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1 Introduction

The purpose of Work Package 5 is to showcase the individual progress of use cases through the developed demonstrators, user apps and pilots. Technical feasibility of the use cases will be demonstrated by involving the end users and running pilots.

More specifically, the deliverable 5.2- is for the creation of the demonstrators, integration of wearables, data algorithms and feedback into the user apps. The result is working demonstrators to be used for further pilot studies.

The following use cases will be overviewed in this document:
1. Screening for sudden cardiac arrest and monitoring functional capacity in patients and recreational athletes
2. Recovery monitoring in claudication, venous ulcers and diabetic foot patients
3. Recovery monitoring after orthopaedic surgery
4. Cognitive preparation of athletes
5. Holistic preparation for football (PSV Eindhoven) and hockey (Testify Performance) competition and safe return to play after injury
6. Sleep Analysis and Support Application for Healthy Life
7. Monitoring patients participating in a prehabilitation programs prior to cancer surgery
8. Disease Prevention by Big Data Aggregation

2 Use cases

2.1 Screening for sudden cardiac arrest and monitoring functional capacity in patients and recreational athletes

2.1.1 Short description of use case

The majority of sports-related deaths occur among athletes older than 35 years of age. In these master athletes, atherosclerotic coronary artery disease is the leading cause for the occurrence of major adverse cardiovascular events. More than 80% of sports-related sudden cardiac arrest in middle-aged athletes is associated with coronary artery disease. Vigorous exercise is associated with an increased risk of acute myocardial infarction and sudden cardiac arrest. Athletes can have undetected coronary artery disease and be at risk for adverse events.

2.1.2 Current status of demonstrator

We aim to better monitor master athletes with (sub)clinical coronary artery disease and identify individuals at high-risk of adverse cardiovascular events. Our initial focus is on direct measurements in the field, the most important and innovative being the detection of myocardial ischemia. New wearable ECG sensors are being tested in patients and athletes.

Results of our clinical studies can help us to design a platform with connected wearable devices and usable parameters.

The Philips wearable monitoring eco-system as defined in deliverable 5.1 can be feasible for both data platform and dashboard features. It provides a portal for healthcare professionals to:

1. Create a study to collect and process metrics from a set of subjects as depicted in Figure 1.

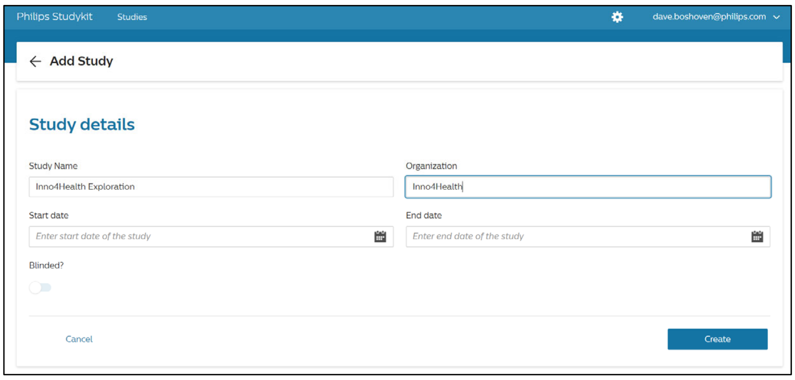


Figure 1: Creation of a study

After a study has been created it will be visible in the studies overview screen as depicted in Figure 2.

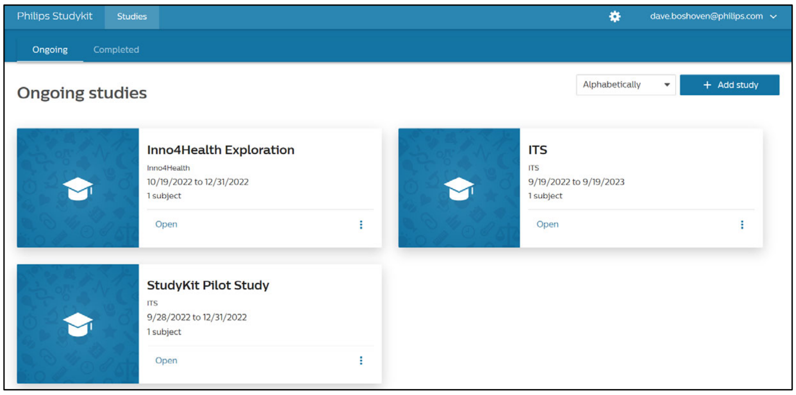


Figure 2: Studies overview

2. Creation of the subjects participating in a study.

   After creation of the study, subjects can be assigned to an existing study (Figure 3). For each subject, personal properties can be filled in, like for instance age, height, handedness, etc.

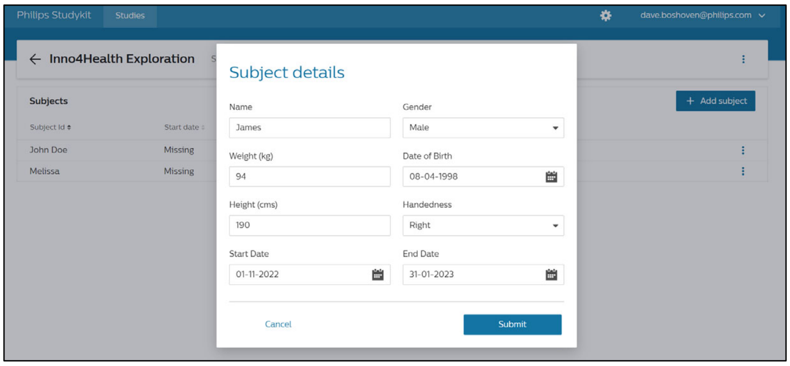


Figure 3 : Creation of a subject for a particular study

   When the subject is created, the subject will appear in the subject overview of the study as depicted in Figure 4.

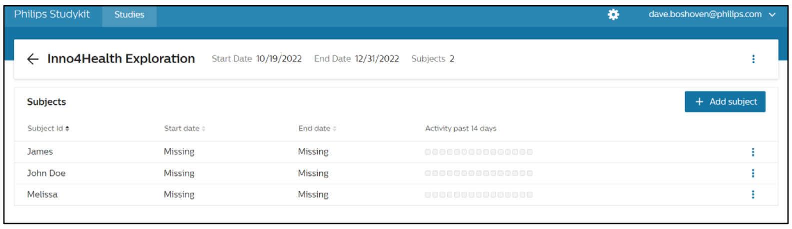


Figure 4 : Subject overview of a study

3. Assign device(s) to a subject

   Before data can be collected for a subject, a single or multiple devices must be assigned to the subject. The device type (e.g. ECG Holter monitor, PPG monitor, etc.) must be selected and the body position set (Figure 5).

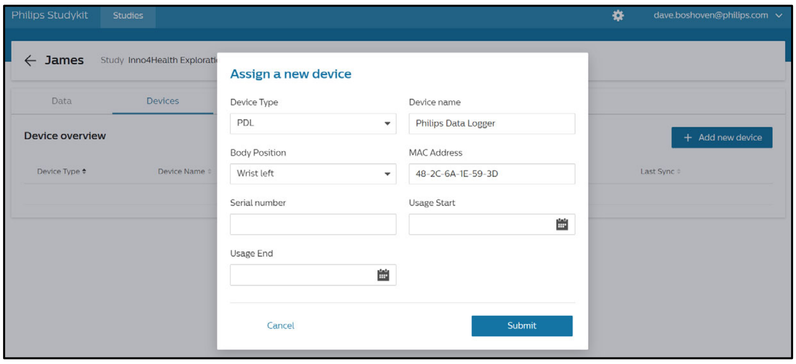


Figure 5: Assign device (i.e. PDL) to the subject

For the subject, a list of all assigned devices will be displayed as depicted in Figure 6.

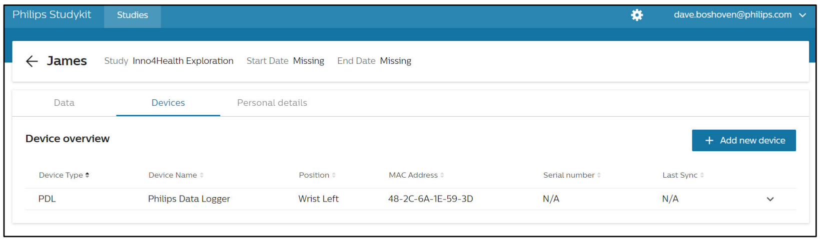


Figure 6 : Overview of devices assigned to a subject

4. Visualize and inspect collected and processed data

   After data has been collected from the subject's device, the data will be processed by the Philips wearable monitoring eco-system and can be viewed as different metrices in the metrics dashboard. Based on the insights needed of the healthcare professional, metrics can be selected/deselected. Figure 7, Figure 8 and Figure 9 show some examples of how metrics are visualized.

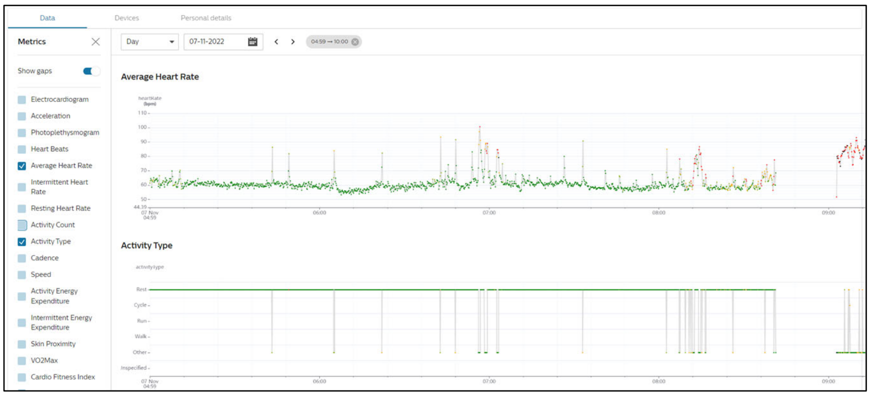


Figure 7 : Average heart rate and activity type visualization

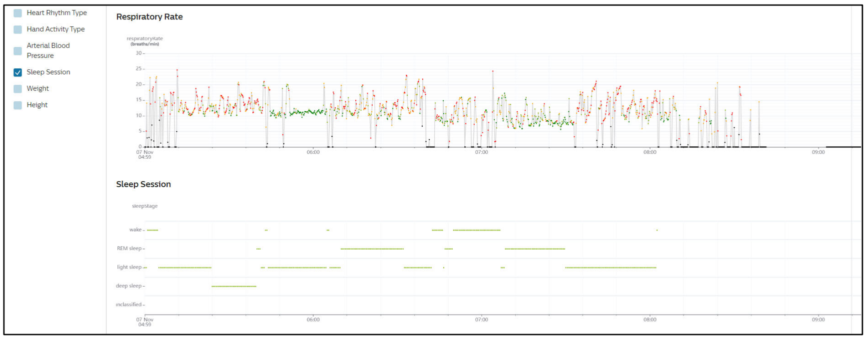


Figure 8: Respiratory rate and sleep session visualization

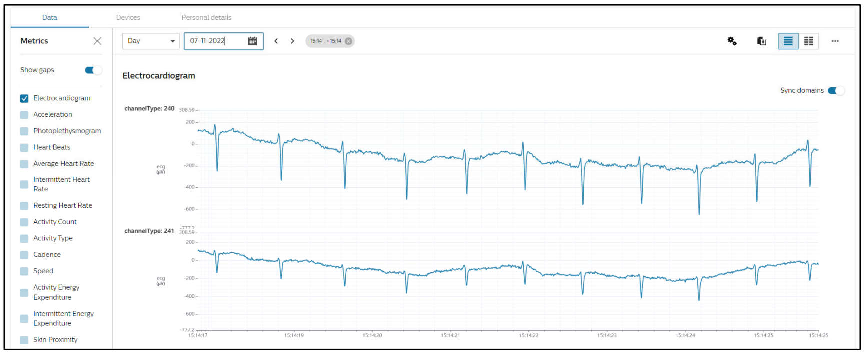


Figure 9: ECG visualization

To provide even more insights to the healthcare professional, the dashboard also supports features like zooming in/out and period selection.

2.2 Recovery monitoring in claudication, venous ulcers and diabetic foot patients

2.2.1 Short description of use case:

Vascular diseases affecting lower extremities, such as intermittent claudication (IC), leg venous ulcers, and diabetic foot (DFU), are clinically relevant as they can incur considerable loss of mobility and quality of life, requiring frequent follow-up and hospitalizations. Standard treatments are usually defined according to the patient's condition and comprise pharmacological and physical activity interventions for controlling disease progression and improving the overall health status. Nevertheless, follow-ups are performed sporadically due to barriers to monitor the patients outside of healthcare facilities, compromising treatment effectiveness.

The aim of this use case is to provide a solution combining wearable sensors, IoT communication technologies and advanced data analytics for smart monitoring of patients with IC, leg venous ulcers and DFU. Regarding IC, sensors will be used to measure walking capacity, monitor physician exercise plans adhesion and progress and determining the moment at which ambulation cannot continue due to maximal pain. For leg venous ulcers, sensors will be used to monitor the interface pressure under compression apparatus, apart from measuring motion and temperature. Plantar foot pressure and temperature distribution will be the main parameters for DFU patients, as well as motion and position parameters, measured with force and temperature sensors embedded in insoles. End-users (patients and healthcare professionals) will interact and receive feedback from the system through mobile applications, being able to check the patients' health status in real-time. The main innovation aspect of the proposed system consists in a set of intelligent services that allow the smart coaching of patients and healthcare professionals, promoting healthy behaviours and increasing the involvement in treatments, addressing current health needs in the context of the aforementioned diseases.

2.2.2 Current status of demonstrator:

The demonstrator associated with this use case includes several types of monitoring sensors integrated to distinct wearable devices, paired with mobile phone applications, an associated data ingestion structure and a data processing/analytics platform.

Monitoring sensors for this use case have been developed by Wiseware and include:

1. an ultra-slim forcing sensor resistor to measure and log pressure under compression apparatus, motion, position and temperature in venous ulcers patients, continuously (around 7 days). Alternatively, an air-filled pillow shaped device is currently under development to measure pressure in places where bands cannot reach due to body shape.
2. Ankle bands measure motion and physiological parameters using in IC patients continuously (over than 150h).
3. Insoles to measure foot temperature and plantar pressure at 8 distinct points of the foot, gait analysis and step counting in diabetic foot patients, continuously (over than 100h).

The aforementioned devices use Bluetooth Low Energy (BLE) or Near Field Communication (NFC) technologies.

The mobile application related to IC monitoring presents the following features:

1. To create patients' user profiles with their information.
2. To visualise a list of wearable devices and their status, as well as enabling retrieval of their logbook.
3. To allow physicians to create personalized treatment plans (e.g., definition of intermediate and final goals in terms of daily or weekly walking distances).
4. To compute and enable historical data comparison during the treatment, enabling the assessment of treatment plans and goals.
5. To display personalised feedback and clinical insights to help health care professionals during decision making.
6. To display activity levels over time and provide alerts to help and motivate patients to adopt adequate behaviours and improve the compliance and progress with the treatment.
7. To receive and analyse data from the ankle bands sensors for the measurement of walking distance in meters over time, speed, slope, frequency and duration of pauses to rest, heart rate and blood oxygen saturation levels (SpO2).
8. To enable measurements of the slope of the walking surface for patients with IC, as well as the percentage of walking distance performed with and without slope.
9. To enable the reporting of stops induced by maximal pain and to enable the reporting of the moment when the pain episodes start and finish.

10. To enable the reporting of pain site through a lower limb body map.
11. To allow the measurement of the Absolute Claudication Distance (ACD) in order to verify clinical goal achievements.
12. To enable data recording.

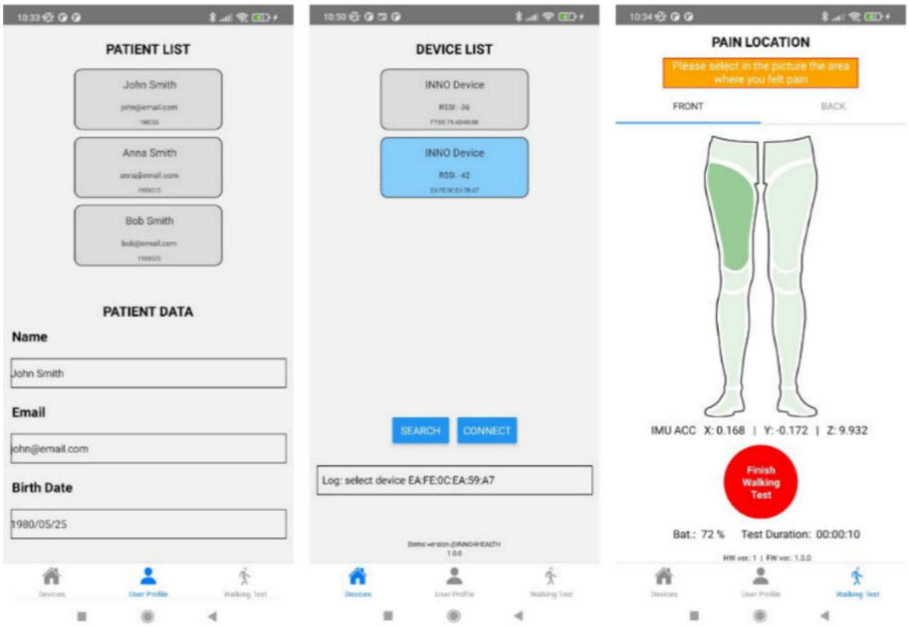


Figure X. Mobile application user interface for IC monitoring

The mobile application related to diabetic foot monitoring presents the following features:

1. To create patients' user profiles with their information.
2. To visualise a list of wearable devices and their status, as well as enabling retrieval of their logbook.
3. To receive and analyse data from the insoles, namely plantar foot pressure and temperature, position and motion parameters.
4. To enable the measurement of DFU healing time to verify clinical goal achievements.
5. To enable the measurement of DFU onset time.
6. To display a foot map showing plantar pressure at key points of the foot.
7. To display a foot map showing foot temperature at key points of the foot.
8. To display walking distance in meters.
9. To display calories consumed.
10. To display slope and position parameters.
11. To enable data recording.

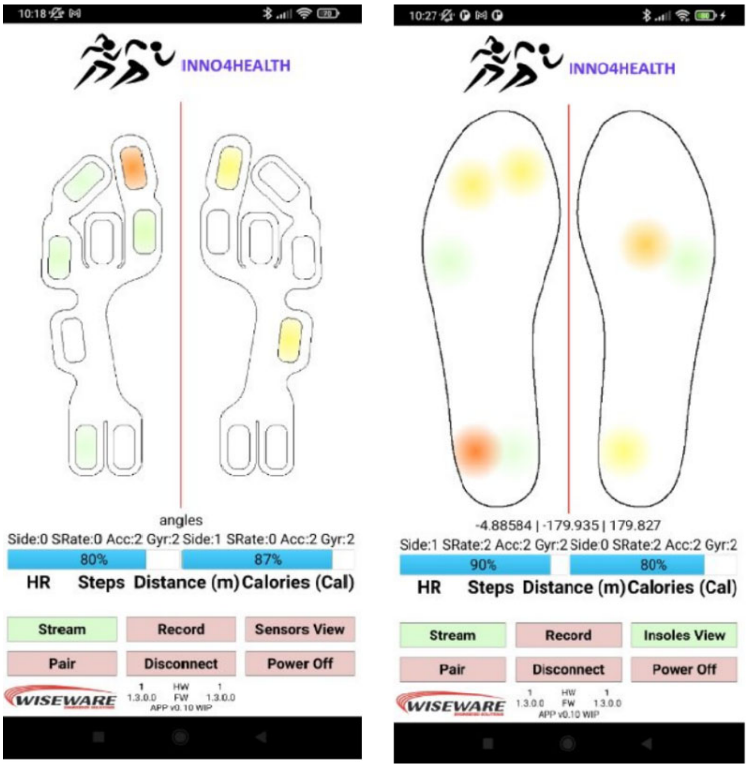


Figure Y. Mobile application interface for diabetic foot monitoring

The mobile application related to venous ulcers monitoring is currently under development and will present the following features:

1. To create patients' user profiles with their information.
2. To visualise a list of wearable devices and their status, as well as enabling retrieval of their logbook.
3. To receive and analyse data from the ultra-slim forcing sensor resistor, namely interface pressure under compression, temperature, position and motion parameters.
4. To enable the measurement of venous ulcer healing time to verify clinical goal achievements.
5. To enable the reporting of venous ulcer status.
6. To enable the reporting of pain episodes.
7. To enable the reporting of duration of pain episodes.
8. To display interface pressure.
9. To display walking distance.
10. To display slope and position parameters.
11. To enable data recording.

The features and interfaces of the mobile applications to be used for diabetic foot and IC monitoring have already been developed, including the insoles and ankle bands. Data ingestion and storage structure has been constructed, using standard security protocols (e.g., TLS - Transport Layer Security, FHIR - Fast Healthcare Interoperability Resources standard) for data transmission and storage. The exchange of data between the

monitoring sensors, mobile applications and the central server hosted at ISEP is currently implemented and functional, following testing conducted internally.
Future work includes the development of the monitoring sensors and mobile application for venous ulcers monitoring, and the implementation of a data processing platform enabling coaching feedback and recommendations to patients and healthcare professionals based upon data received from patients and a rule-based system encompassing medical knowledge and guidelines inserted by clinicians.

2.3 Recovery monitoring after orthopaedic surgery

2.3.1 Short description of use case:

Application use case for recovery monitoring after orthopaedic surgery consists of developing mobile device and desktop application, which are collecting and monitoring gyroscope data's with WT901BLECL (Bluetooth Gyroscope) and WT901Wifi (Wi-Fi Gyroscope) devices (WT901BLECL for mobile application and WT901Wifi for desktop application). Gyroscope devices are arranged on specific parts of a relevant person and then the person begins to exercise with directives caused to move specified body parts.

These applications aim to collect exercise movement data and then monitor, compare, and detect anomalies from specific parts of the human body. WT901Wifi and WT901BLECL devices can collect 50 data per second, our inventions produce highly sensitive data to visualize every single movement for specialist. Moreover, after the surgery, relevant people will be able to collect and visualize their own daily movements with the mobile application. Specialists easily access and analyse details of data with the database services, and the services include an AI with a preview system for anomaly possibilities and unexpected movement notifications.

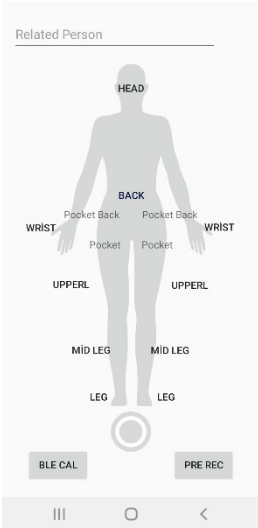
2.3.2 Current status of demonstrator:

Recovery monitoring after orthopaedic surgery application provides the functional requirements and features given below. This use case includes cooperation with the mobile application, database services, and desktop application:

- Creating a Record Profile
- Selecting Multiple Body Parts
- Sensors Calibration
- Streaming and Storing Records Data
- Visualize and Comparing Records Data

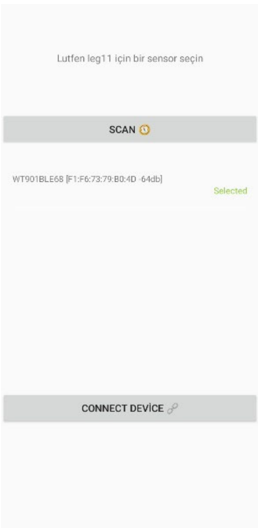
Creating a Profile Record

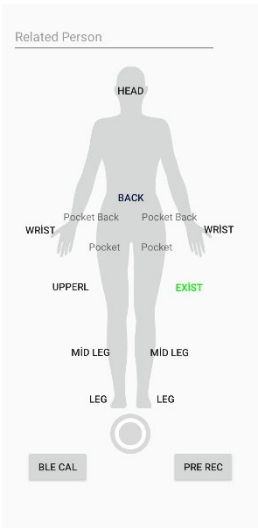
The mobile applications greet users with an opening page, then the user can be able to create a profile record by using a user-friendly simple interface. First step is providing patients’ name and last name. This is essential for relating data with each patient individually. The mobile application automatically creates dates, selected body parts’ names, and more.

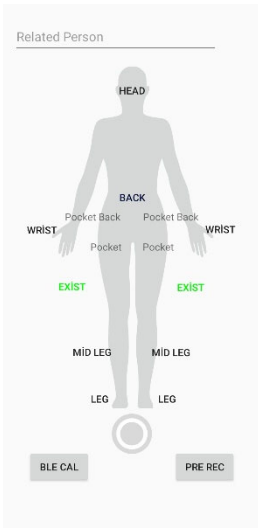


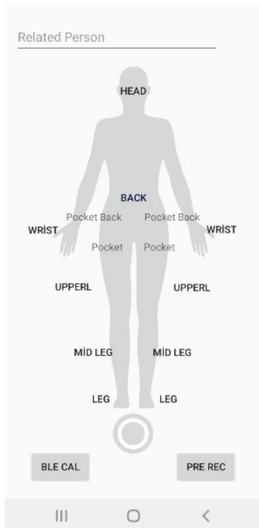
Selecting Multiple Body Parts

After the Profile Record is created, users place a device on an area of their body that has been operated on or has to be monitored. Upon user’s desire; a new device can be added, and devices can be replaced piecemeal and disconnected when no longer used.



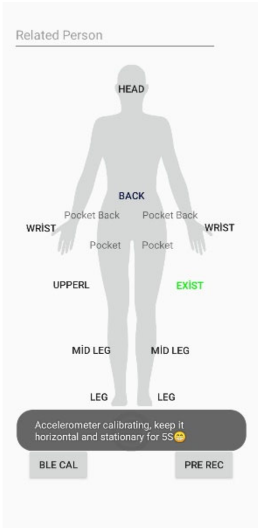






Sensors Calibration

If sensors associated with body parts properly, WT901BLECL devices are ready for calibration. Each gyroscope device has their own x, y and, z (Acceleration-x, Acceleration-y, … Angular Velocity-x, Angular Velocity-y, … Angle-x, Angle-y, …) axes values in Euler-Space which have placed on the body. The calibration sets the devices x, y and, z initial values for position value on a body.

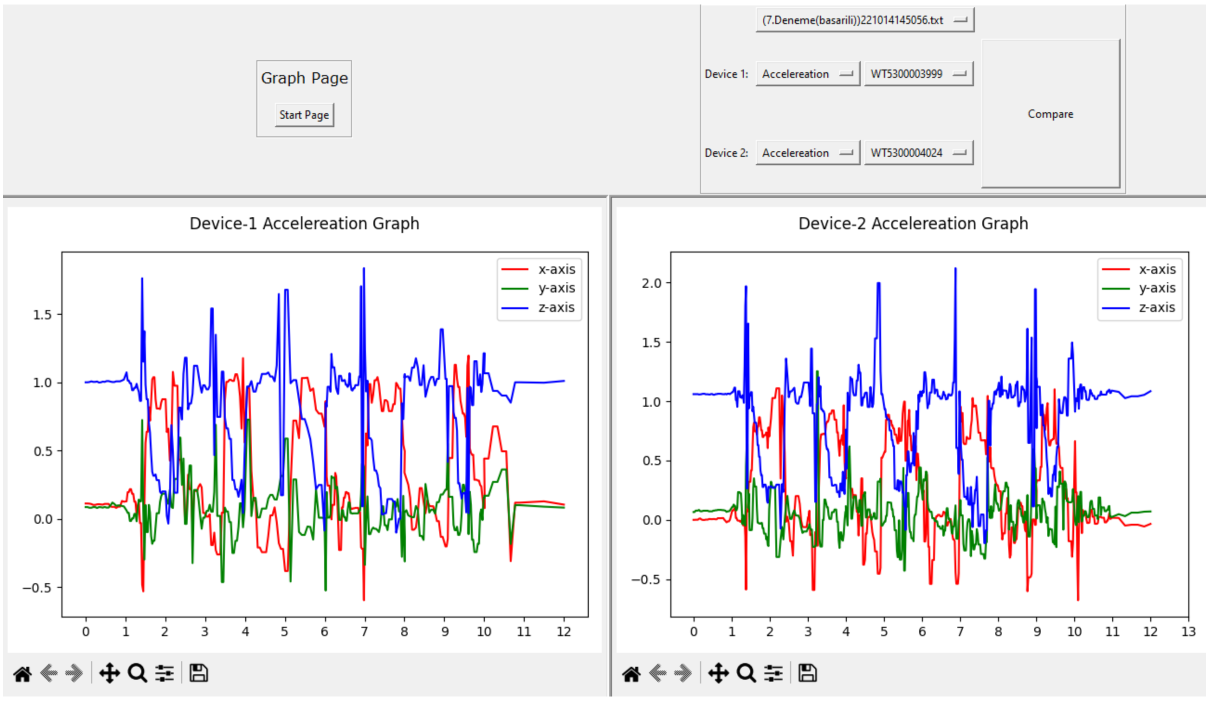


Streaming and Storing Records Data

The user must calibrate the devices before for a proper session recording. After setting accelerometers properly, recording can be started. During the recording, users cannot calibrate or add a new device (or remove), this condition is imperative for reducing the noise of recording data. And, during the recording the mobile device send stream data to database to be stored and analysed.

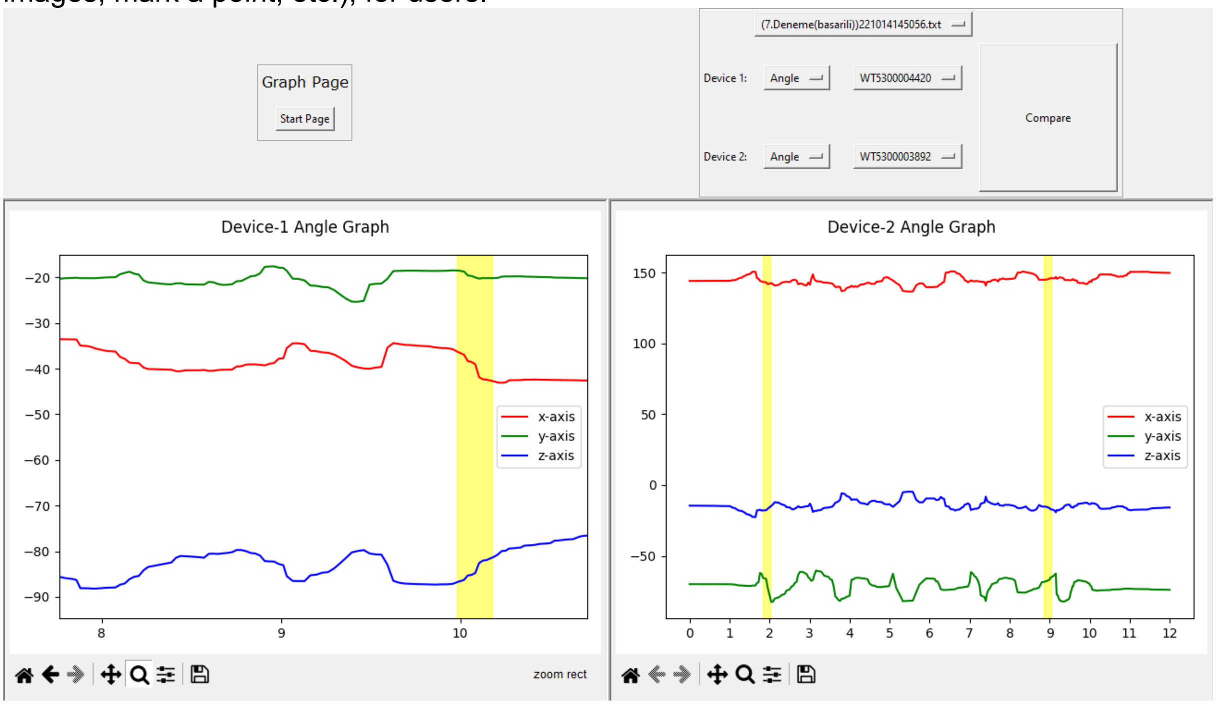
Visualize and Comparing Records Data

The database collects and tabulates each record and streams data for relevant people, if specialists want to examine it in detail, they can access each person's data from the database. The desktop application provides the records data visualization and compares



two devices' data on a single page.

The graphs (the matplotlib) provide a lot of different tools to visualize (zoom, save graph images, mark a point, etc.), for users.



2.4 Cognitive preparation of athletes

2.4.1 Short description of use case:

Training of mental functions for the preparation of athletes was gaining traction worldwide, now it is commonly talked about in Sport Psychology conferences. There are digital testing solutions like "Vienna Test System", or digital training solutions like MPU-Easy. None of these are built with the athlete in mind. After COVID mental health of elite athletes has become more popular and important, there are already attempts at measuring certain cognitive factors, also with the help of VR like "React" VR training by Enhance. But until now there is not a well-defined platform for athletes to test and improve cognitive skills with mental training in conjunction with optimal physiological states.

Our innovation is to combine current sensor and mobile technology with expertise in athlete mental preparation to create a digital solution for testing, training, and thus optimizing the mental psychophysiological profile of an athlete for maximum results.

2.4.2 Current status of demonstrator:

The aim of this demonstrator is to use evaluation and testing tool to measure athletes' cognitive abilities and prepare training plan that includes individualized mental exercises.
The use case already has a working demonstrator with three cognitive training aspects (concentration, attention transfer, orientation in space/time). It is a web-based aplication tailored to be used with VR glasses to create a "sterile" environment for testing/training. It can also be used on mobile devices, tablets, PCs. There is also an interface with monitoring sensors like Polar H10 so that the HR, HRV data can be monitored during check up.

Visual presentation below:

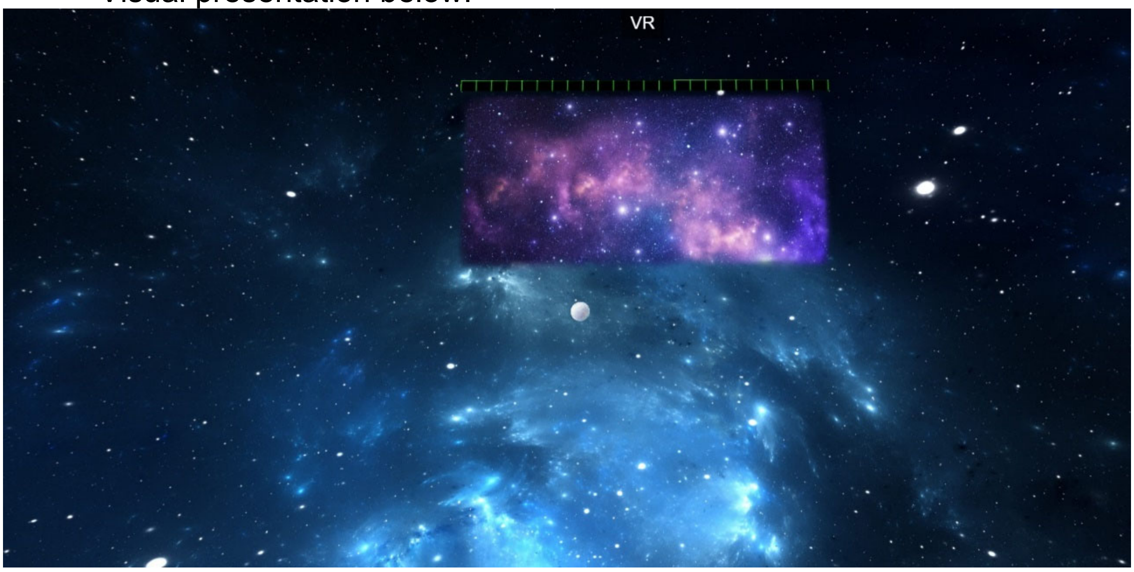


Figure 1. Anticipation demonstrator

Anticipation is highly important for all sports and crucial for most. Weakened anticipation can have detrimental effects for athlete performance, e.g. a swimmer starts at a wrong time, football player is unable to anticipate the ball. Our demonstrator can already be used to test the anticipation factor of athletes, training tasks for both time and space is also created.

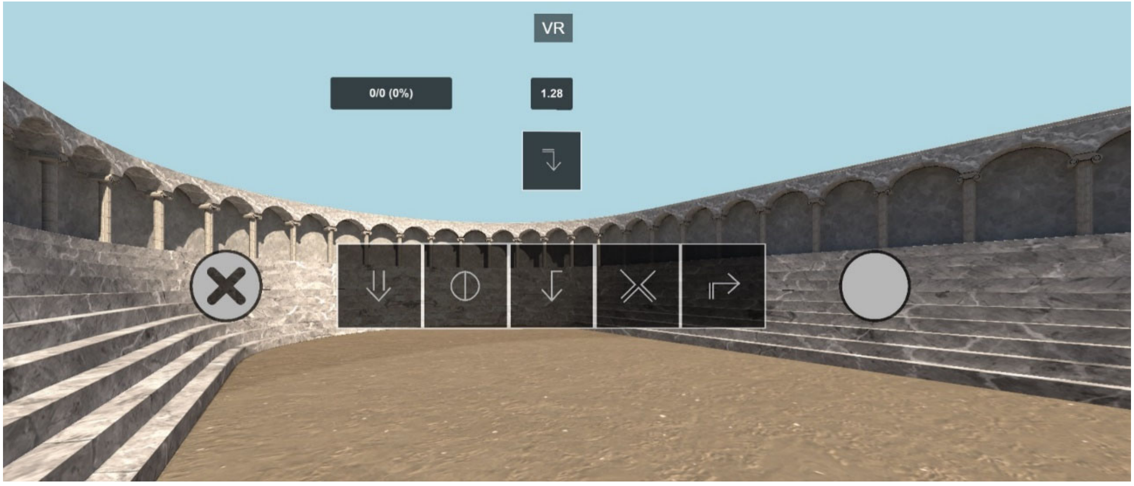


Figure 2. Concentration demonstrator

Concentration is another inseperable aspect of athlete performance. Our demonstrator tests the concentration of an athlete, we have implemented a unique new concept of IPUTs- impossible to process but understandable tasks. A study conducted with sports aviators by Lipse has shown that IPUTs significantly increase the number of mistakes in otherwise easy tasks. The demonstrator also has a training segment where a mental strategy – self talk – is learned, allowing better management of concentration. Use of self talk in such way has shown an increase in performance in other concentration tests, as shown in another study we conducted. Both of these case studies have been presented in highest ranking sports psychology conferences in Europe – FEPSAC 2022 and ASP Tagung Muenster 2022.

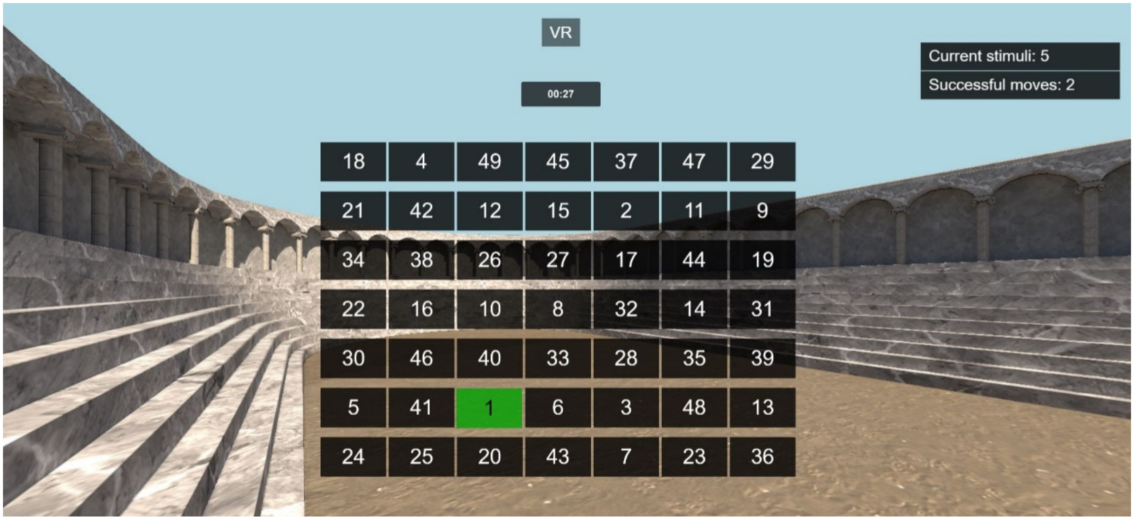


Figure 3. Attention Transfer demonstrator

Attention transfer is a cognitive ability to shift one's attention from one stimulus to another. Deficiencies in this ability can cause emotional disbalance, inability to concentrate on the task at hand and so on. With this tool we are able to evaluate athlete's ability to shift attention and then train it.

Figure . Graphical representation of wearable data

The demonstrator has an integrated interface for wearables so that it would be possible to collect relevant physiological data.

To conclude, our demonstrator has three working segments for cognitive ability testing and training. We are able to gather physiological data from wearables via integrated interface to aid in evaluation. The demonstrator is already in such a state that we able to conduct studies.

2.5 Holistic preparation for football (PSV Eindhoven) and hockey (Testify Performance) competition and safe return to play after injury

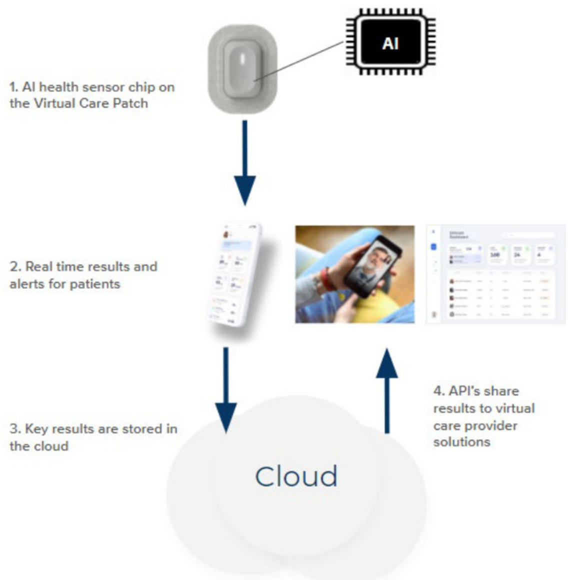
2.5.1 Short description of use case:

The overall goal is to enable athletes to return to sport safely and confidently through the completion of a series of comprehensive assessments and activities supported by AI data and interactive monitoring and engagement tools. The system will support the athlete during training as well as during the recovery from an injury.

Further, the application will offer the option of providing feedback to the athlete, coach and clinician in order to improve the daily activities proposed as part of training or rehabilitation to achieve high-level of personalization in the solution. Lastly, biometric authentication will be incorporated in this software application.

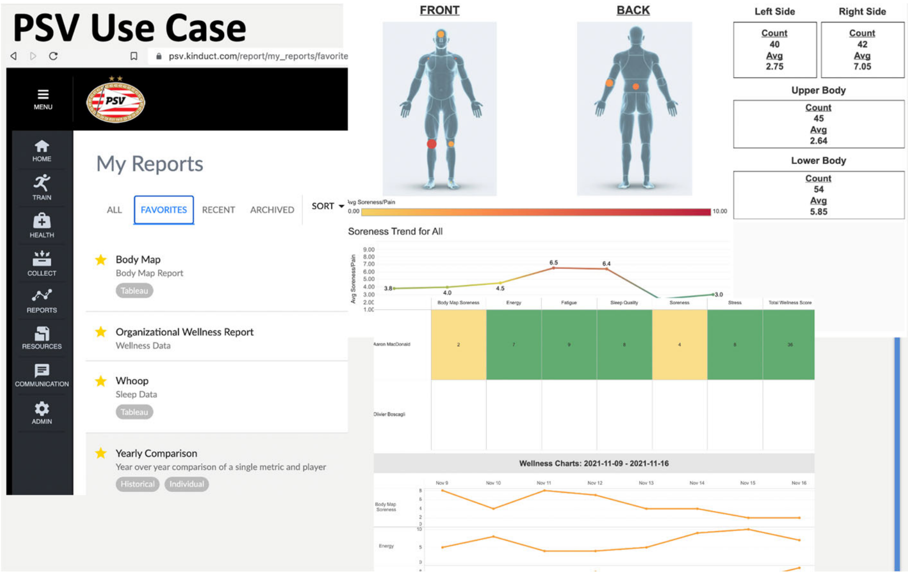
2.5.2 Current status of demonstrator:

This use-case is developing an App for injury risk assessment and recovery management in athletes. XCO's Virtual Care Patch and Movella's Kinduct Human Performance Software SaaS platform (HP SaaS) collects movement data, cognitive data and biometric data from athletes. The devices will then use singular and aggregated algorithms to deliver meaningful outcome (actionable) data to users through reports and visualizations delivered to user native and web applications that makes the data engaging to the user and beneficial to rehabilitation.



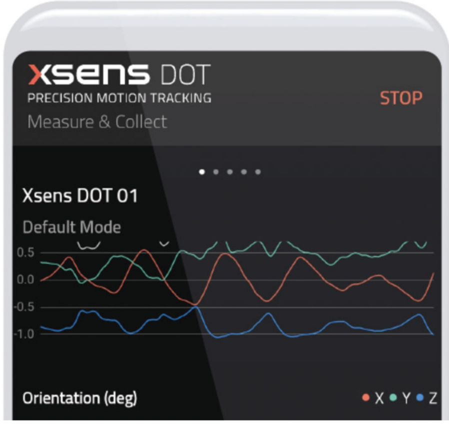
XCO and Movella are currently integrating output from wearable technology into Movella's Kinduct HP SaaS. Data from XCo's ReconHealth Patch native application will be automatically pushed to Movella's open integration API to the Kinduct HP SaaS. Ultimately this functionality consolidates the objective patch data with other subjective and objective data in Kinduct and facilitates the data fusion opportunities with data across domains such as general health, movement, cognition and biometrics.

The data is consolidated in a way that provides feedback to the stakeholders allowing them to customize the daily activities of the athletes. This can be proposed as part of training or rehabilitation to achieve a high-level of personalization in the solution. The reporting methods offer the virtualization of data for the assessment of injury or performance based on activities, either on the field or in their own home, combined with wearable data.



In order to create daily personalized training plans, 6 athletes from PSV will be wearing the sensors and collecting data. It is preferred that there is as little self-reported (subjective) data as possible These sensors are able to send hour min/max average of HR, HRV, RR, and SPO2 to Movella. The data is moved into a centralized system to be accessed by the sports specialist team (i.e., sports doctor, physio, nutritionist, coach, strength conditioning specialist). The data will be used by the specialists to make decisions about each athlete's training program.

Six of XCO’s Virtual Care Patches are set to be delivered to PSV within the next two weeks. Movella’s Kinduct HP SaaS is configured and ready for data collection. The TU/e student team is utilizing the Tableau reporting environment [i]embedded in Kinduct to develop new reports and visualizations of the data. Tableau is free for use by students and this approach enables an enhanced iterative process for optimizing reports and quickly releasing them to a production environment.
Movella has also introduced the DOT product [ii] to the team for non-obtrusive collection of motion data during regular activities (i.e. remote monitoring of regular ambulation activities – walking, jogging, etc.). The TU/e student team is working with the data to determine meaningful signals to present to the end users in reports and visualizations.



After validation of XCo's patches with the PSV trial, we will repeat the process with Testify Performance for adaptation to the ice hockey use case.

2.6 Sleep Analysis and Support Application for Healthy Life

2.6.1 Short description of use case

Sleep Analysis and Support Application Use Case is related to develop a mobile application which is combined with smart alarm, sleep tracking and gamification features. It is possible to set multiple alarms and repeat the alarms every day or specific days of the week that is preferred. Sleep tracking provides to analyse the sleep with daily, weekly, monthly and yearly graphs and statistics. User can define the target sleep time and wake up time. As many people have troubles waking up by delaying the alarm, gamification features overcome the struggle with waking up in the morning playing different games. User can select different games to close each alarm.

The application will assist people in gaining insight into their sleeping habits. These applications can help people figure out how much sleep they're getting if they're uncomfortable at night.

2.6.2 Current status of demonstrator:

Sleep Analysis and Tracking Application has the listed functional requirements and features.

- Creating a User Profile
- Creating an Alarm System
- Support for Falling into Sleep
- Sleep analysis
- Tracking Sleep Time
- Tracking Sleep Patterns

The app analyses the information received by the mobile cell phone to reach conclusions about sleeping habits. In order to calculate sleep quality, the app takes into account body motions during sleep, as registered by the device's accelerometer and also the noise level as recorded by the device's microphone. The total amount of time sleep, the quality of sleep, and the amount of time spent in different sleep phases are all included in these measurements. The app displays this data in a visual dashboard to provide advice on how to improve the sleep statistics.

- Creating a User Profile

When the users download the app to their device, they are welcoming with intro screen. After tutorial, the users are able to create user profile by setting age, gender, weight and height info.

- Creating an Alarm System

User can determine the wake-up time by setting alarm period (weekly, daily) and sleep time. The user can specify the sleep target and choose the games how to turn off the alarm.

- Support for Falling into Sleep

Application provides many sleep sounds to help people fast fall asleep. User can adjust the sound time how much to listen it.

- Sleep analysis

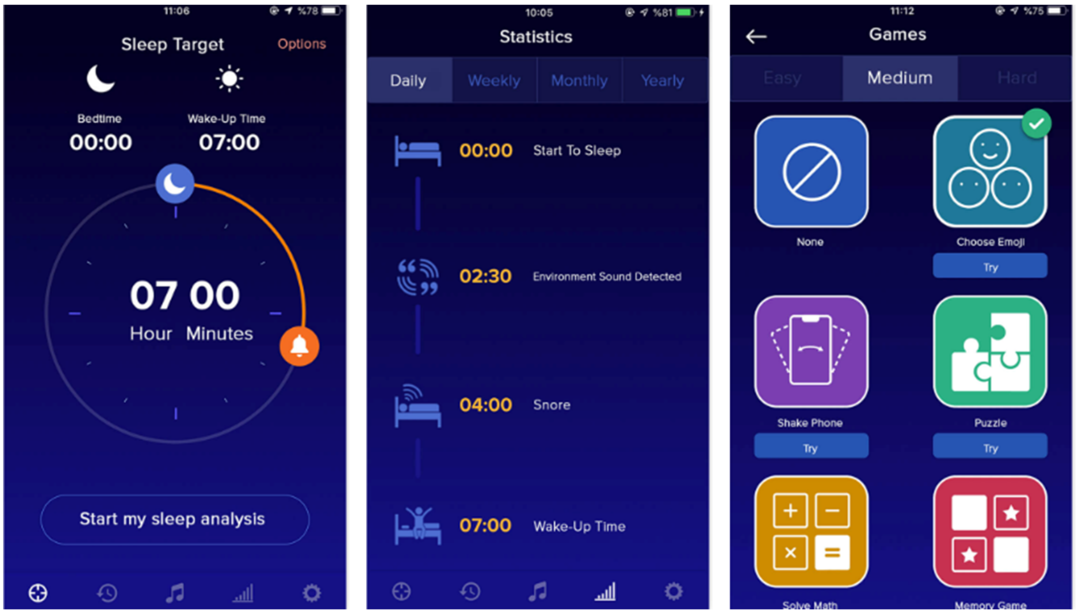
User can activate the sleep analysis by clicking the start button. Until stopping the sleep analysis function, the device continues to listen the around. Environment noise and snore voice are recorded, stored on device (never sent outside of device) and graphically shown to the end users. Users can see a list of the sleep sounds recorded by the app and use the scroll bar to start, stop, or advance the sleep audio recording.

- Tracking Sleep Time

Users can view the sleep history with the details such as sleep target, wake-up time and sleep time based on sleep quality. Users can choose how many hours s/he sleeps each night from a menu on the screen.

- Tracking Sleep Patterns

Users can analyse the sleep patterns with statistics. S/he can select a date range from the calendar on the screen for which statistical data is to be displayed, and the system updates the results accordingly. It is possible to compare user’s sleep score with other users.



The whole features and screens of application are developed. Prototype user testing has been conducting internally, the application will be launched on stores.

2.7 Monitoring patients participating in a prehabilitation programs prior to cancer surgery

2.7.1 Short description of the use case

Prehabilitation is the program to optimize the patient’s physical and mental condition prior to major surgery. This 3-4 weeks program consists among others of supervised high intensity training to improve strength and condition. There is increasing evidence that prehabilitation increases functional capacity and leads to faster recovery and reduction of complications after surgery, leading to a shorter hospital stay, improved quality of life and a reduction of hospital costs.

In Maxima MC, prehabilitation is standard of care for colorectal cancer patients. As part of this program, a number of in-hospital tests are performed to monitor the patients’ functional capacity. Baseline measurements are performed for patient safety and determination of eligibility to the program. Further tests are performed to monitor progress both for individual patients However, in-hospital tests cannot be used for registration of activity patterns nor track progress over time. Moreover, they are prone to day-to-day variability.

Long-term monitoring with wearable devices is necessary to obtain continuous registration of the patients’ functional capacity and actual performance. Development of new interfaces to communicate the data of these wearables with health care professionals could increase patient safety and optimize individual prehabilitation programs. Furthermore, with the use of Artificial Intelligence (AI), interpretation of the data might help to understand physiological processes and give input for prediction models that relate physical performance to surgical outcomes.

In this use case we examine the feasibility of tracking activity and other health variables by the use of wearable sensors. More specifically, we will use the BioTel ePatch for measuring ECG and the GeneActiv accelerometer for measuring activity during a 4-week prehabilitation program. With the measured health variables, we aim to develop an algorithm for prediction of functional capacity.

2.7.2 Current status of the demonstrator

The main purpose of this demonstrator is to provide clinicians with data to support supervised training in improving strength and condition of the patient prior to major surgery.

To support the clinician, Philips is developing a secure eco-system to retrieve personal health metrics from wearables, store the data in the cloud and visualize data via a dashboard, as defined in deliverable 5.1. This system is also used for use case 1 about screening for sudden cardiac arrest, and its current status is described in section 2.1.2.

Currently, the ecosystem is operational; data from specified Philips wearables can be uploaded and stored into the health cloud and parameters derived from these data (using ‘simple’ algorithms for example to obtain heartrate from ECG data) can be visualized via the dashboard.
We are now working on transforming data from other wearables (for example the GeneActiv accelerometer) such that these can be uploaded via the gateway as well.

Furthermore, we are working on optimization of data presentation. On the one hand by integration of algorithms via the analytics engine. On the other hand, we are conducting interviews with health care professionals as well as patients, in order to verify how they would like the data presented. Information from these interviews could be used to adapt the dashboard accordingly.

3 References

[i] https://www.tableau.com/university-students
[ii] https://www.xsens.com/xsens-dot