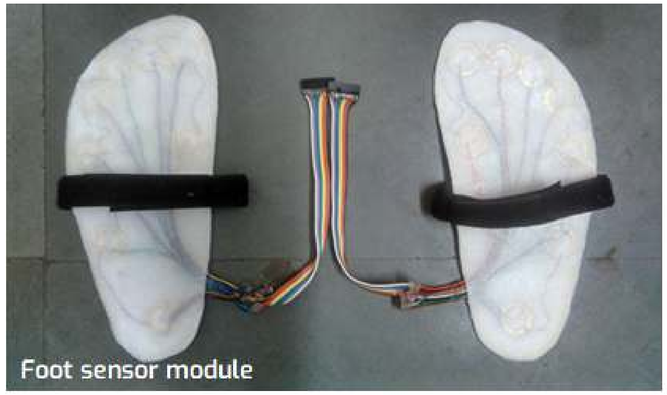
- Feasibility study to test whether IMU sensor is good enough to be used for our product.
- To know different errors that could arise in capturing the gait patterns due to communication lag of the prototype, location of the prototype on the foot, disturbances caused during walking.
- To check whether people can understand their gait patterns from graph plots, and the colors used in the plots.
- To capture and visualize gait patterns while walking barefoot and with footwear.

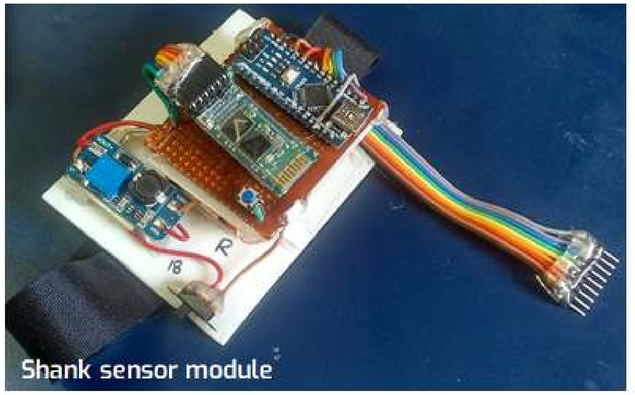
Initial Prototype

Prototype









Initial Prototype

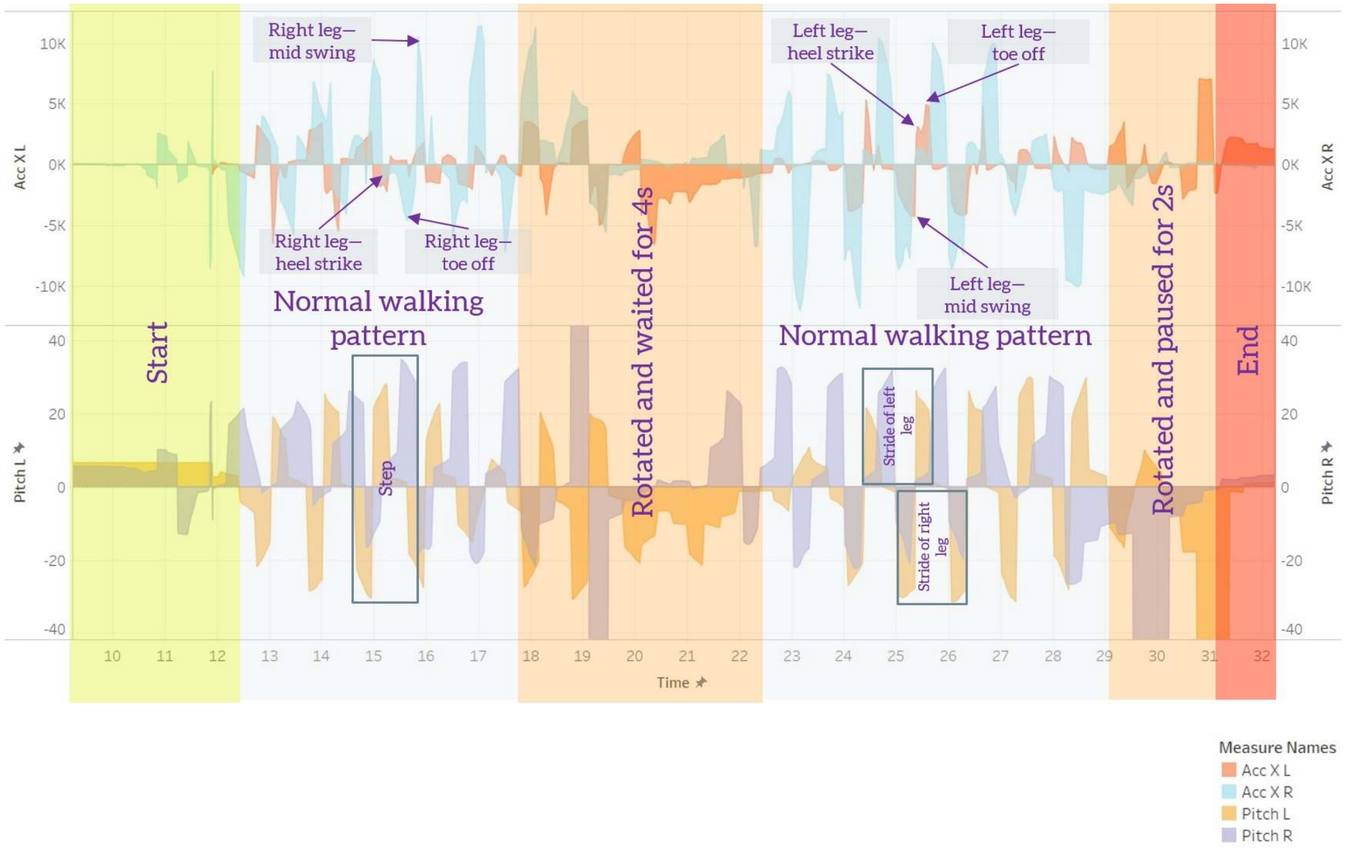
Prototype


Connecting shank and foot sensor modules


Overall look

Initial Prototype

Data Visualization



Initial Prototype

Feedback from Doctors

- Impressed by the fact that prototype cost less than Rs.1500.
- Small setup
- Applicable for multiple situations—ortho, physiotherapy, sports, developing customized shoe, showing a patient about her altered gait pattern against a normal gait pattern.
- For a normal person to understand, it is better to display the parameters through visuals of foot than displaying plots.
- Beneficial for bowlers, and athletes, looking for improving performance and technique.

Initial Prototype

Feedback from Doctors

- Cost of a gold standard gait analyzing equipment is around 20–30 lakhs, and it is expensive for patients to spend money on gait analysis.
- Number of gait analyzing labs are less in India.
- Increase the accuracy and validate against a gold standard gait analyzing equipment.
- After validation on accuracy, develop the prototype into a product, because, low cost gait analyzing devices are required currently in the Indian market. Therefore the product will be bought by athletes, doctors and hospitals.

Initial Prototype

Feedback from Doctors

- Do 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.
- Target the product for sports.

Conclusion

- IMU sensor is feasible enough to be used in our product.
- Captured and visualized the changes occurring in gait patterns when different type of footwear was worn.
- Participants positively agreed that wearing their footwear changed their gait patterns from their barefoot gait pattern.
- We also evaluated our initial prototype with doctors. With their feedback, we decided to focus our initial prototype towards running sport, and integrating a running technique and fatigue alert for running athlete.

Conclusion

- Next steps includes increasing accuracy, 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 assistance.

- 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 [9].”

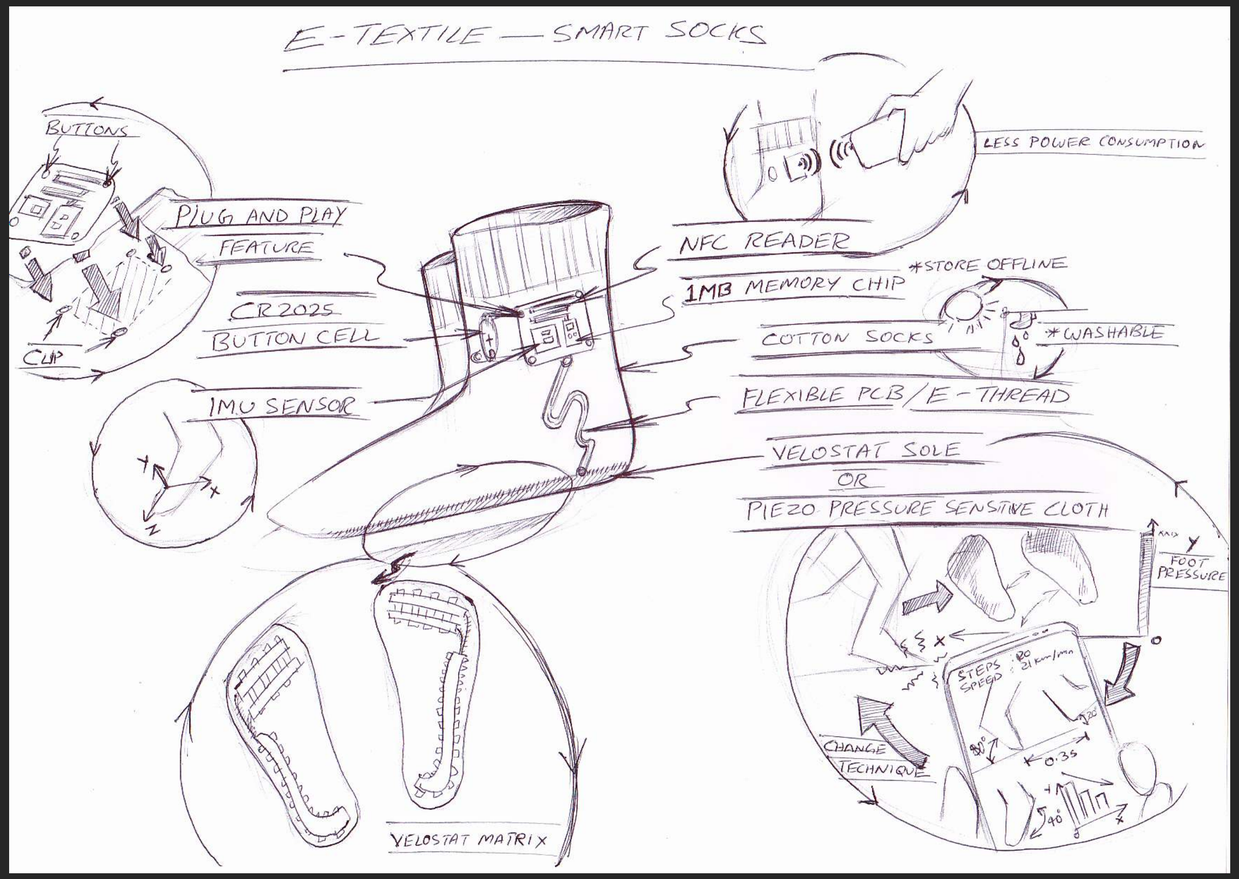
Ideations and Concepts

Ideations and Concepts

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.

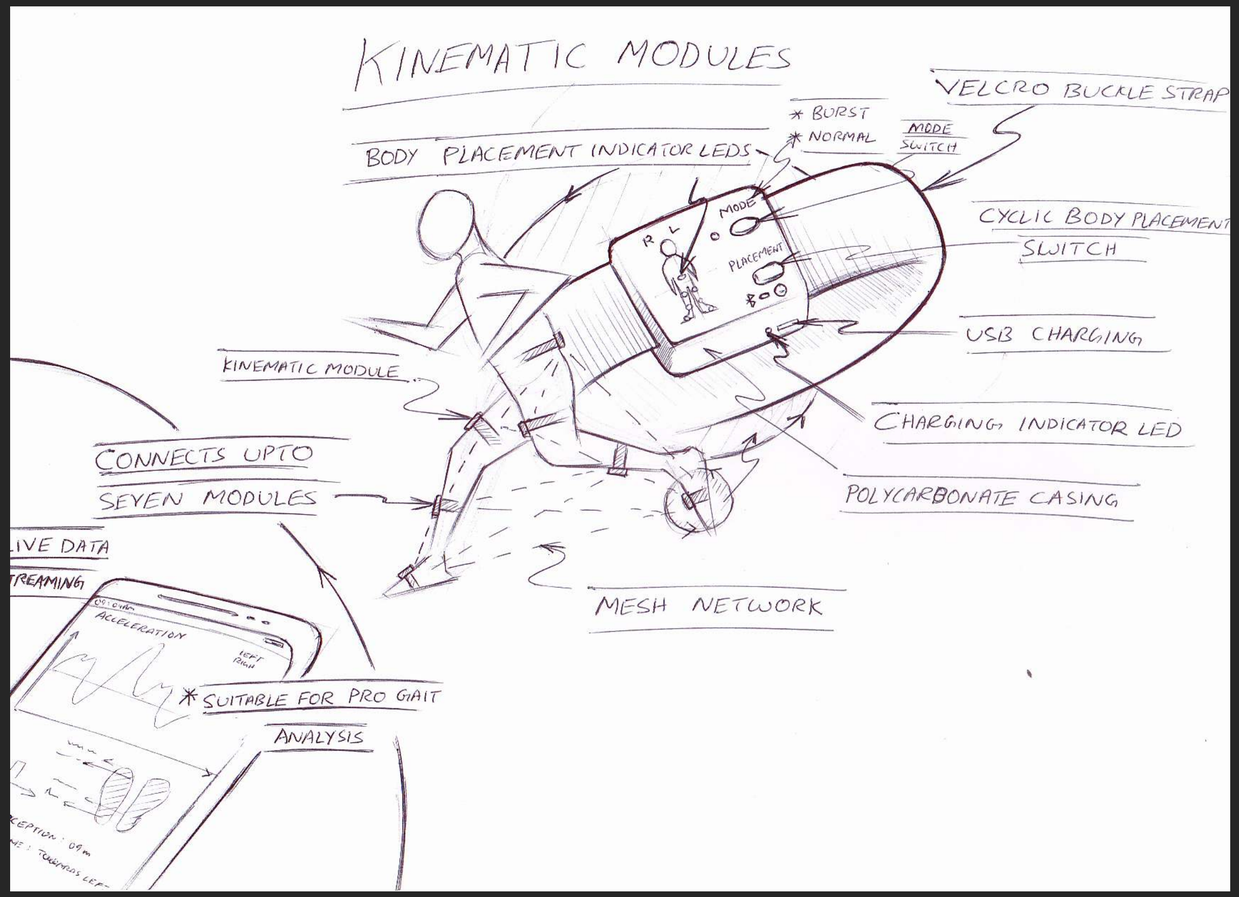


Ideations and Concepts

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

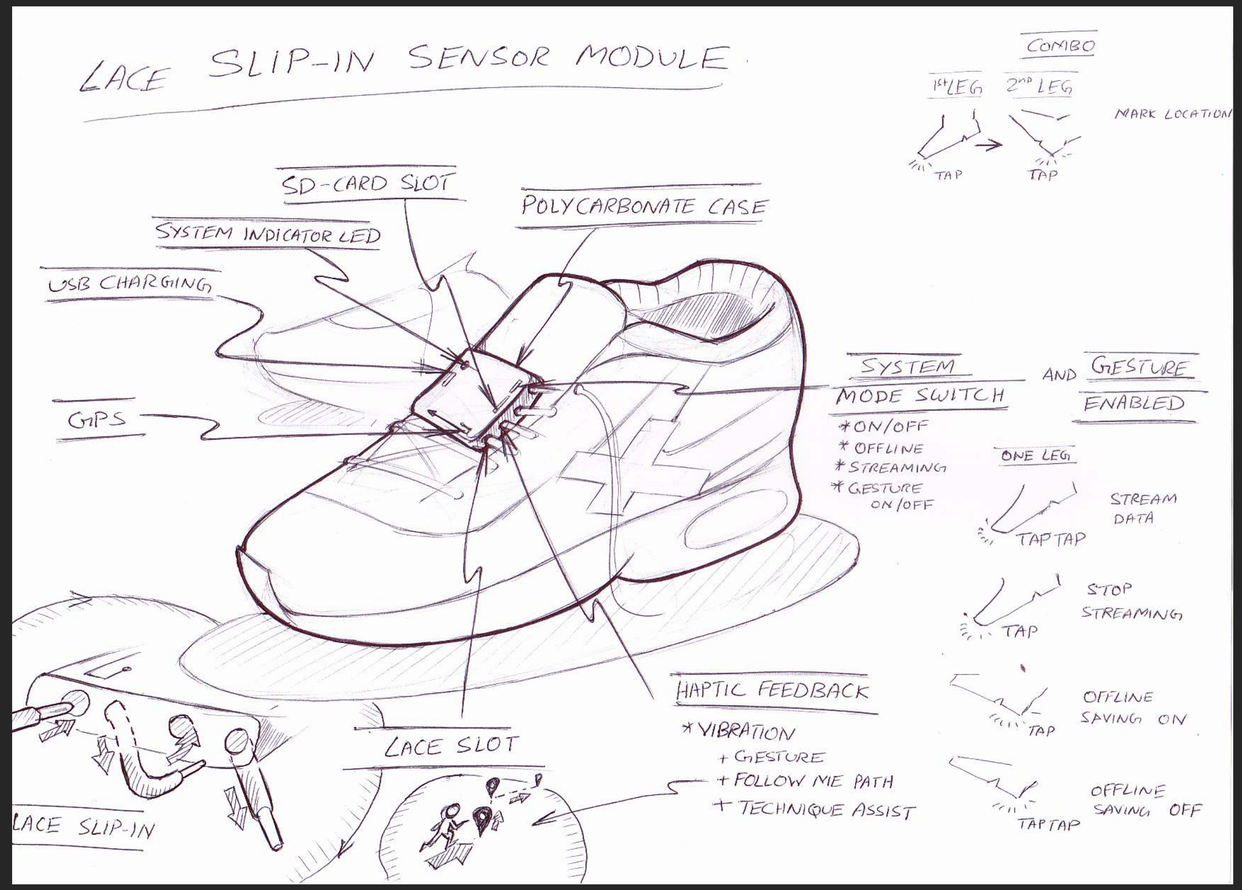


Ideations and Concepts

3. Lace Slip-In Sensor Module

Features

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

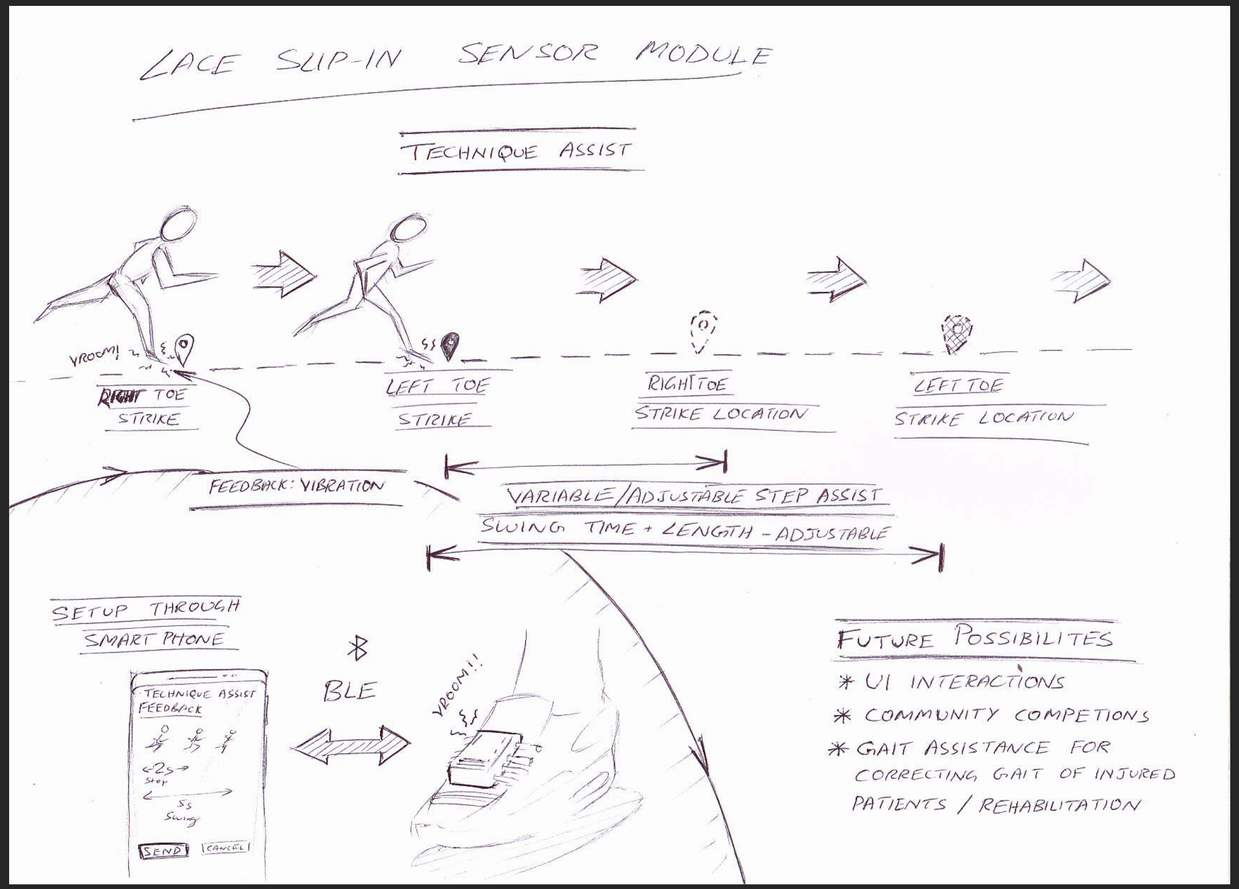


Ideations and Concepts

3. Lace Slip-In Sensor Module

Future Possibilities

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

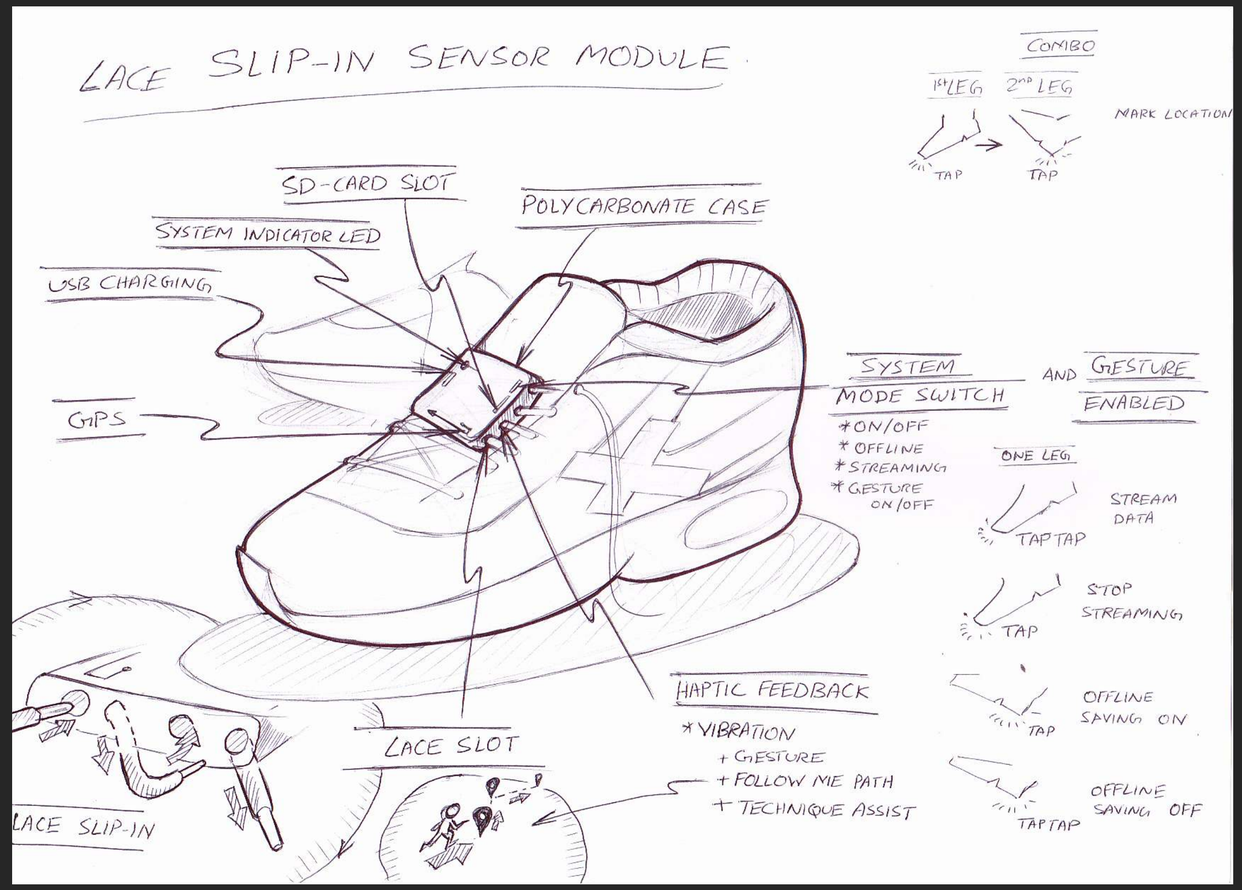


Ideations and Concepts

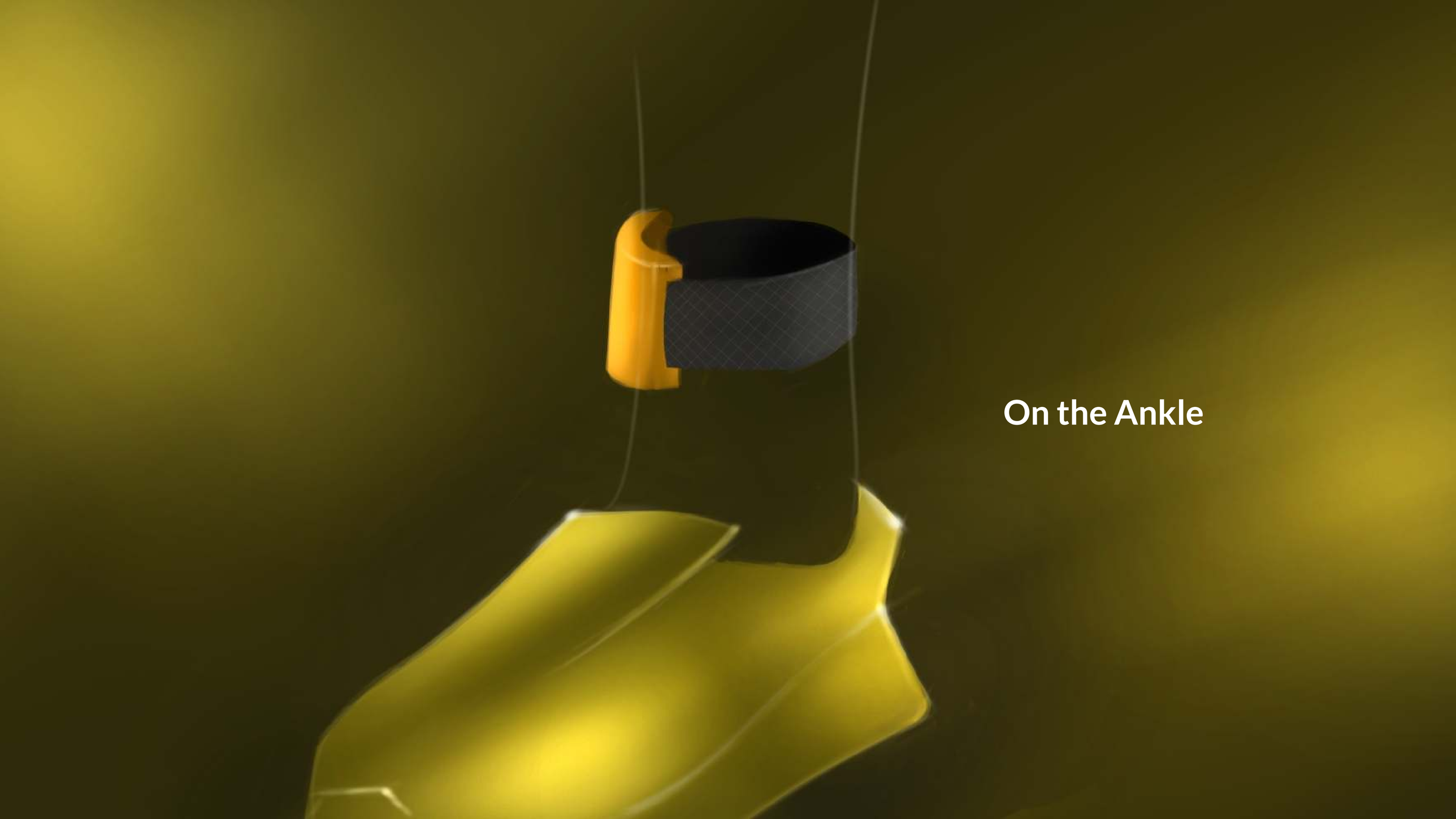
Final Concept—Lace Slip-In Sensor Module

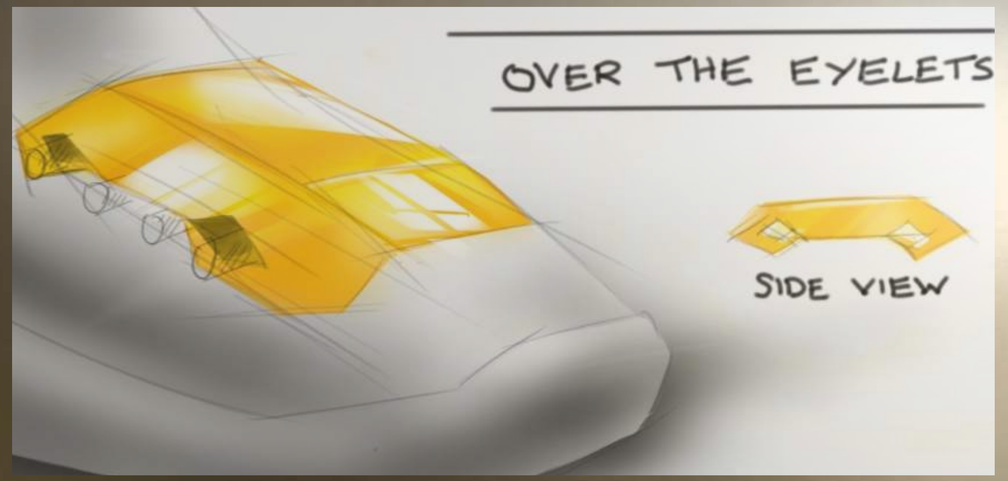
Advantages

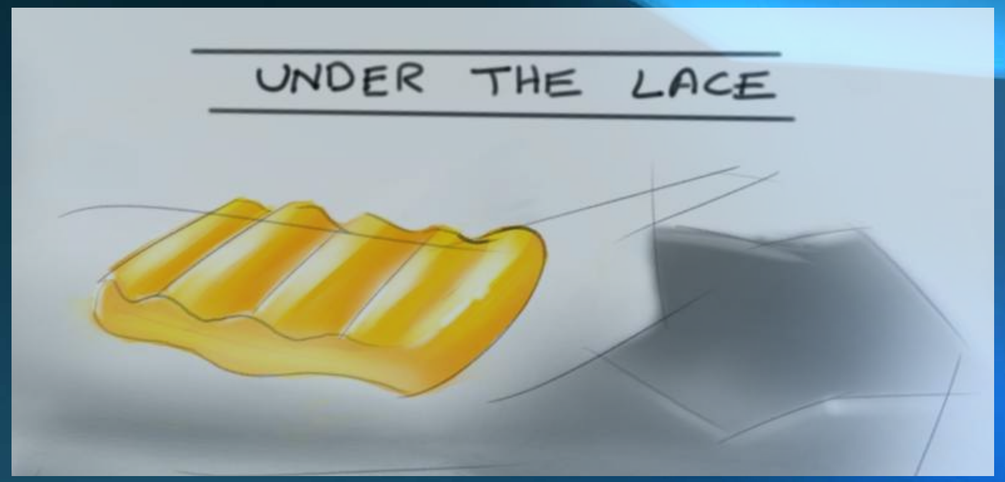
- Tied firm to the shoes.
- Requires 2 modules.
- GPS tracking.
- Offline and live data streaming capability.
- More useful for running athlete.

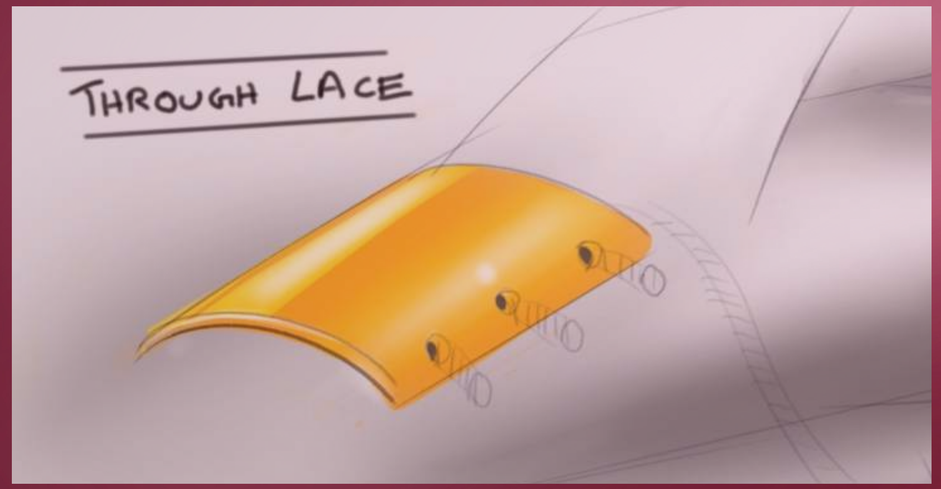


Product—Placement Exploration

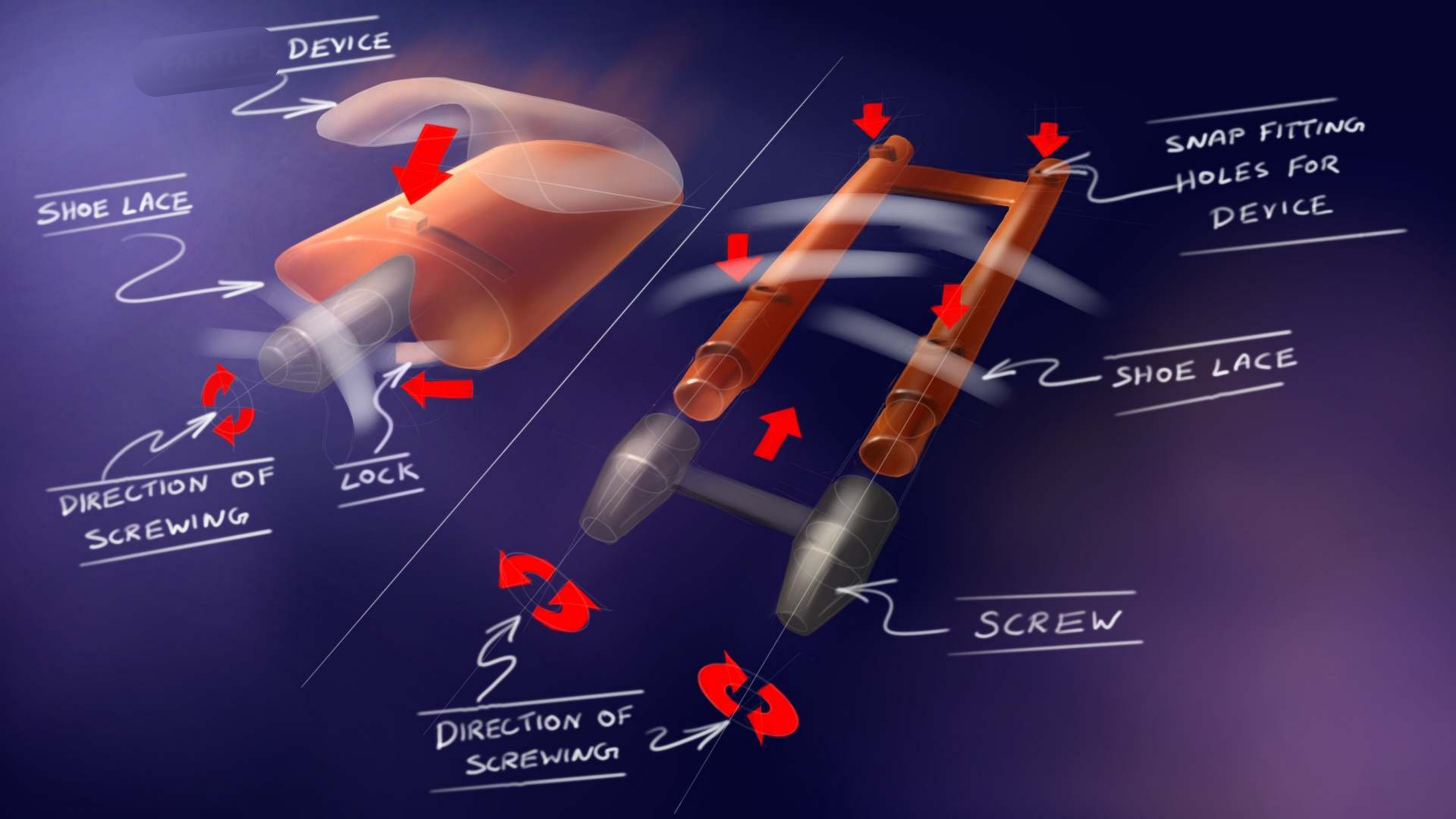

On the Ankle

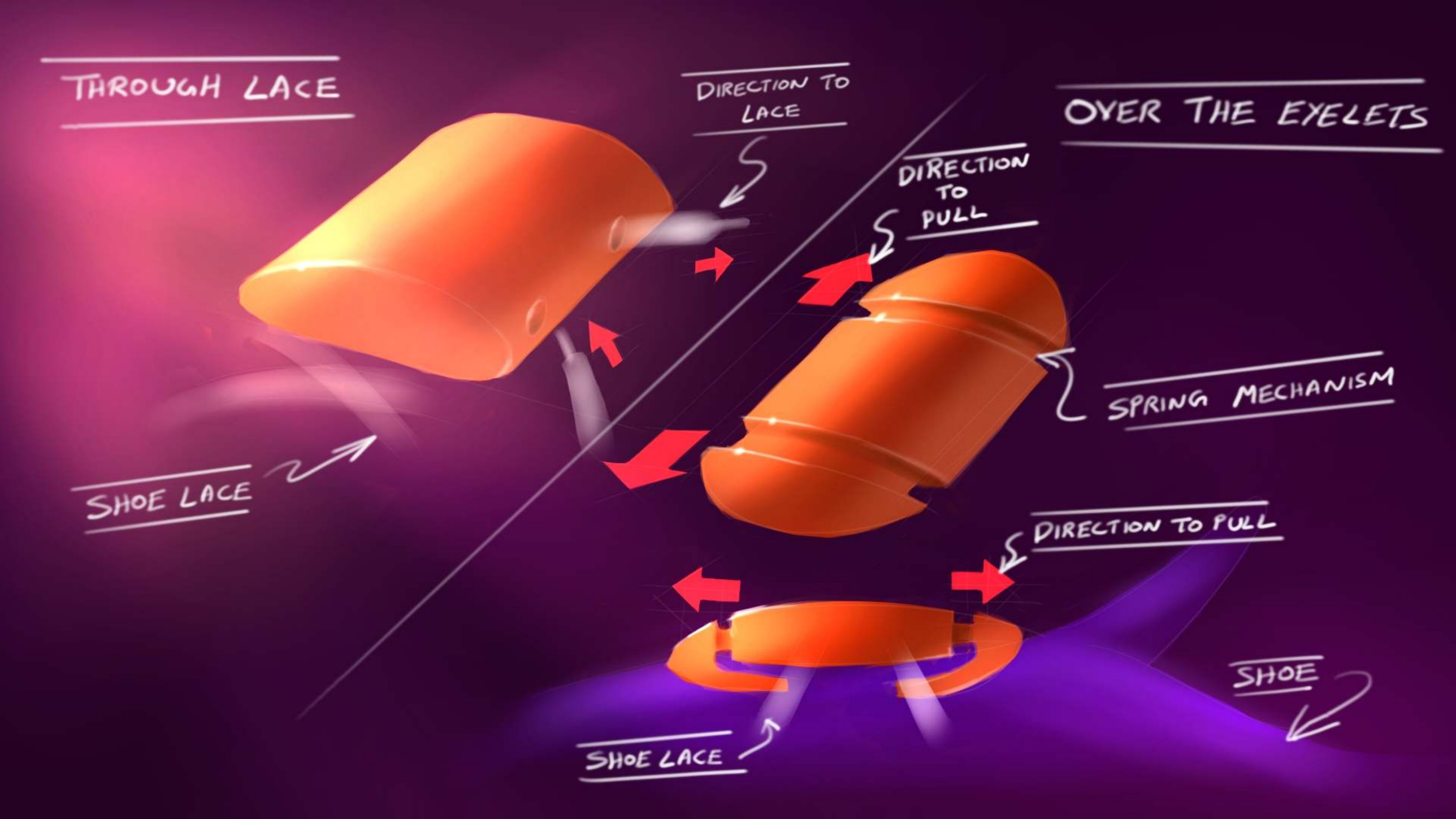

OVER THE EYELETS
SIDE VIEW


UNDER THE LACE


THROUGH LACE

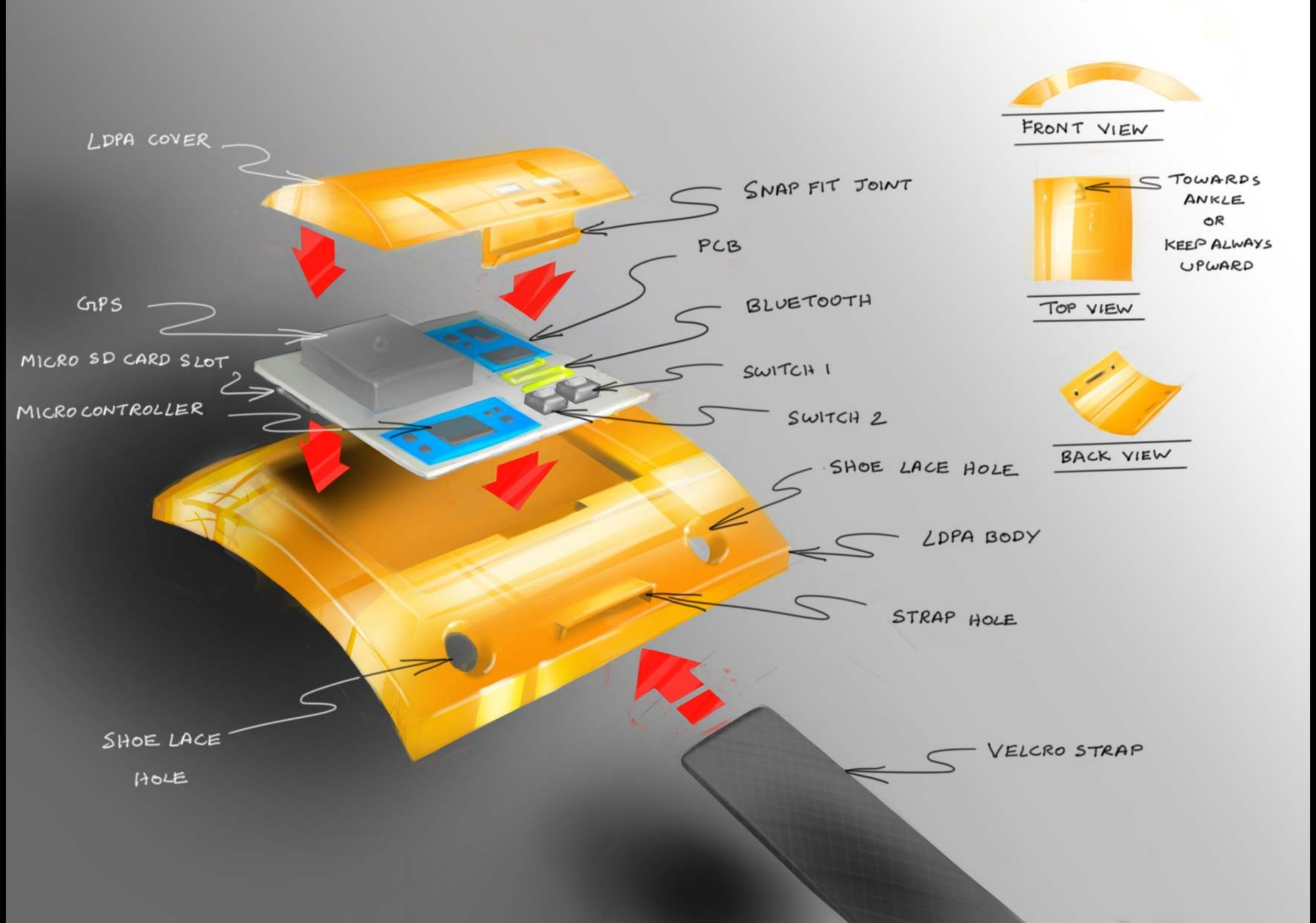
Product—Shoe Locking Explorations

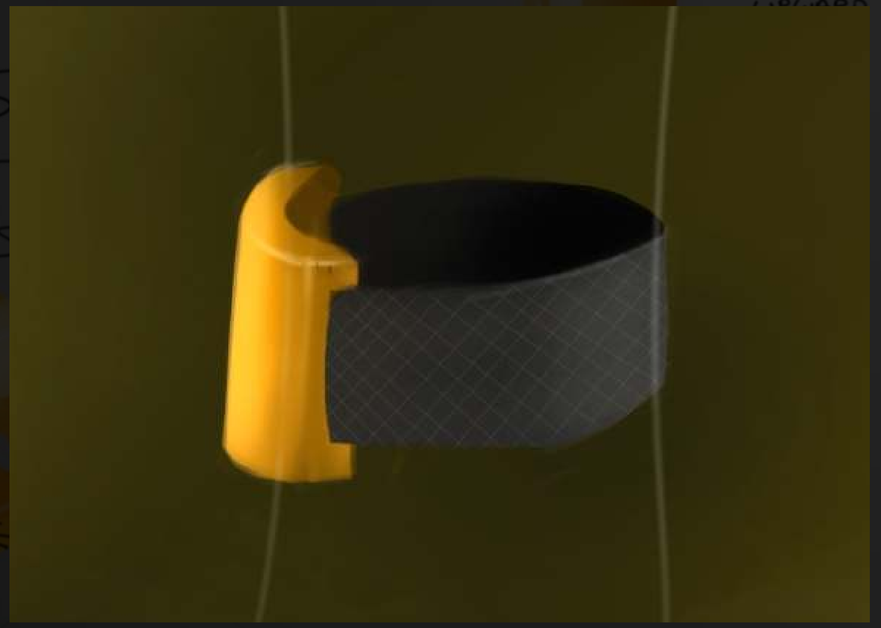

[redacted] DEVICE
SHOE LACE
DIRECTION OF SCREWING
LOCK
SNAP FITTING HOLES FOR DEVICE
SHOE LACE
SCREW
DIRECTION OF SCREWING


THROUGH LACE
DIRECTION TO LACE
OVER THE EYELETS
DIRECTION TO PULL
SPRING MECHANISM
SHOE LACE
DIRECTION TO PULL
SHOE
SHOE LACE

Product—Form Explorations

Proposed Product


LDPA COVER
SNAP FIT JOINT
PCB
GPS
BLUETOOTH
MICRO SD CARD SLOT
SWITCH 1
MICRO CONTROLLER
SWITCH 2
SHOE LACE HOLE
LDPA BODY
STRAP HOLE
SHOE LACE HOLE
VELCRO STRAP
FRONT VIEW
TOWARDS ANKLE OR KEEP ALWAYS UPWARD
TOP VIEW
BACK VIEW



Proposed Unique Features

- **Contact Time** (duration of the contact between the foot and the ground)

- Step Rate, Stride Length, Foot strike Type (part of the foot that strikes the ground first: heel, midfoot or forefoot), **Heel lift**.

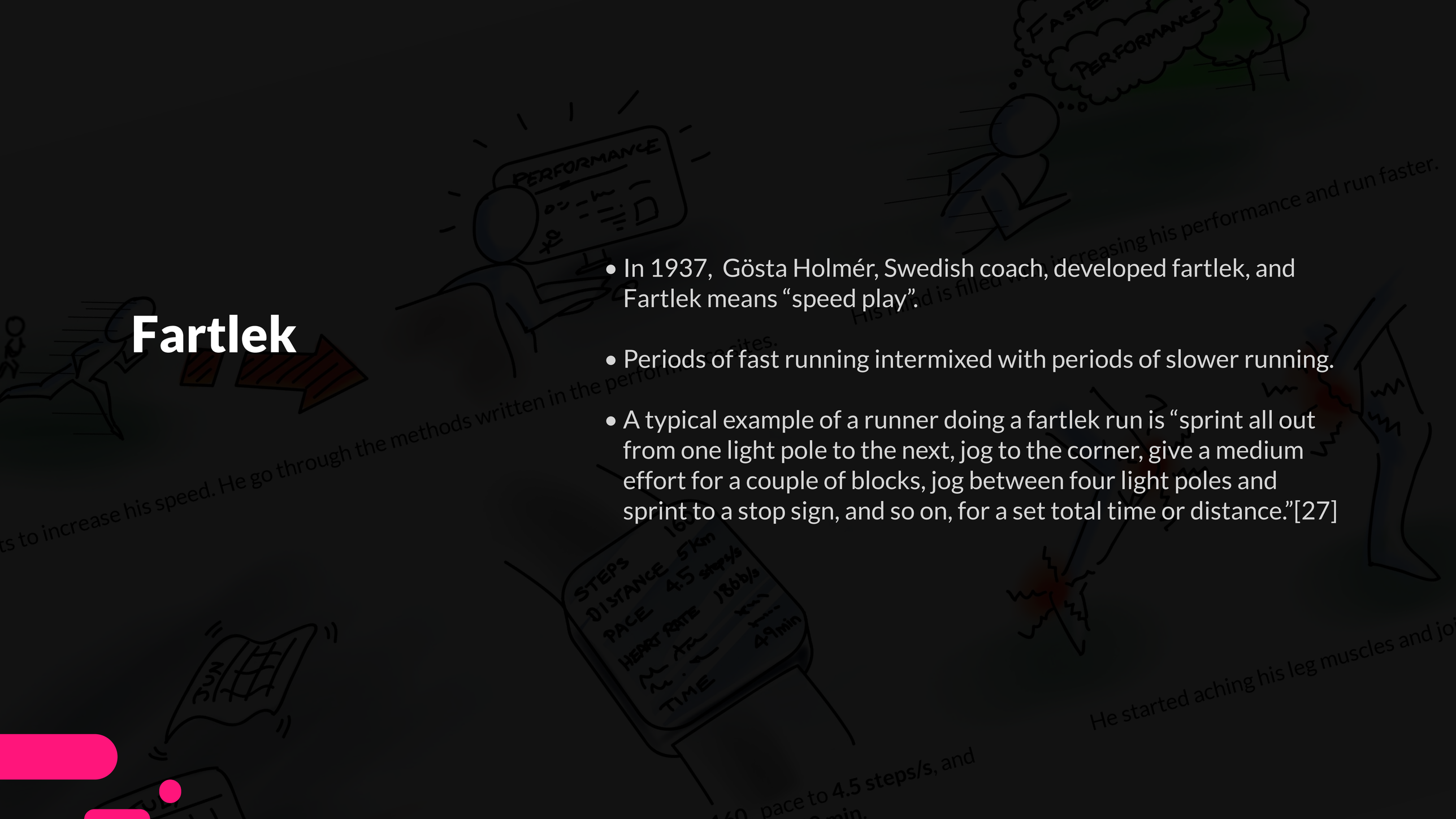
- **Max Pronation Velocity** (maximum angular rate at which the foot pronates between foot strike and the point of maximum pronation),

- **Pronation Excursion** (total angular range the foot rolls inwards)

- **Stance Excursion** (total range of pitch angular movement between foot strike and toe off).

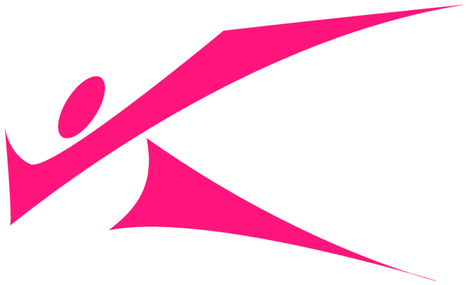
Fartlek

- In 1937, Gösta Holmér, Swedish coach, developed fartlek, and Fartlek means “speed play”.
- 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]



Product Name

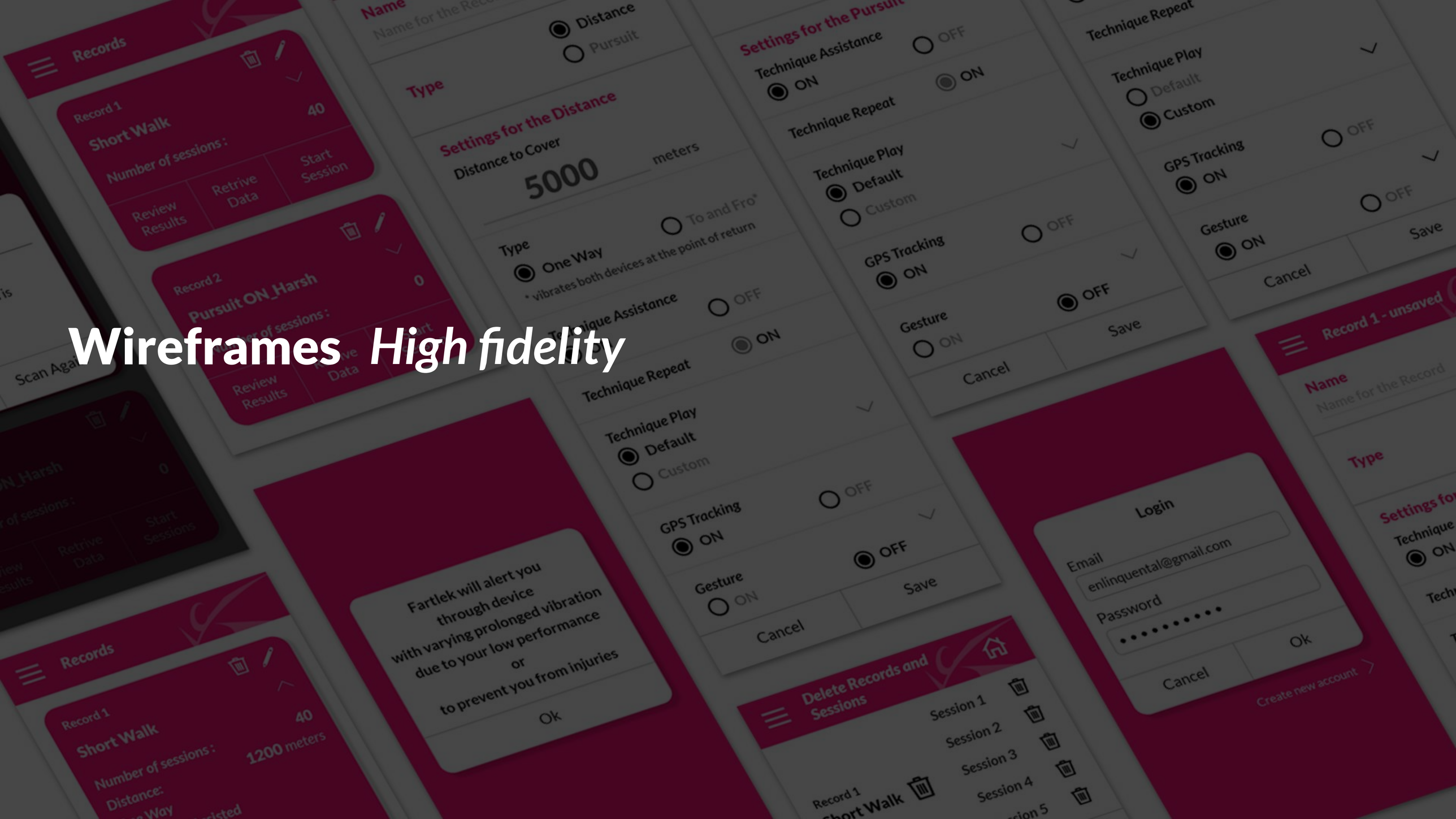
Slingshot™



Logo inspired from the posture of a running athlete initiating a sprint.

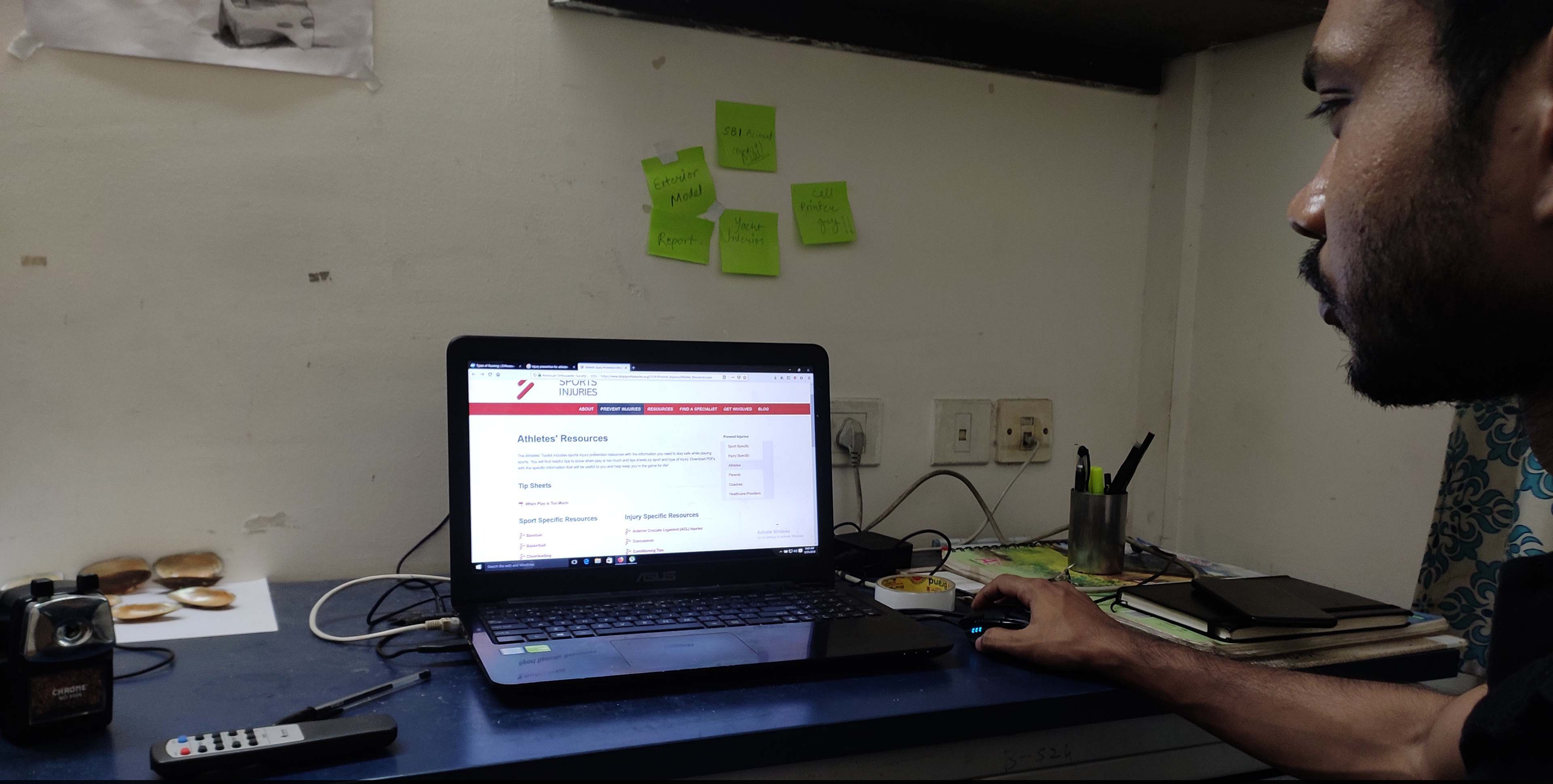
Wireframes


LOGIN
email
password
OK
CANCEL
CREATE NEW ACCOUNT
RECOVERY
DISTANCE
TIME
5min
10min
START OF SPRINT
SPEED
DISTANCE
1500
meters
TIME
VIBRATION INTERVAL
30ms
10ms
90ms
EASY RUNNING
DISTANCE
200
DISTANCE
200
meters
TIME
VIBRATION INTERVAL
600ms
600ms
DISTANCE
TAP
OFFLINE ON
TAP
OFFLINE SAVING OFF
TAP TAP
BEFORE 1ST LEG
2nd LEG
MARK LOCATION
TAP
TAP
SAVE
CANCEL



Wireframes *High fidelity*

Concept



User may know about different techniques of running and fatigue prevention through internet

He gets to know about Slingshot from friends and through internet, because of its unique features from fit band. So he orders it online and gets it delivered to him.

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

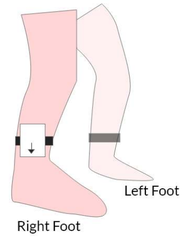
Continue

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

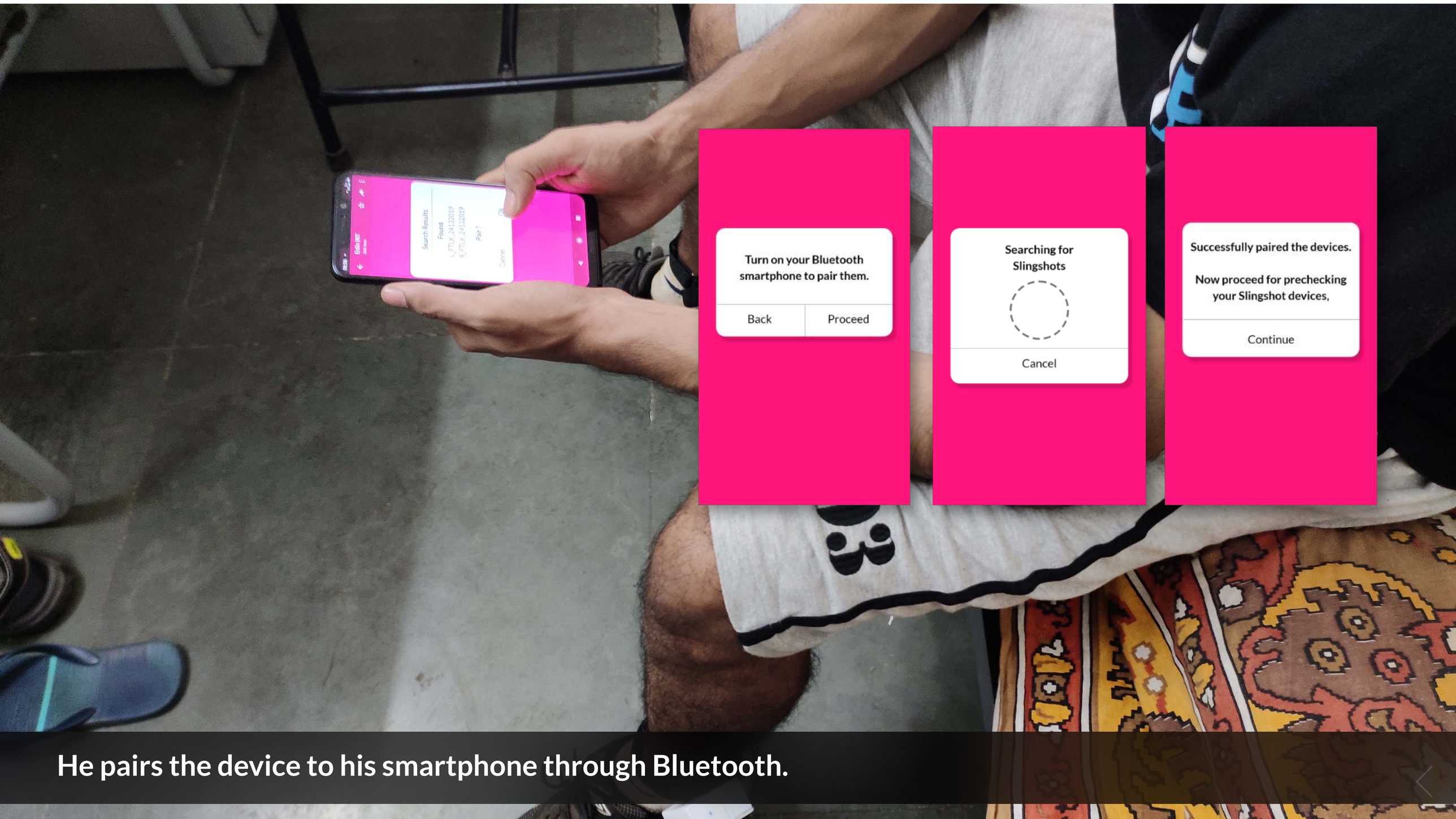
Fix the devices on your respective foot close to the ankle as shown.



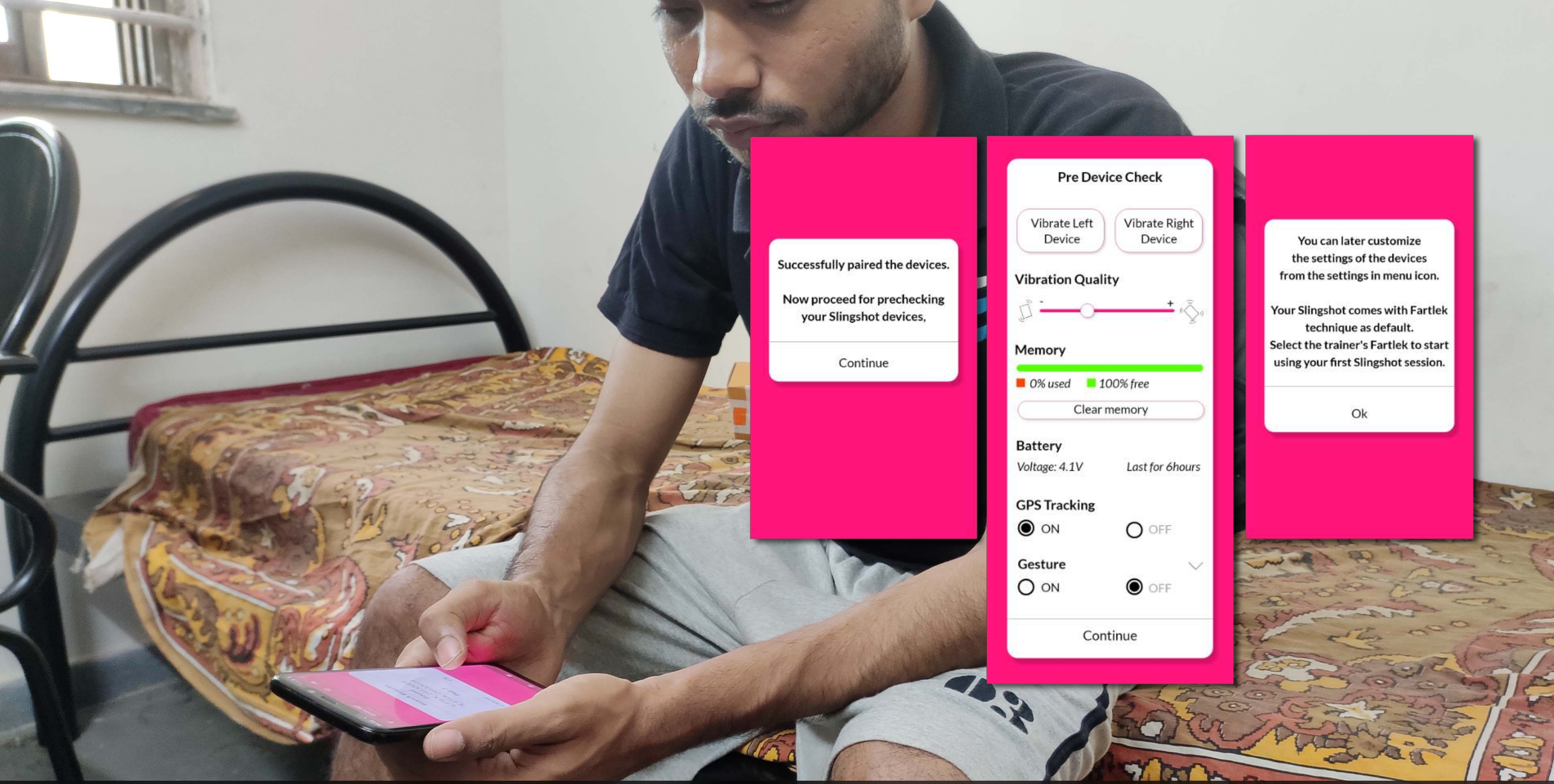
Make sure the arrow marks labelled on the devices are pointing towards ground.

Back | Proceed

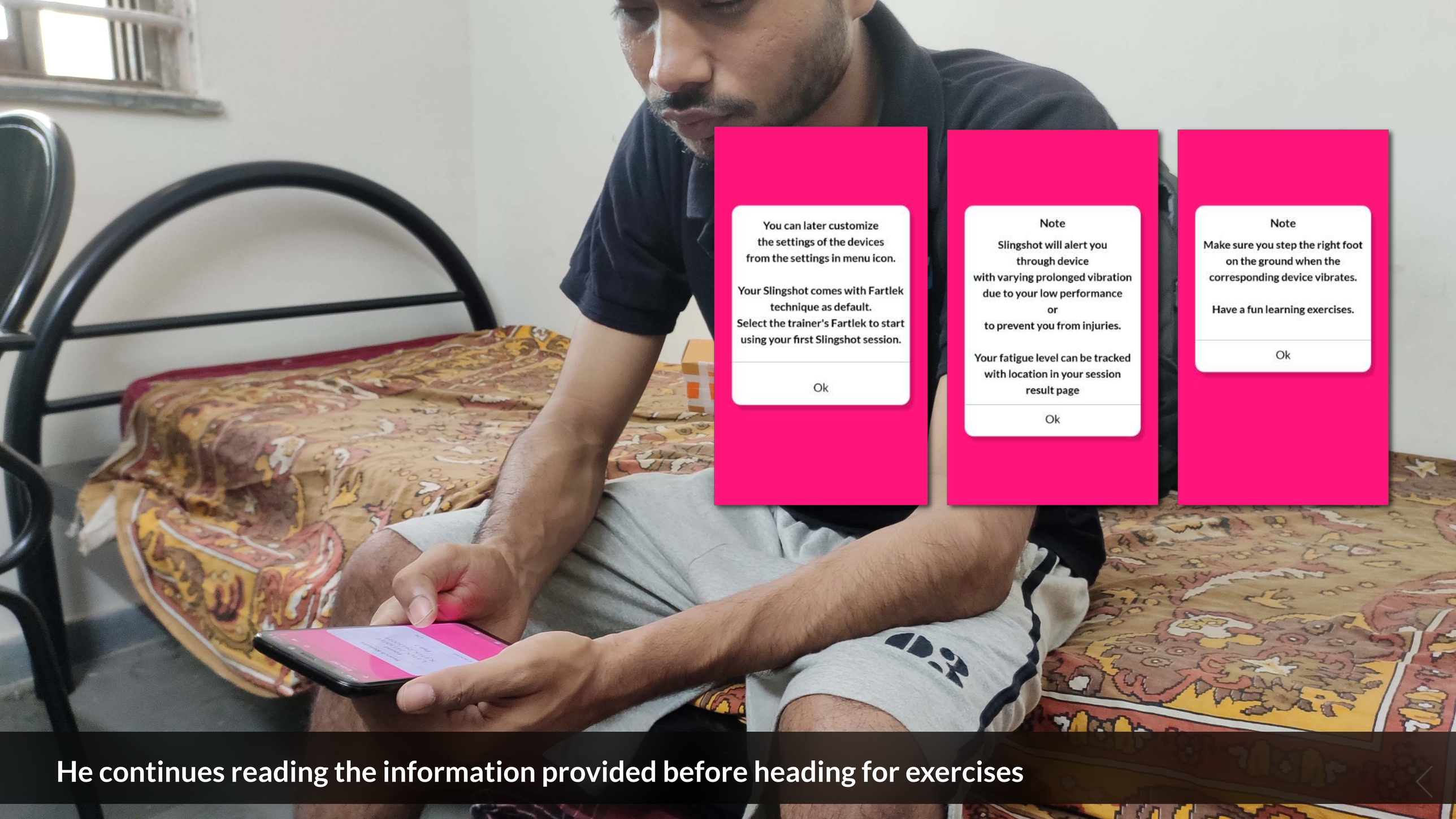
He goes through the instructions



He pairs the device to his smartphone through Bluetooth.



He continues reading the information provided before heading for exercises



He continues reading the information provided before heading for exercises

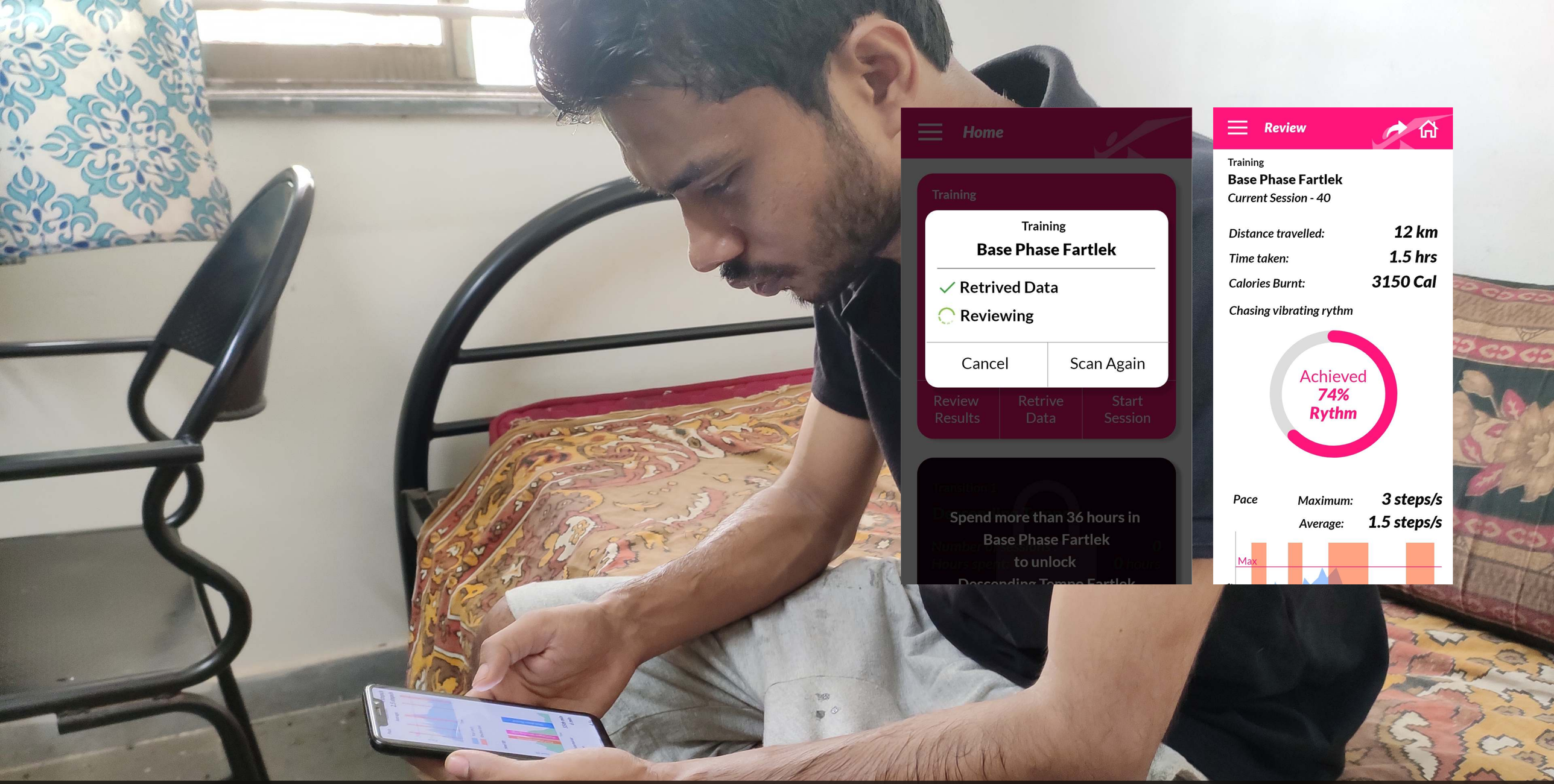
He selects the training session and gives it a try.

He tries to maintain the rhythm of running with the help of the vibrations of the devices

He experiences pain in his calf muscles, but continues to run.

His devices alert him of possible fatigue through varying vibrations. So pauses for sometime to get some rest.

After a period, the devices come online and he continues his exercise



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

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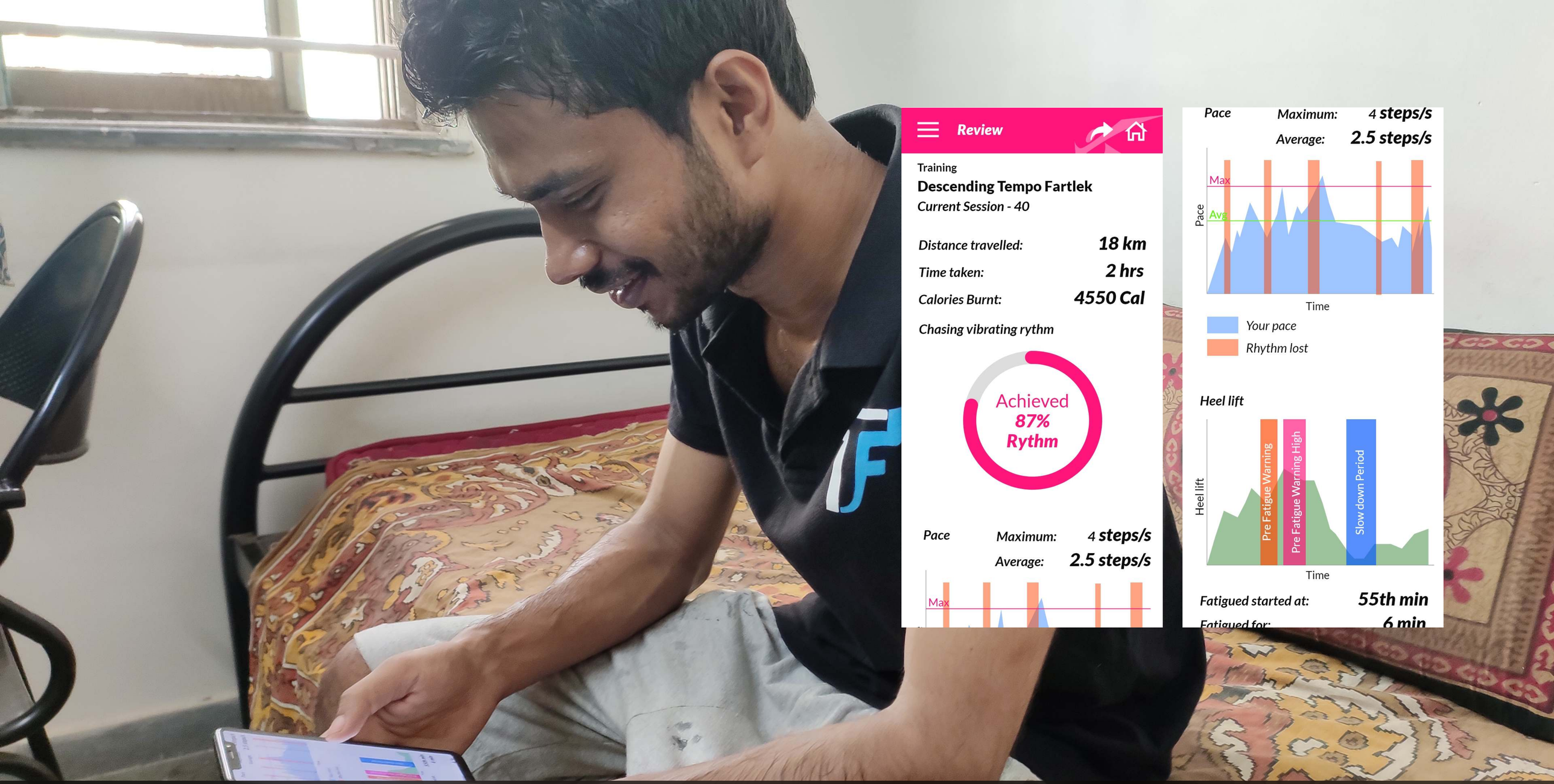
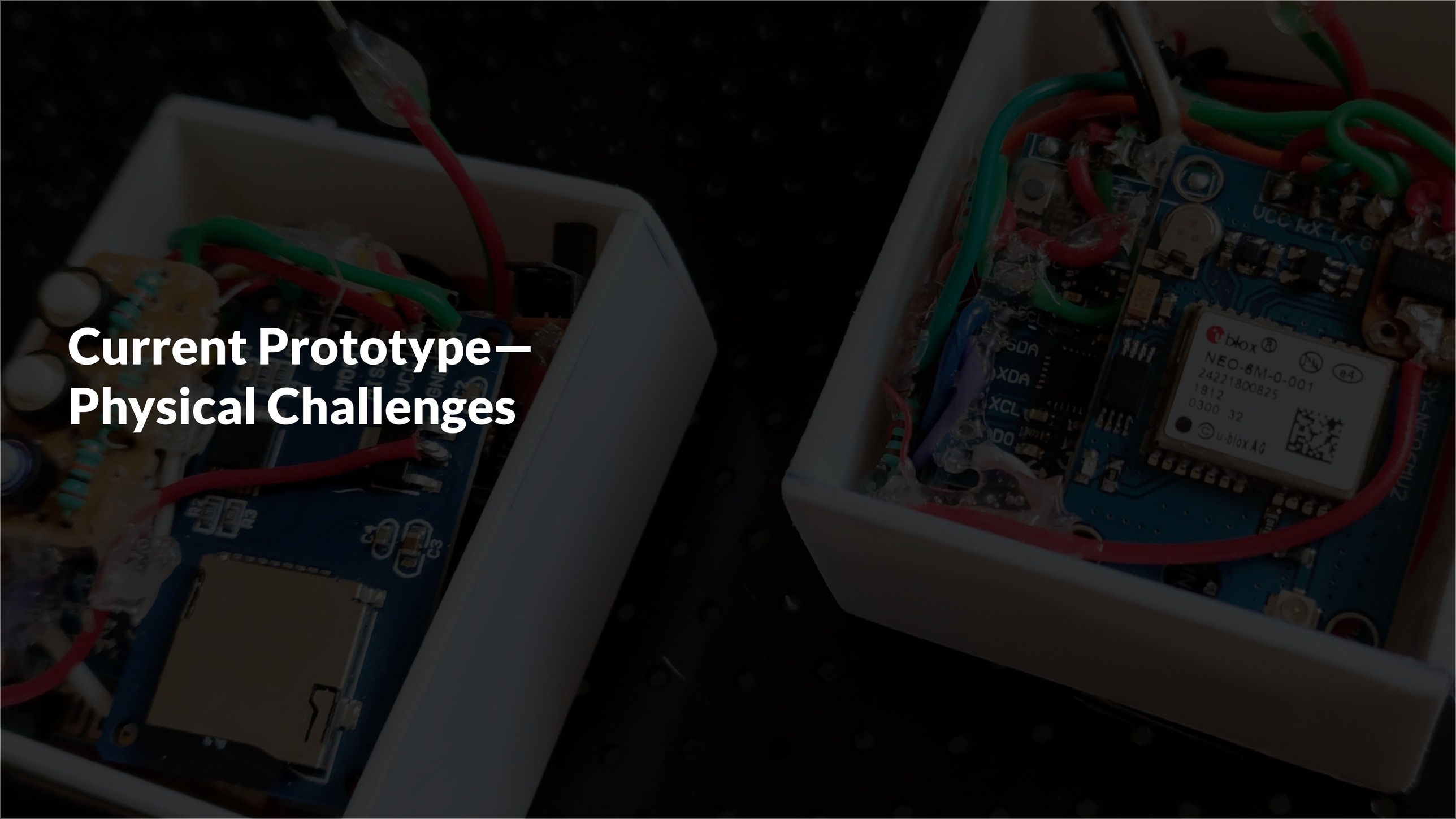


After one week of exercise, he finds happy to see his improved performance through Fartlek technique

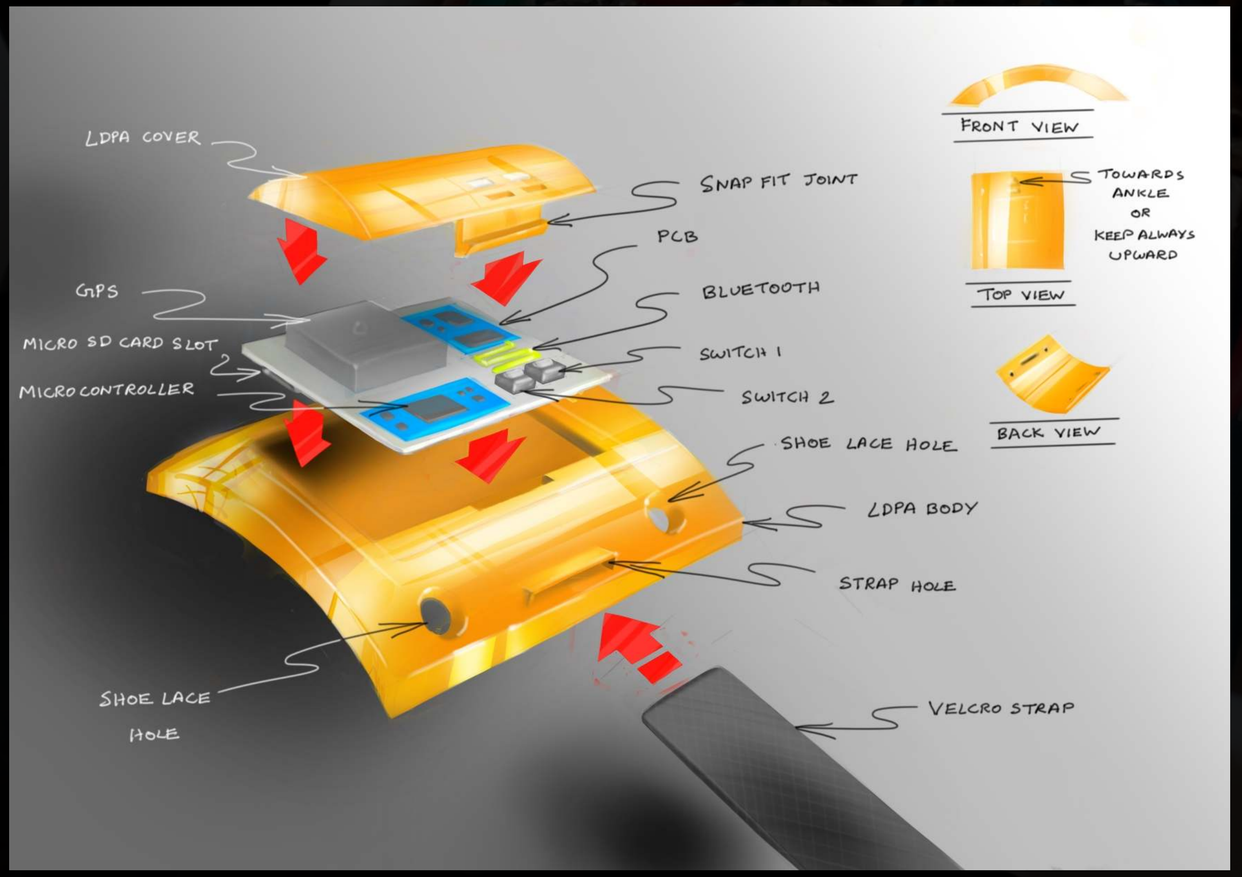
Current Prototype—
Physical Challenges



Ideal Prototype

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



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, GLONASS
Storage: 4GB
Battery: 3.7v 300mAh Lipo

Samsung Gear Sport—Overall look on a shoe

Samsung Gear Sport—Overall look on a foot

Existing Products

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

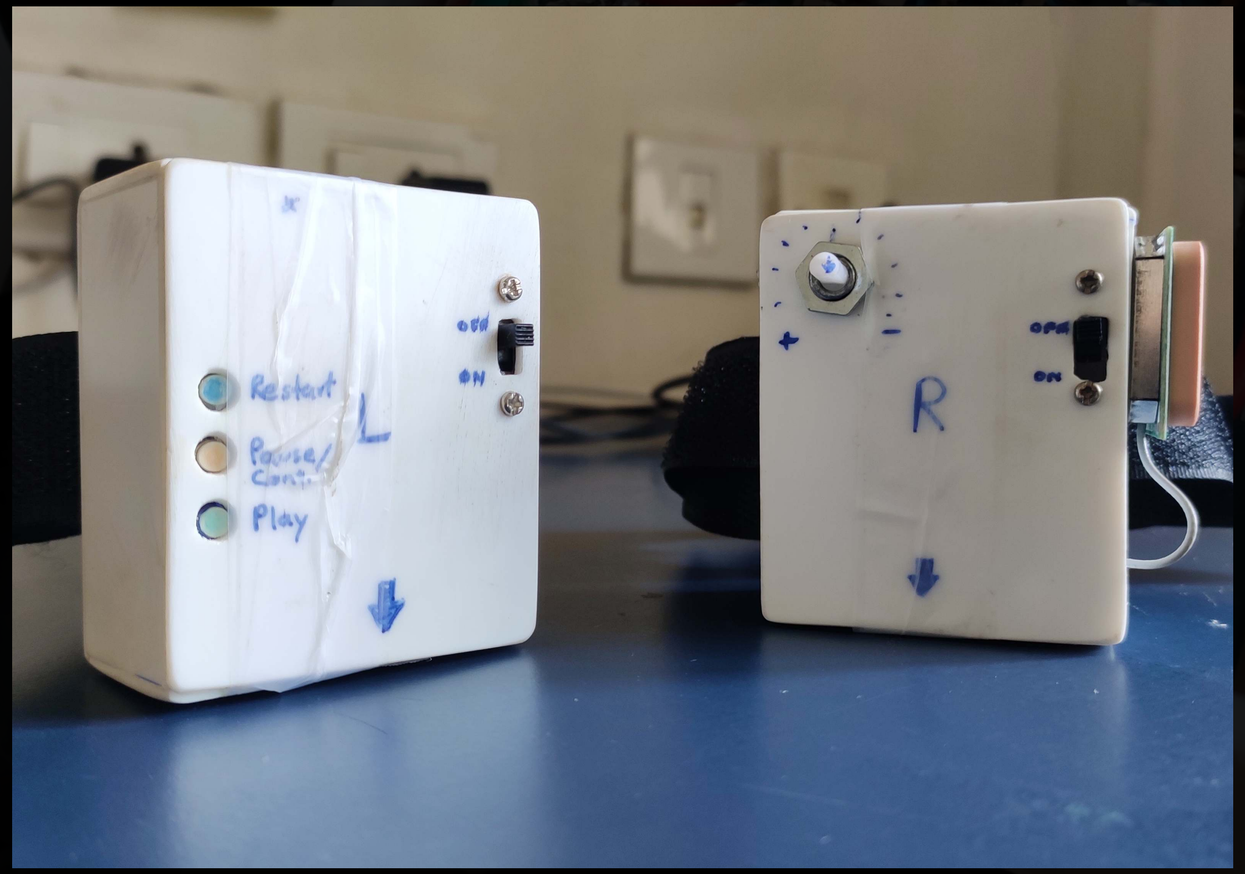
MI Band v1—Overall look on a shoe

MI Band v1—Overall look on a foot

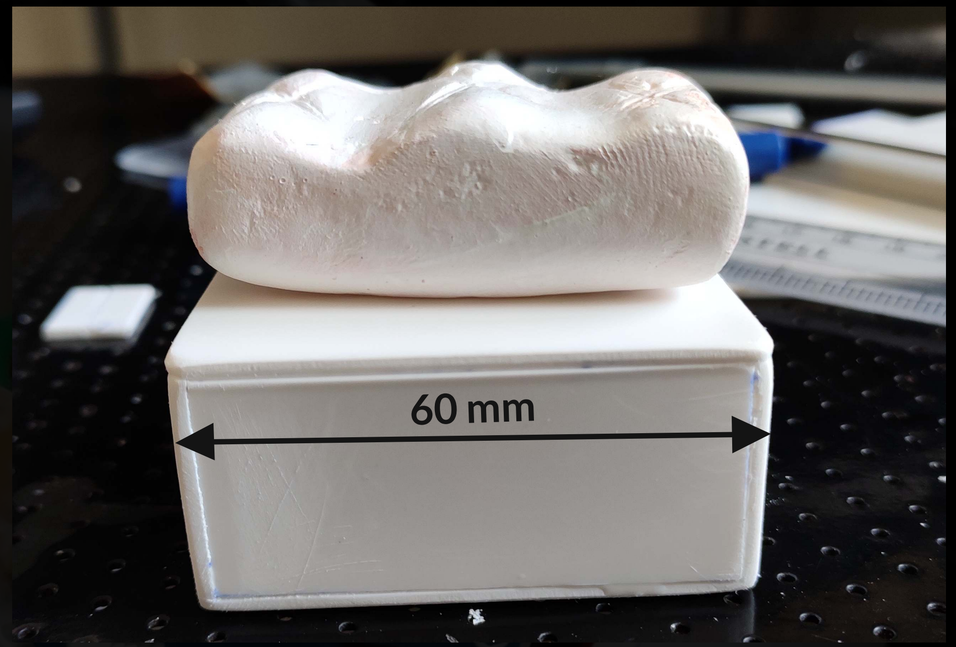
Currrent Prototype

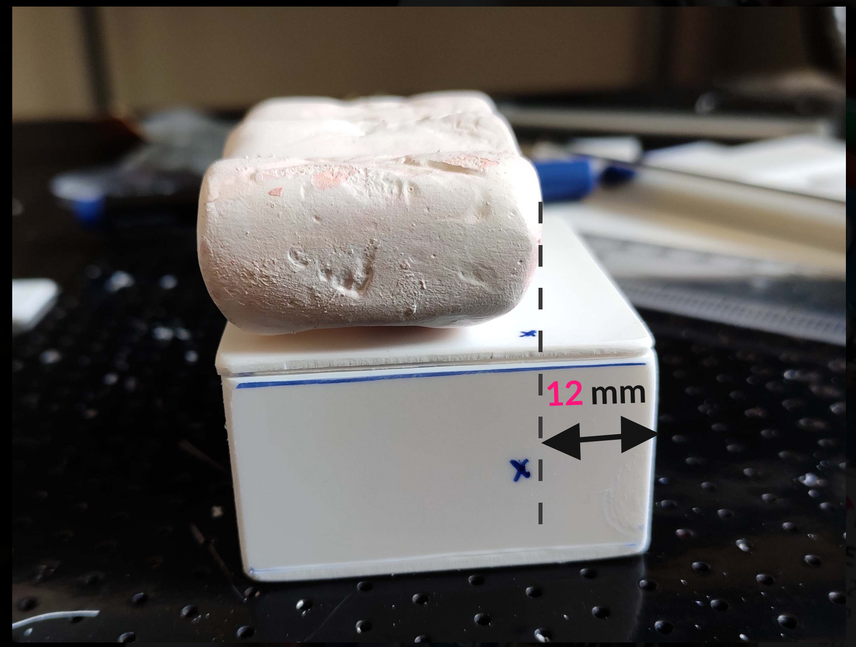
Pre-final Product—Specifications

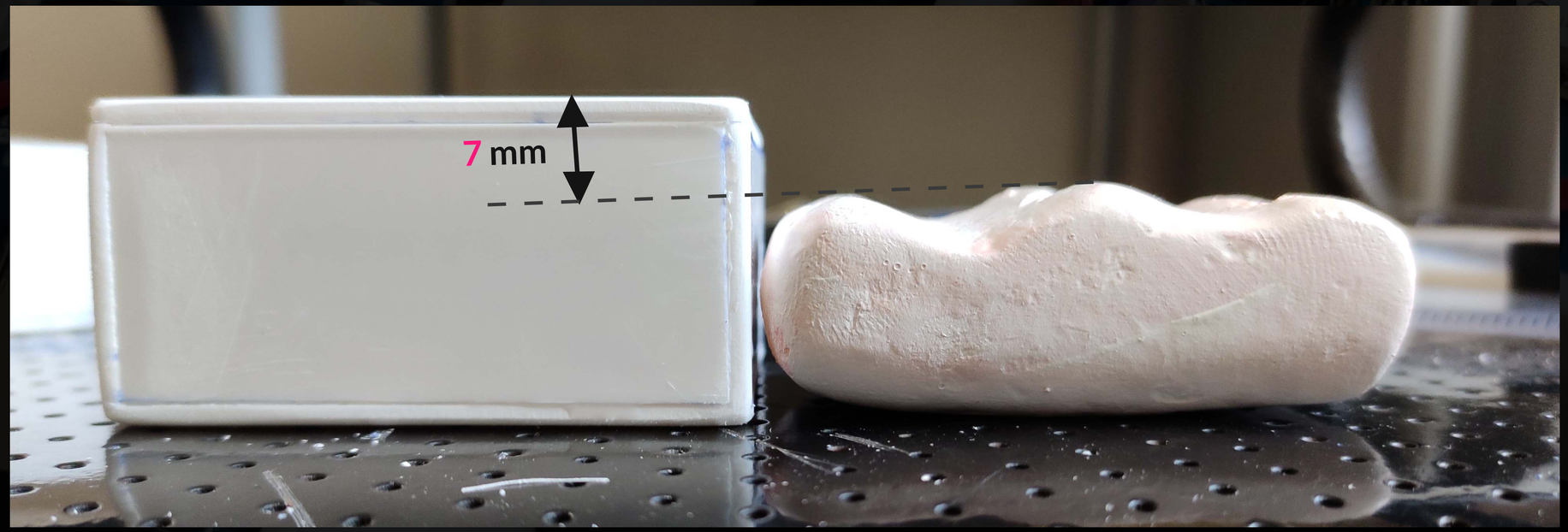
Outer case material: Styrene
Dimensions: 60 x **50** x **30** mm
Weight: **56**g
Display: none
Connectivity: Bluetooth 2.0
GPS: yes
Storage: 2 GB
Feedback: vibration
Battery: 3.7v 360mAh lipo battery



Dimensions







Weight

Weight of the device for left foot

Weight of the device for right foot

Current Prototype vs Exisitng Products

Pre-final Product

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

Samsung Gear Sport

Dimensions: 42.9 x **44.6** x **11.6** mm
Weight: **50**g
Display: AMOLED
Connectivity: Bluetooth 4.*2*
GPS, GLONASS
Storage: 4GB
Battery: 3.7v 300mAh Lipo

MI band v1

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

Evaluation

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

Place:
IITB campus

Time:
20 minutes per user

Evalaution
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.

Evalaution
Method

- 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.

Evalaution
Questions

1. Did the system affect the jogging/running pattern?

2. Comfortability of the product

3. How challenging it was to match the vibrational feedback given by the device?

4. Understanding of the visualization

5. Effects of introducing a new running technique and the changes in performance

6. Potential of the device

7. Pros, cons, areas of improvement, adding/removing features, etc.

Evalaution

Feedback

Information on heel, mid and toe strike, and fatigue information were new and were good features of the product.

While walking, the vibration feedback was sensible otherwise on running it was not sensible.

The strap was not comfortable and strapping should be easy.

Weight of the product was fine.

The missing dimension of the x-axis(time) was not intuitive.

Evalaution

Feedback

Did not introduce the new technique, neither was challenging nor improved the performance from the device due to less skin sensitivity to the vibration feedback from the device, during running.

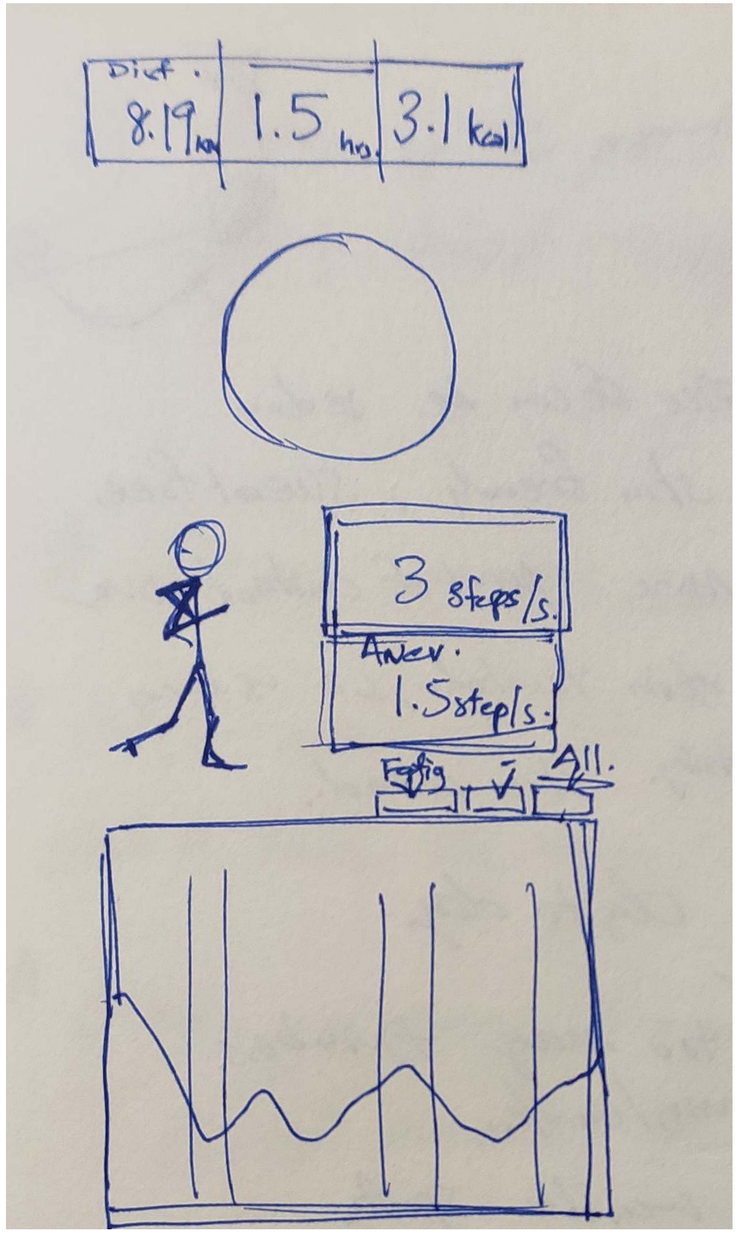
For the regular athlete, the application was understandable as he had tried out other fitness tracking devices and applications.

For the general female athlete, graph and visualizations were not understandable as she hasn't used any fitness tracking devices and applications.

Live feedback on data collected was necessary—an indication that product was functioning properly.

Evalaution

Feedback



Evalaution

Feedback—*Takeaway*

Improving the visualization.

Area to explore on different ways the rhythmic pattern can be given to the running athlete.

Displaying the parameters and values on the product.

Skin friendly/sweat free pad which that increases the skin contact with the product.

Interested to use and test out the product as it had unique features.

Conclusion

We achieved in developing an IMU based product which successfully captured and visualized the gait patterns.

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.

The product will be improved and upgraded in the near future, to create a positive influence among joggers/running athlete.

Acknowledgement

I would like to thank my guide, Prof. Girish Dalvi, for his extreme support, valuable suggestions and guidance throughout my project.

Special thanks to Prof. G.G. Ray for sharing his experiences, knowledge and suggestions on gait analysis.

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Thanks to all my IDC friends for supporting me, giving valuable suggestions, and helping me out when needed.

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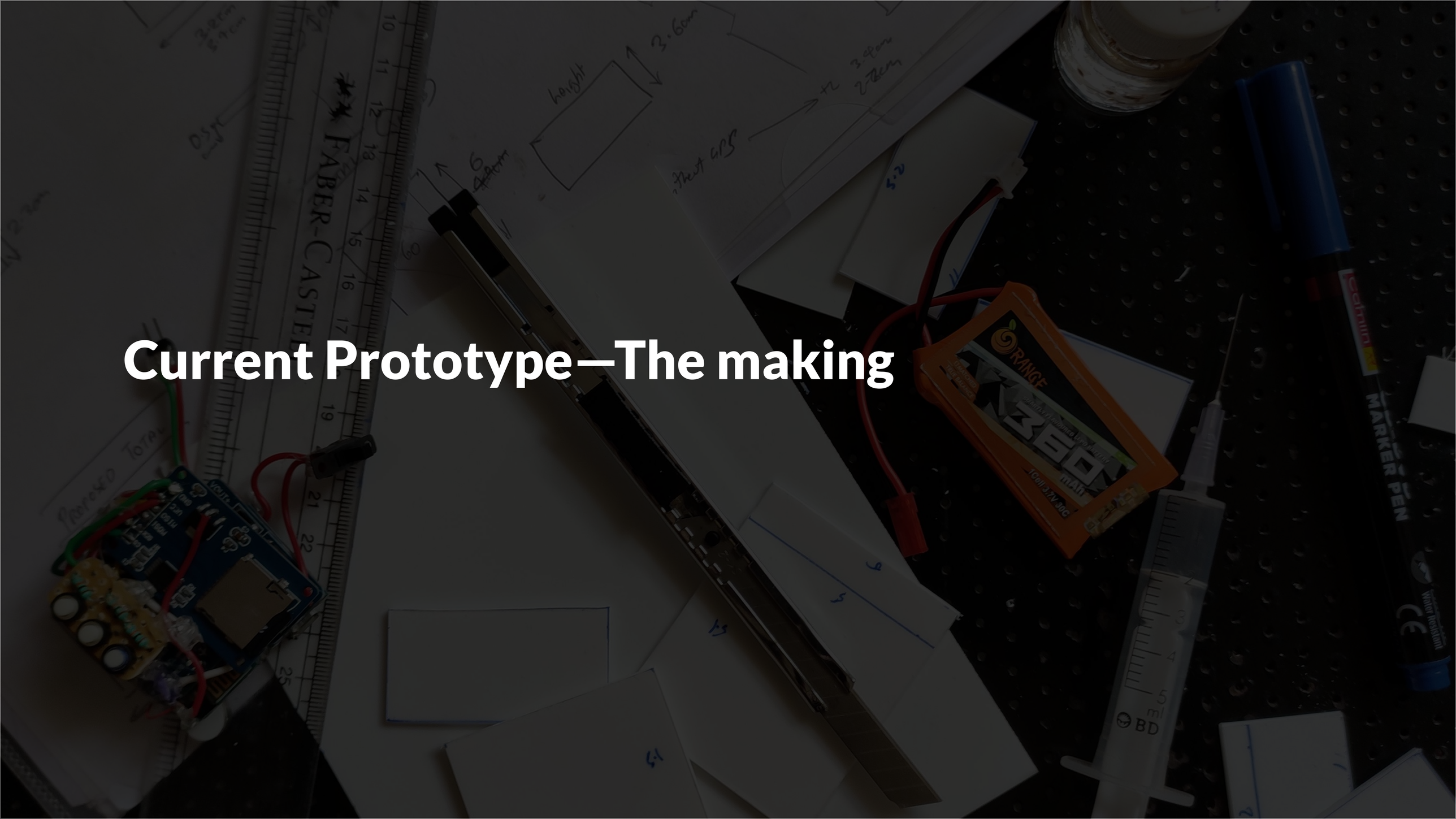
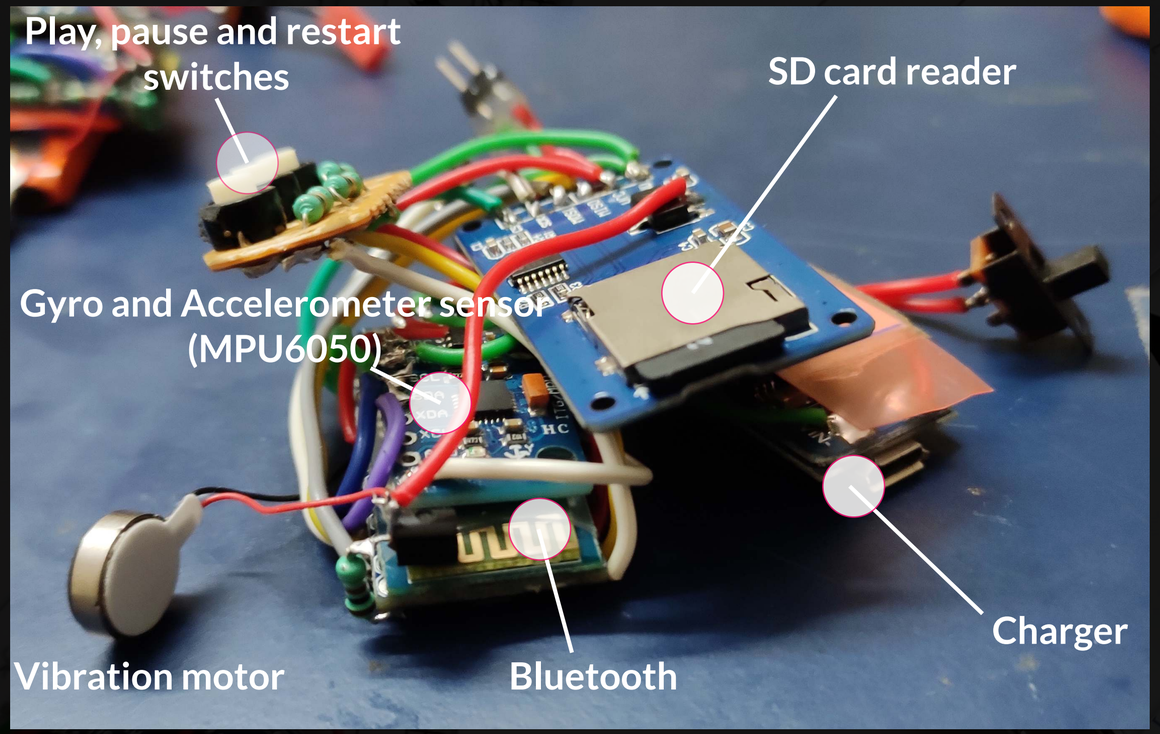
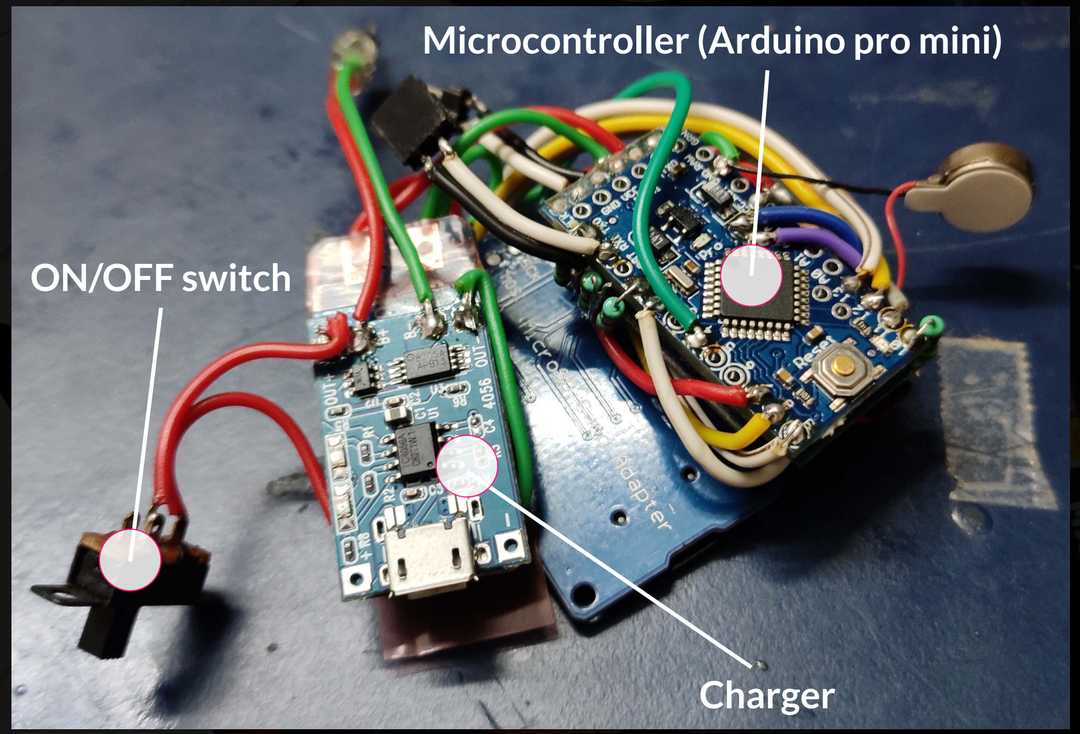
Thank you

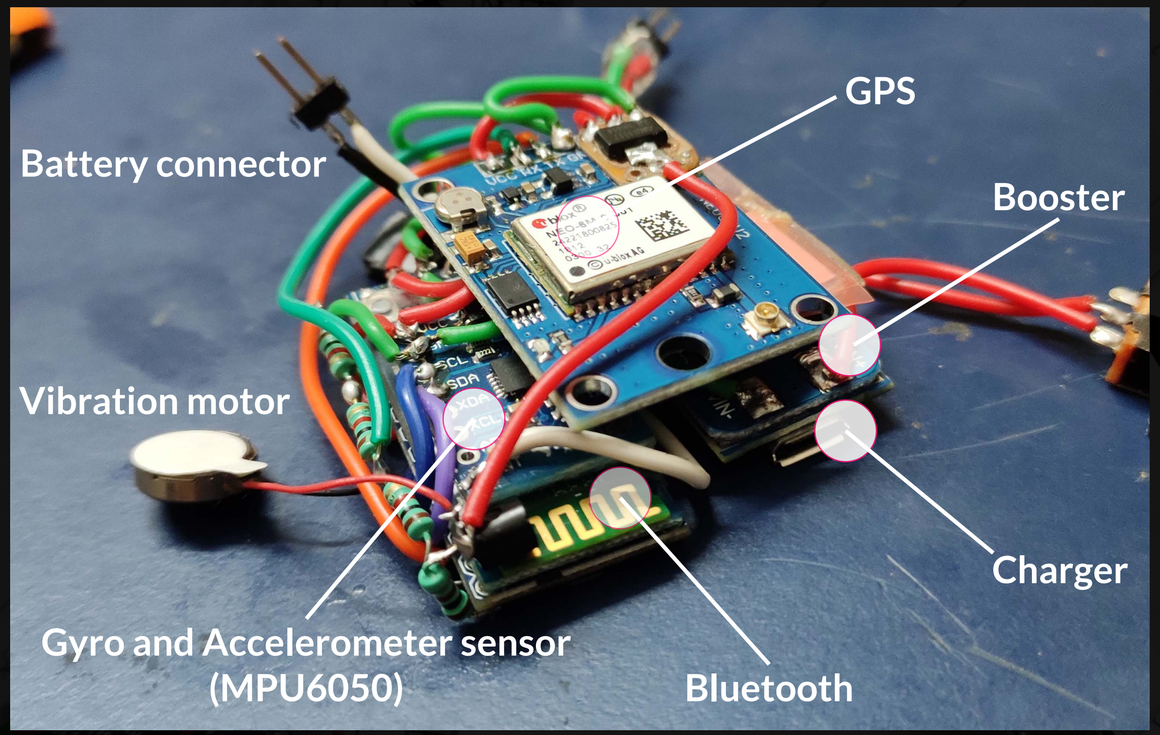


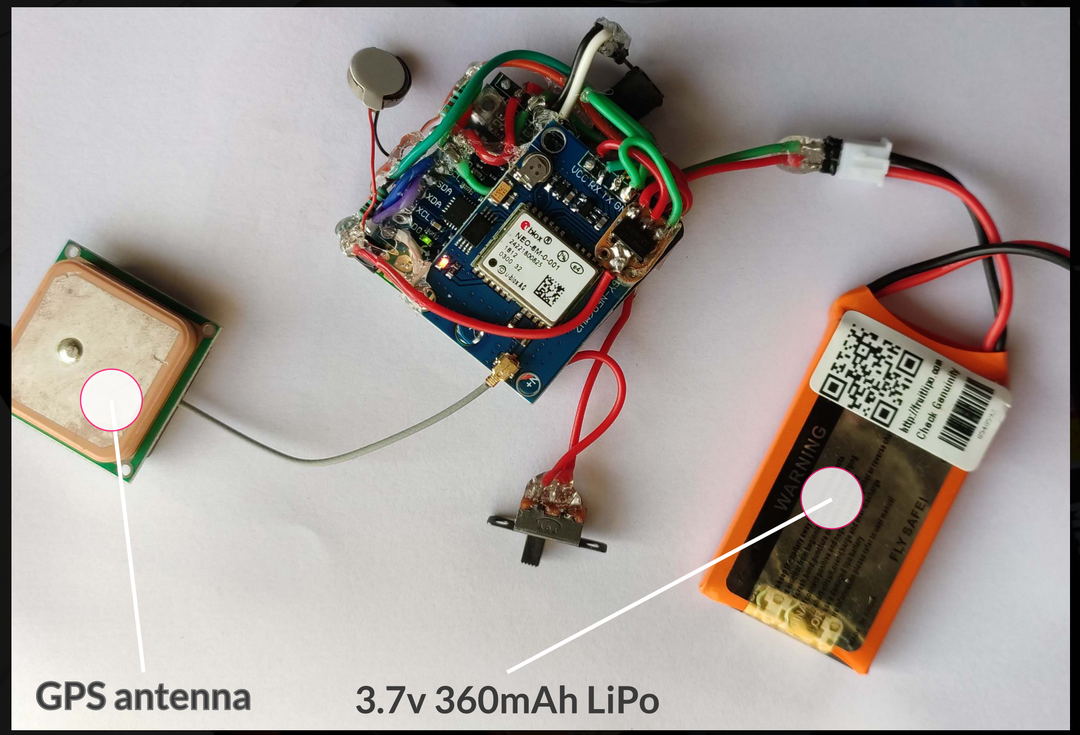
Current Prototype—The making



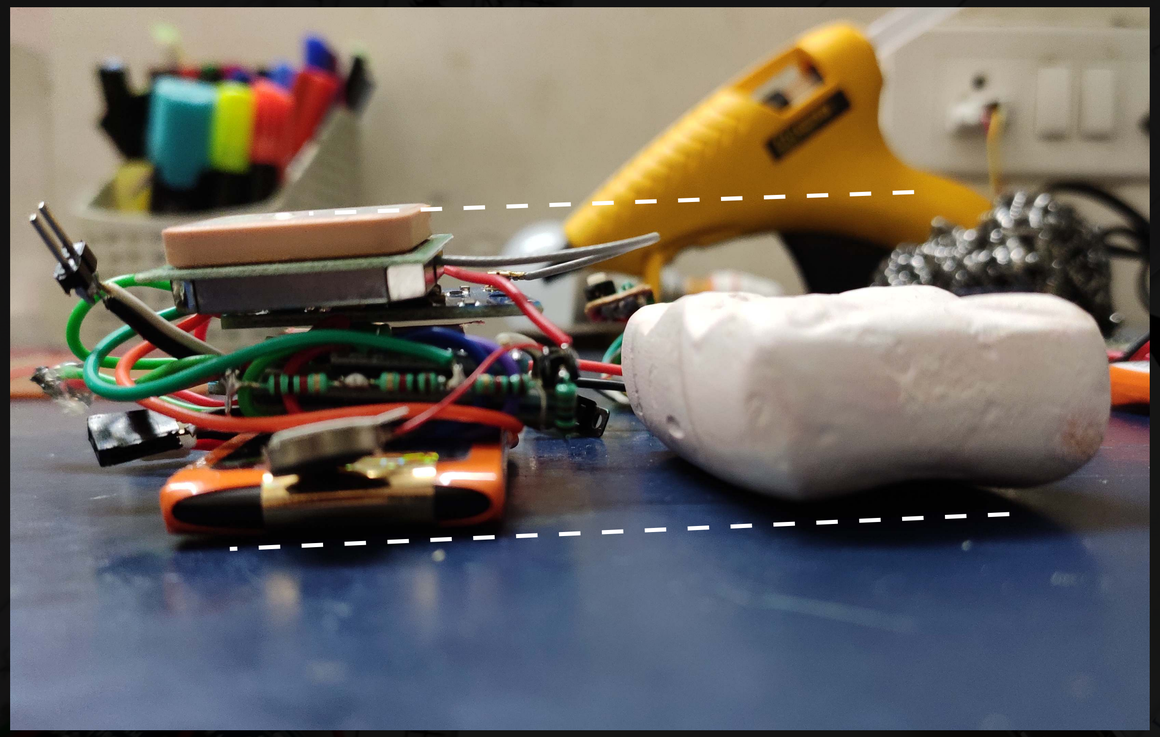


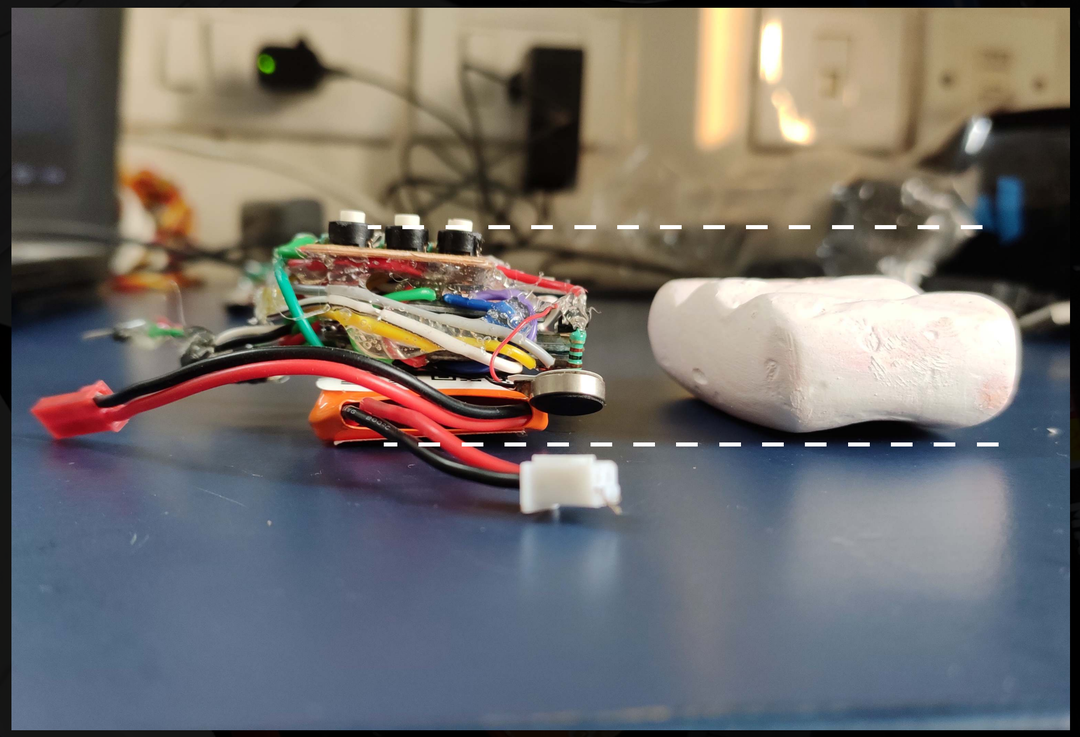
Internal components of the device for left foot



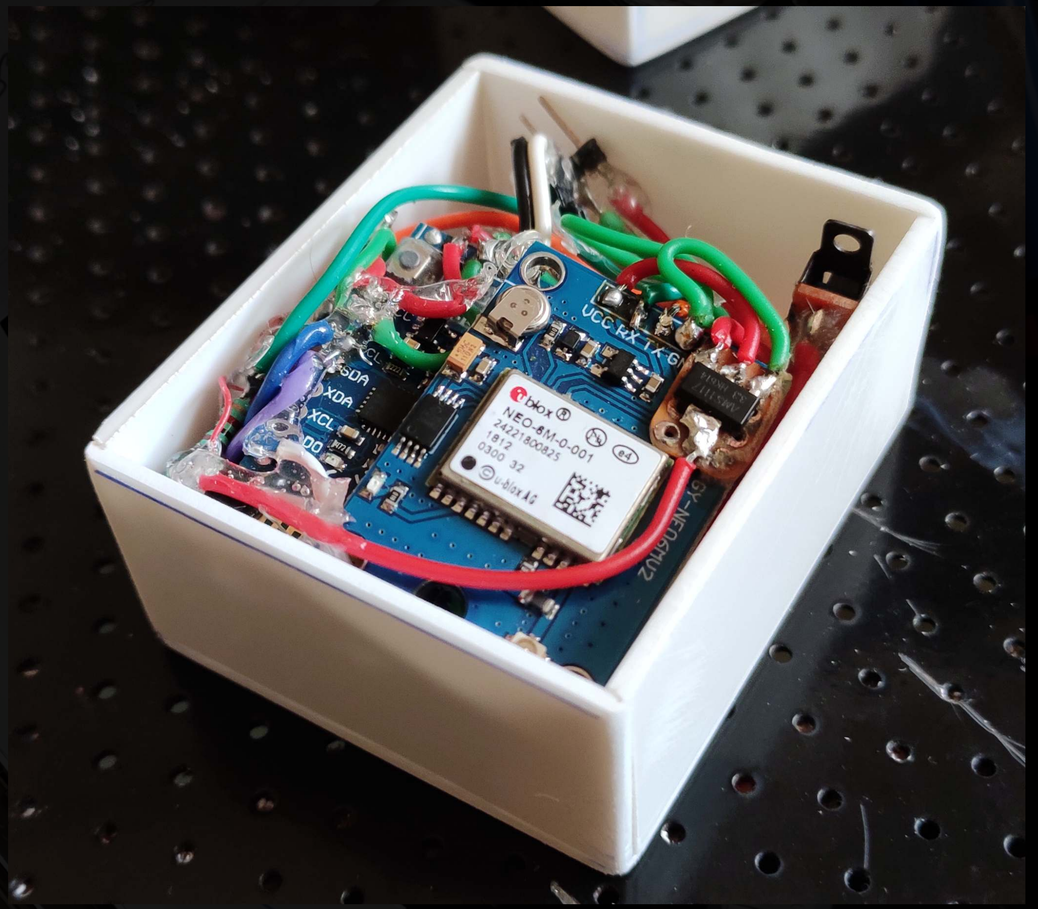


Internal components of the device for right foot

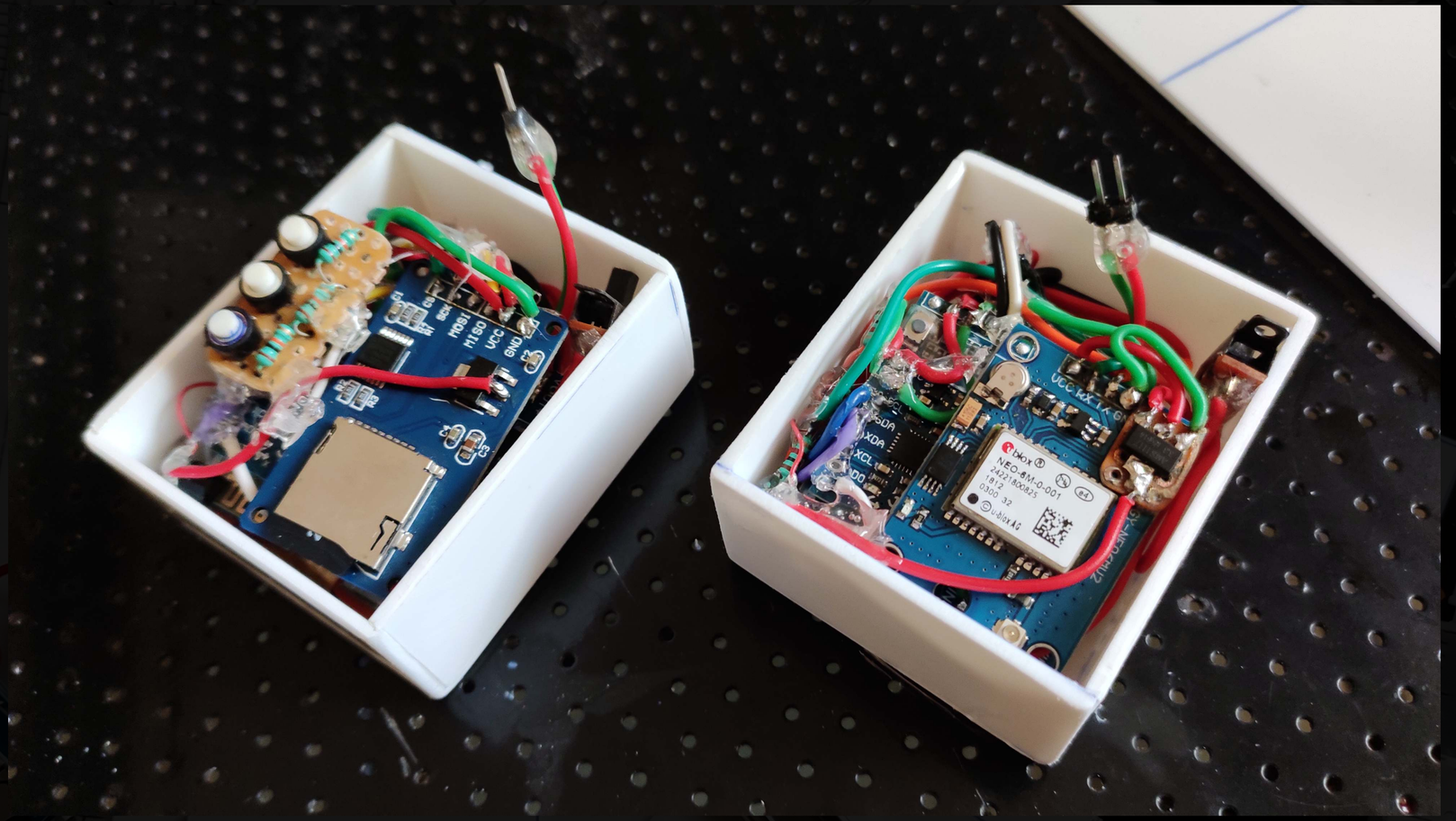




Height of the devices compared to proposed model



Casing—material: styrene—made for the prototype



Casing—material: styrene—made for the prototype

Slingshot™

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 rhythm, will again increase the challenge of doing Fartlek run.

The means of keeping rhythm 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.