### Deliverable D4.1. Description of use case scenarios and their technical requirements

<table>
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<tr>
<td>Abstract</td>
<td>This deliverable defines a first set of use cases involving all the elements of the future STARR platform. The usefulness and feasibility of these use cases will be further discussed with stroke survivors, carers, medical personnel and designers and a number of these use cases will be implemented.</td>
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Deliverable Description
The primary objective of this deliverable is the definition of use case scenarios for the sensing technologies to be developed in the STARR project. This definition is based on input from WP2 and WP3 (i.e. users’ profiles and users’ needs) and discussions with designers, partners from the consortium and medical staff. The scenarios concern services and technical requirements for the sensing technologies. The definition of the services to be provided to all the users we target is also linked to WP5. The scenarios consider both the monitoring of progress in rehabilitation tasks and the monitoring of daily activities. We also include outdoor scenarios.

As for the discussions with designers, 4 brainstorming sessions were organised with 21 technology designers (5/7/5/4 people) to assess technology candidates and feasibility. In addition, 3 brainstorming workshops were organised: two at CEA and Hopale with partners from the consortium and medical staff (occupational therapists and physiotherapists) and one at TSA with ULUND with stroke survivors to clarify both the needs and interest of therapists and stroke survivors and carers. These brainstorming sessions helped to refine the initial project proposal. The major point that emerged and is highlighted in the various scenarios is that what matters most is the measurement of the general activity to ensure stroke survivors do not significantly lose their level of mobility acquired at the end of their rehabilitation rather than monitoring with precise measures of performance. In particular, the various scenarios should engage stroke survivors in physical exercising and self-managing their risk factors and should monitor any significant decline that could result in complications.

These conclusions led to the initial proposition of the following scenarios:

- **Scenario 1: exercising at home**
- **Scenario 2: daily lower and upper limb activity monitoring**
- **Scenario 3: indoor and outdoor exercising**
- **Scenario 4: spasticity monitoring**
- **Scenario 5: general self-management**

The usefulness and feasibility of these use cases will be further discussed with stroke survivors, carers, medical personnel and designers and a number of these use cases will be implemented.

These use case scenarios will be described in more details in the subsequent sections by covering all the aspects including the link to the risk factors and privacy issues.

I. **Exercising @home**

1. **Scenario Objective**

   The idea here is to help stroke survivors exercise both their lower and upper limbs. The focus would be on helping them exercising to move (standing or walking) and especially train them to apply the right pressure on each leg in a secure way. During the exercises, to rest their lower limbs, tasks could also involve moving their upper limbs to ensure ongoing mobility. The setup could also enable measuring balance and the load when standing with tasks involving standing up and sitting down. The main objective are: 1) to ensure they
keep practising once back at home; 2) to help them keep the acquired competence; 3) to help them gain confidence in their daily living activities such as moving about or grooming.

Data about general performance would be collected in two ways:

- The first by focusing on the evolution of the stroke survivor’s activity, measured and displayed every time the stroke survivor exercises with the system (local records). It would inform him/her and their carer, for example, about duration, frequency of exercising and in particular alert them of any degradation (see Subsection Technical Requirements).
- The second at predefined moments (e.g. every 15 days or once a month) with an evaluation exercise to provide therapists (e.g. doctors, physiotherapists, etc.) with a standardised monitoring that can enable them both to evaluate consistently the patient’s progress but also the efficacy of the system (record on the STARR system so therapists can access it).

The exercising system would also be used in hospitals and rehabilitation institutions together with physiotherapists. The self-management program would be designed by the therapists in the hospitals and institutions. The stroke survivor would then be trained to the use of the system. Having the same apparatus as during rehabilitation would ensure ease of use and confidence in the system, and consequently could potentially ensure motivation for use. Once at home, the liberal physiotherapists would adjust the self-management program according to the stroke survivor’s evolution.

2. Target Users
This scenario targets stroke survivors with:

- Walking ability: should be evaluated by the therapist beforehand. However, the scenario targets level 3-4 minimum on FAC (see Table 1)
- Balance ability: should be evaluated by the therapist. However, the scenario targets stroke survivors able to balance themselves with moderate support, either level 2 minimum on the FAC or a score >20 on the Berg Balance scale (<= 20 referring to wheelchair bound).

<table>
<thead>
<tr>
<th>TABLE 1: FUNCTIONAL AMBULATION CLASSIFICATION</th>
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<tbody>
<tr>
<td>0. Non Functional Ambulator</td>
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<tr>
<td>1. Ambulator - Dependent for Physical Assistance (level 2)</td>
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<td>2. Ambulator - Dependent for Physical Assistance (level 1)</td>
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<tr>
<td>3. Ambulator - Dependent for Supervision</td>
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poor judgement, questionable cardiac status, or the need for verbal cuing to complete the task.

<table>
<thead>
<tr>
<th>4. Ambulator - Independent, Level surfaces only</th>
<th>Patient can ambulate independently on level surfaces, but requires supervision or physical assistance to negotiate any of the following: stairs, inclines, or non-level surfaces.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Ambulator - Independent</td>
<td>Patient can ambulate independently on nonlevel and level surfaces, stairs and inclines.</td>
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There will be two types of exercises:

- Walking/moving and grasping for users able to stand up and walk a bit
- Standing up and sitting down to exercise balance for users unable to walk but able to stand

This scenario aims to target a wide range of stroke survivors who suffer from lower and upper limb disabilities. In the UK, 80% of stroke survivors have their general movement affected, 70% their arm movement and 40% are unable to use one arm in the long term [1]. More recent statistics in the UK listed that 77% of stroke survivors suffer from upper limb/arm weakness and 72% from lower limb/leg weakness (the highest in the list of disabilities) [2]. In Australia, impairment in the ability to undertake physical activities was the most common impairment for people who experienced impairment as a result of a stroke (close to 60% of the stroke survivors affected) [3] as seen on Figure 1. Difficulties using arms or fingers, gripping or holding things and using feet or legs were also frequently experienced problems.

**Figure 1: Impairments for Australian stroke survivors (Taken from [3])**

### 3. Technical Requirements

**Possible Apparatus**

- TV for display
- Virtual reality (VR) worlds

- Serious games: an example could be a game based on science fiction scenarios involving both exploration tasks (walking or moving around) with lower limbs and upper limbs tasks by reaching for targets. However, the scenarios of the serious games will be further discussed and refined.
  - Ideas of planet exploration like in Star Trek (e.g. a desert planet with some trees here and there with fruits to grasp to survive, or an icy planet, etc.)
  - A purpose is needed that also involve others to ensure motivation and engagement
  - The science fiction idea (rather than a real life scenario) could be used to maintain engagement and curiosity in the game, anything can happen as opposed to an environment mimicking the daily one
  - No accessory addition as it would provide distraction from the main task and can potentially add several technical implementation constraints (correspondence between the virtual object and the real accessory)
  - No real time feedback in a separate screen as it can also add distraction or use of an avatar as stroke survivors do not have a body scheme
  - Also some collaboration games with the family

- A secure motorized treadmill: the feasibility needs to be further investigated as it raises issues of security and cost. However it could help train walking indoors which is an interesting challenge yet to explore

- A bike to provide the cardiovascular training achievable by some patients to enable moving in the serious games or VR worlds

- A 3D sensor to detect both real time postures and movements but also emotions and valence through facial expressions (possibly Kinect 2): positioned on the TV between 1 and 2.5m

- Motion and gesture sensor such as the leap motion for tracking the hand in exercises requiring finer manipulation and grasping

- Insoles or shoes with pressure sensors for walking monitoring (therefore it is linked to the feasibility of the walking platform)

- Physiological sensors: heart rate sensors for the cardiovascular training sub-scenario. Integrated mostly in a wrist wearable or if acceptable, preferably in a torso belt

- Balance equipment such as balance boards

- Box with computational capabilities (or a computer)

Requirement: the whole system or its elements should be compact, easily movable, easy to setup and affordable.
Measures

- An initial calibration step: it would be performed with the professionals to measure the stroke survivors’ physical abilities (in terms of movements such as bending, leaning, etc.). It would serve as a baseline for comparisons between sessions and for the evolution statistics
- Duration of sessions
- Frequency of exercising
- Heart rate for the cardiovascular exercises (cardiac frequency to reach, the maximum authorized is computed with the following formula: 220 - patient’s age for about 75-85% of the stroke survivors depending also on the medication as for some drugs the heart rate is lower, e.g. with betablockers)
- Emotion analysis (face detection and analysis with the 3D sensor combined with physiological sensors)
- Height levels of the arms (with the 3D sensor)
- Tracking of the hand/fingers for finer motor control and grasping tasks
- Pressure applied on each foot, weight transfer measurements: heat maps to highlight the use of the feet for the balance exercises.

If a solution for a walking platform is found, additional measures can include:

- Gait measurement with general posture with the goal to highlight walking defects and walking evolution (measured by the 3D sensor)
- Length of step, stride, speed, pressure on the heels (measured both by the 3D sensor and pressure sensitive shoes or insoles)
- Spatial-temporal parameters: support duration, double support duration, walking asymmetry (acceptable range within the sustentation polygon, if not computable with the setup, could be part of a calibration step with the therapist to define the acceptable asymmetry through modifiable acceptable levels of inclination to account for evolution) (measured both by the 3D sensor and pressure sensitive shoes or insoles)

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1 For example as depicted in [https://quizlet.com/19712641/abnormal-gait-patterns-flash-cards/](https://quizlet.com/19712641/abnormal-gait-patterns-flash-cards/)
Kinematic parameters: articulations angles, angular velocity, resulting forces (measured by the 3D sensor)

Pressure applied on each foot, weight transfer measurements: heat maps to highlight whether each foot was used for walking and the tensions on the toes/extremities (measured by the pressure sensitive insoles or shoes).

Most of the data will be post-processed, i.e. that the computations are not performed in real-time but rather at the end of the exercising session. Only the general gait measurement or the weight transfers will be used in real-time as an input to the actions of the game (serious exploration games or balance games).

Analysis
The movement measurements and analysis (gait and weight transfer measures) aim to provide feedback both to the game in real-time to adjust the actions the stroke survivor needs to perform and also to the stroke survivor at the end of the session through a general summary. The general summary would provide information about performance and improvements such as inadequate postures or lack of weight transfers on the paretic limb delivered through intuitive representations (for example, heat maps). The form of these representations will be iterated upon and further defined in WP5 with the inputs from WP3 and WP4.

Also, the comparison with prior movements’ performances during the standardized evaluation exercise will help assess the evolution of the competencies acquired during rehabilitation with the therapists. In particular, it aims to detect a decline in the stroke survivor’s ability (length of step reduced, no weight transfer on the paretic limb, or simple decreased activity) to raise the necessary alerts, as the quantity of movements has an impact on risk factors.

The overall data would be regularly inputted to the main STARR system to update the predictive risk factor modelling.

The analysis of emotions aims to measure the adherence to the use of the walking platform and the serious games (frequency of use, games pleasing or not). If feasible, it could also tackle the motivational aspects of the patient during the exercising, e.g. by sending motivational messages at the right moment or increasing the level of difficulty through boredom detection.

Display
The display of the information would be realized on the screen used for gaming or exercising, either the TV or a computer/tablet depending on the types of games and apparatus involved.

In real-time:

- Gait tracking incorporated into the task and used for the actions of the serious games / world navigation
- Weight transfers incorporated into the task and used for the actions of the balance games
- Motivational messages based on emotions analysis (feasibility to be investigated)

At the end, the post-processed data could be displayed as a summary with:
Possible flow diagram
The diagram (Figure 3) shows an initial common interaction flow for the general scenario that relates the different elements of the proposed STARR system in D6.1 and which will enable a final technical discussion at the end of this deliverable to input technical functionalities to help WP6 in the architecture design and implementation.

4. Scenarios
Walking/moving platform with serious games
Since being back home, without the regular assistance of therapists, James had been feeling demotivated to keep walking regularly. He had experienced a fall once outside on his own, which had been humiliating...
and painful and since then he had been walking outside only with his wife and barely inside the house. As his wife was still working, he used to mostly watch the TV. His physiotherapist had noticed the decline in his walking abilities and had suggested him to use the STARR system with its walking platform at home, in a similar way as in the rehabilitation center, so he could keep practicing and regain confidence to go outside on his own during the day. As he was familiar with the platform, he has been giving it a try. He connected the STARR walking platform (treadmill, Kinect, instrumented shoes and the STARRbox) to his TV that he can rotate easily without having the walking platform in the middle of his living room. He plays the games every two days or so, on the days the physiotherapist is not coming. He enjoys it as it feels secure at home and as the games are pretty entertaining. The games are science-fiction games where he has been exploring new planets in outerspace. In one of them there were even flying pizzas that he could catch to survive on the hostile deserted planet, it really made him laugh. The games usually combine tasks involving pure exploration such as following the steps of an explorer to rescue and tasks involving interacting with the world objects with the arms. He also gets motivational messages to encourage him when he is less successful. Sometimes, the system somehow guesses he is getting bored or that he is performing easily too well, and the level of difficulty slightly increases. At the end of the game, a dashboard displays the results of the performance of the day as well as the evolution with prior sessions. Sometimes it also displays a recap on the risk factors with some suggestions, especially if there has been a decline in the evolution. As the STARR system also includes input information from the other risk factors (such as weight, blood pressure, etc.), he understands better the link with physical activity and the risk of having another stroke.

Every two weeks, when his physiotherapist comes, he makes him perform the standard evaluation exercise using the platform. Then, they take a few minutes to look at the performance evolution provided by STARR. The physiotherapist thus gives tailored performance goals and advice on issues to watch out for and how to improve them, for example related to weight transfers, and other possible games that would be suited to James. When he goes to see his doctor once a month, the doctor also has a look at the general walking activity data provided by STARR, and assists with inputting medical data about other risk factors (e.g. blood pressure, blood sugar, etc.) to keep an accurate picture of the evaluation of risk factors. It helps the doctor adjust the medical treatment as he has quantitative data to support it in addition to the feedback provided by James.

**Balance games**

Kim has problems with his balance. Because of these problems, he avoids many activities that he used to enjoy. He discussed this with his physiotherapist, and was told that if he worked on it, his balance could improve – but also that it could be a good idea to get some kind of walking support to prevent a fall. Furthermore, he was told that balance training is a useful physical exercise. With this information Kim bought a small balance board and, following the recommendation of his therapist, placed it in front of a window frame so that he had something to hold on to. He tried to do the exercises but quickly lost his motivation: he found it boring to just stand there, and he couldn’t really feel he was making any progress.

At the next physio appointment, he grumbled about this to his therapist. The therapist told him about the new STARR balance training program, and asked him if he would like to try it. Not really expecting much, Kim agreed. He bought the soft mat and STARR platform and got help to set them up at home from his kids. It was actually quite easy to install and connect it with the user guide, a bit like the installation of internet.
He started with the music game as suggested by his therapist. By moving his feet on the soft mat, he can play something similar to “guitar hero” – feet movements add instruments/melodies to a tune that Kim has selected and the goal is to play the tune right. Sometimes they even use it during the sessions so that the physiotherapist can provide tailored advice to correct issues and suggest other interesting games. There are other available games, for example that connect to a tablet or a screen, but Kim finds the visual feedback distracting and prefers the music game for now. Also this way he can put the mat anywhere. He now finds it easier to keep the motivation for the training – and can also follow his progress through increasing high scores. When his grandchildren visit, they also think it is fun to try out the game. As time passes, Kim finds it a little easier to walk (although he still needs the walking support) and starts to be more active (thus reducing the risk of a second stroke).

The mat also sends information to his tablet about his evolution to the STARR application. The interface displays his scores, general tips to improve his balance based on his results and through the measurement of the activity, provides occasional updates on the various risk factors and the risk of a second stroke. It provides him with an overall view of his state that also motivates him to keep exercising.

5. Challenges

- Design feasible and acceptable technological solutions for exercising
- Gait and gesture tracking with possible occlusions from the various technological solutions involving security support (e.g. support bars)
- Linking the gait tracking to the feedback and actions in the games / exploration worlds
- Emotion tracking for assessing the game quality (and adapt the content accordingly)
- Linking of physical activity or inactivity to the risk factors

6. Link with Risk Factors

Several studies have been conducted that highlight that stroke survivors, once back home, may have a reduced level of physical and/or general activity. In a meta-review, Field et al. [4] report that stroke survivors do not reach recommended levels of activity. They add that further research is necessary to “identify how to promote physical activity amongst ambulatory stroke survivors, and how to reduce disability so that stroke survivors are able to participate in levels of physical activity that are likely to have an effect on secondary stroke prevention”. As mood or depression can be both a cause and consequence of reduced level of physical activity [4], it is important to develop solutions that not only deal with physical activity but other aspects related to engagement, motivation and self-efficacy. Gaming at home with secure equipment could answer some of these needs and challenges.

Inactivity or cardiovascular deconditioning is a risk factor in itself but also has an impact on various other risk factors. For example, a decline in walking abilities can have an impact on the stroke recurrence or appearance of complications through for example a reduced functional ability, reduced autonomy and pain. These in turn can impact the diet, the weight, the bad habits such as smoking or drinking abusively and the emotional state through depression. Hence, lifelong participation in programs of exercise after stroke should be encouraged [5]. Recognised national recommendations state that all adults should accumulate 30 minutes of moderate activity on most days of the week. Indeed, exercising generally produces positive
effects even though there is still insufficient evidence due to the size of studies. As reported in [5], there may be positive effects from cardiovascular training on gait speed, stair climbing, human activity profile, motor function, workload and exercise time. Jennings et al. [6] demonstrated that a regular moderate exercise leads to a clinically significant fall in resting blood pressure associated with a fall in peripheral resistance and an increase in cardiac output. They conclude that “increased physical activity in young sedentary normal subjects has effects that should reduce the possibility of subsequent development of cardiovascular disease” and that “30 min of bicycle exercise at 60% to 70% of Wmax three times weekly is sufficient for most of the beneficial hemodynamic and metabolic effects to occur”. Although these results were obtained for young normal participants, they also add that similar mechanisms would occur with “more protracted comparable activity, or in older subjects”. These various studies show the importance of performing regular physical activity to lower risk factors.

7. Privacy Implications
The tracking of the user’s gait and facial expressions will be performed with the users’ agreement (with some optional functionalities). The post-processing analysis of the data collected during the exercising will be displayed on the TV and on the users’ peripheral running the STARR system (computer, laptop, tablet, etc.). The data measured during the sessions (see Section 3. Technical Requirements) will be stored locally on the stroke survivor’s computer (or any hardware with storage and computational capabilities) running the games thus limiting privacy issues with online storage. In some cases, solely the result will be stored and not the raw data collected: for example, for the emotion analysis, the face of the stroke survivor does not need to be stored, solely the emotions recognised as an output of the emotion recognition algorithm. The same local storage will be used for the data inputted into the system regarding the risk factors and profile of patient (age, medical history, weight, etc.). The stroke survivor will assign the authorizations to other members of the family or carers to have access to the data.

Privacy will be at stake with the data to be shared with the therapists concerning the evolution and performance measures. To ensure privacy is respected, this data should only be shared upon agreement of the patient thus defining the mode of transmission (either the stroke survivors show themselves the local data to the therapists on their device or it can be sent automatically through the secure STARR system servers) and the type of data to be shown (raw, just post-processed data, etc.). Data security measures will be implemented to ensure privacy as advised in the work conducted in WP8, and in particular in the deliverables D8.2 and D8.3.

II. Daily lower and upper limb activity monitoring

1. Scenario Objective
The goal here is to simply monitor any regular physical activity and especially the inactivity to raise the appropriate alerts. The information collected would be mostly qualitative. No precision or specific performance is required but rather global measures such as the distance travelled per day, frequency of activity or the level and time of pressure applied by the paretic limb. Data about general activity could thus be collected at different moments for further evaluation (e.g. with doctors, physiotherapists, etc.) and also to let the patient keep track of their efforts and encourage them to keep moving and being active.
2. Target Users

- Walking ability: level 3-4 minimum on the FAC (see Table 2)
- Also patients able to move about in a wheelchair independently
- For upper limb monitoring, upper limb disability: level 2 minimum on the Enjalbert Scale (see Table 3)

**Table 2: FAC**

<table>
<thead>
<tr>
<th>FAC Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Non Functional Ambulator</td>
</tr>
<tr>
<td>1</td>
<td>Ambulator - Dependent for Physical Assistance (level 2)</td>
</tr>
<tr>
<td>2</td>
<td>Ambulator - Dependent for Physical Assistance (level 1)</td>
</tr>
<tr>
<td>3</td>
<td>Ambulator - Dependent for Supervision</td>
</tr>
<tr>
<td>4</td>
<td>Ambulator - Independent, Level surfaces only</td>
</tr>
<tr>
<td>5</td>
<td>Ambulator - Independent</td>
</tr>
</tbody>
</table>

Patient cannot ambulate, ambulates in parallel bars only, or requires supervision or assistance from more than one person to ambulate safely outside parallel bars.

Patient requires manual contact of no more than one person during ambulation on level surfaces to prevent falling. Contact is continuous and necessary to support body weight as well as to maintain balance or assist coordination.

Patient requires manual contact of no more than one person during ambulation on level surfaces to prevent falling, consisting of continuous or intermittent light touch to assist balance or coordination.

Patient can ambulate without manual contact from another person but, for safety, requires standby guarding of no more than one person because of poor judgement, questionable cardiac status, or the need for verbal cuing to complete the task.

Patient can ambulate independently on level surfaces, but requires supervision or physical assistance to negotiate any of the following: stairs, inclines, or non-level surfaces.

Patient can ambulate independently on nonlevel and level surfaces, stairs and inclines.

**Table 3: Enjalbert Scale for Vascular Hemiplegia**

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No primer recovery. No grasping</td>
</tr>
<tr>
<td>1</td>
<td>Synkinetic approach in the abduction-retropulsion of the shoulder and elbow flexion</td>
</tr>
<tr>
<td>2</td>
<td>Analytical approach without a possible grip.</td>
</tr>
<tr>
<td>3</td>
<td>Analytical approach, global grip but without an active release.</td>
</tr>
<tr>
<td>4</td>
<td>Analytical approach, global grip and an active release.</td>
</tr>
<tr>
<td>5</td>
<td>Existing tri-digits grip.</td>
</tr>
</tbody>
</table>
6  Fine “Surnormal” grasping.

Similarly to scenario 1 focusing on exercising the upper and lower limbs at home, this scenario also aims to target a wide range of stroke survivors who suffer from lower and upper limb disabilities but this time by monitoring the activity of these limbs to help reduce aggravation of the impairment (e.g. decline in mobility and pain). Indeed, in the UK, 80% of stroke survivors have their general movement affected, 70% their arm movement and 40% are unable to use one arm in the long term [1]. More recent statistics in the UK listed that 77% of stroke survivors suffer from upper limb/arm weakness and 72% from lower limb/leg weakness (the highest in the list of disabilities) [2]. In Australia, impairment in the ability to undertake physical activities was the most common impairment for people who experienced impairment as a result of a stroke (close to 60% of the stroke survivors affected) [3]. Difficulties using arms or fingers, gripping or holding things and using feet or legs were also frequently experienced problems.

3. Technical Requirements

Possible Apparatus (depicted in Figure 4)

Monitoring of the stroke survivor could be realized by equipping him/her or his/her accessories with a set of wearable sensors, as no single accessory works at all times for every displacement, such as:

- Inertial sensors in a dedicated wristband (from STARR partners or a commercial one) preferably for the upper limb
- Dedicated instrumented insoles or shoes for the lower limb
- Inertial sensors embedded in an orthosis (lower or upper limb)
- Inertial sensors embedded in the wheelchair or cane (if a dedicated wearable is rejected, and to measure at least the use of the aids and also accommodate the different user profiles, such as one moving solely in wheelchairs)
- Tablet / Smart phone / computer to display the STARR interface and communicate with the wearables

Placement: As what matters is whether patients are moving about, concerning the evaluation of general activity and more so the inactivity, the sensors do not need to be on the dysfunctional limb (e.g. to include the case of the cane) but on any everyday object that is carried at nearly every displacement (e.g. cane, orthosis, or wearable). However for measures related to the dysfunctional limb, such as height levels for the upper limb, the wearables will be placed onto that limb.

Requirement: sensors should be easily embeddable in the everyday accessories (orthosis, cane, and wheelchair or else). Wearables should be affordable, compact and lightweight with an acceptable autonomy.

The continuous measurements should be triggered automatically when the activity is starting (walking, standing up, moving the arm) and go to sleep mode when the stroke survivor is inactive.
D 4.1: Use case scenarios and technical requirements

**Figure 4: Possible apparatus for monitoring the physical activity**

**Measures**

- Duration spent moving (either walking or standing)
- Frequency of movements
- For the upper limb additionally: height levels reached up/down/left/right (according to patients to analyze the level of integration or level of use). Speed could also detect contra-indicated movements (such as uncontrolled movement when standing up and arms rapidly falling down)
- Inactivity
- Accessory used for walking (e.g. patient able to walk but overly using the wheelchair)
- Activity of the paretic limb (e.g. weight transfer with pressure sensitive shoes)

⇒ Precise data about movements is not needed but rather the overall level of activity achieved and its evolution. For example, a decrease in activity of more than 50% is not acceptable.

**Analysis**

The measurements would focus on measuring the overall “moving about” activity (duration, frequency, with additionally height levels reached and speed for the upper limb) or inactivity. The collected data would be shared regularly with carers and if agreed upon with therapists to not only get data about the level of physical activity performed once at home but also to raise alerts in cases of inactivity which could require a rehospitalisation. This applies both to stroke survivors able to walk, but also to stroke survivors in a wheelchair who can independently control it. Indeed, a lack of movements would trigger alerts sent to their carer and after validation through a call centre for example, to the appropriate therapists due to the possible issues of lack of motivation, pain, depression, etc. which could generate further complications or aggravated health. For stroke survivors able to walk but also using a wheelchair at times, this data could also point out the overuse of the wheelchair and the lack of effort to maintain walking skills.

The overall data would be regularly inputted to the main STARR system to update the predictive risk factor modelling and the self-management program.

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icons made by Freepik from http://www.flaticon.com
Display
The display would be done at the end with post processing on the device used to display the STARR interface (either tablet or computer) with the following parameters:

- Estimates of frequency of moving about
- Estimates of duration of moving about
- Levels of height reached by the upper limb
- Estimates of use of the paretic limb and weight transfers for walking and balance
- Estimates of involuntary contraindicated movements
- Inactivity
- Estimates of accessories used for walking
- Link to risk factors

Possible flow diagram
The diagram (Figure 5) shows a common interaction flow for the general scenario that related the different elements of the proposed STARR system in D6.1 and which will enable a final technical discussion at the end of this deliverable to input technical functionalities to help WP6 in the architecture design and implementation.

![Flow Diagram](image-url)

**Figure 5: Flow Diagram for Scenario 2**
4. Scenarios
Moving about

At the rehabilitation center, Lisa felt like she was really getting better and hence was walking a lot. Since being back home, Lisa fell a couple of times and realized she was not really improving any further. Also she started getting really tired and feeling pain at times. So she started to walk less and less and stay inside at home watching TV instead. Her physiotherapist noticed the decline in her walking abilities and suggested her to use the STARR system with its walking monitoring option as it could also raise alerts to her husband and the appropriate therapists in cases of pain and fatigue. She didn’t like the idea of being monitored much, but as the physiotherapist mentioned that the pain would only get worse if she kept being inactive, she thought she should try at least. As they were not too expensive, she bought the patch sensors that she attached to her leg orthosis and the cane she occasionally uses when she feels very tired. The patches were really easy to install so that was a plus. She then paired the patches to an application her son installed on her tablet. She isn’t very much at ease with new technologies but her son showed her the interface and it seemed rather intuitive. Furthermore, she only needs to connect the patches to the interface on the tablet once a week to upload the data so it is not too constraining. She usually does it at the same time she prepares her medication together with her husband for the week, therefore integrating this step in her weekly routine.

When she walks, the patches collect data about how often she walks, for how long, etc. but she doesn’t see anything then. It is only when she connects the patches to the interface on the tablet that a nice dashboard displays all sorts of statistics on her level of activity. She prefers it like that as she does not want walking to become an exercise that she has to be forced to do or obsess about in terms of performance. For her once a week is enough to learn overall how long and how frequently she has been moving actively over the week and the comparison with previous weeks. She feels more motivated this way than if she had to look at it every day. She also gets a recap on her risk factors with some suggestions. As the STARR system also includes input information from the other risk factors (such as weight, blood pressure, etc.), she understands better the link with physical activity and the risk of having another stroke.

When her physiotherapist comes by, in addition to the usual session, they take a few minutes to look at the activity evolution provided by STARR. The physiotherapist thus gives tailored goals and advice on issues to watch out for and how to improve them, for example related to weight transfer to avoid fatigue and pain. When she goes to see her doctor once a month, the doctor also has a look at the general walking activity data provided by STARR, and assists with inputting medical data about other risk factors (blood pressure, blood sugar, etc.) to keep an accurate picture of the evaluation of risk factors. It helps the doctor adjust the medical treatment as he has data to better evaluate her case.

Once, she started feeling very tired again and in pain, she had stopped walking for a couple of weeks. The STARR platform sent her regular reminders and motivational messages to try staying active but she ignored them. Even though the liberal physiotherapist noticed it and told her to contact her doctor, she didn’t as she was feeling rather depressed. However, she received a call from the STARR call center two weeks after she had stopped walking much as the STARR system had raised an alert about the lack of activity. The call
center called first to assess the problem and evaluated that the alert was not the result of a malfunction from the STARR system. Therefore the call center relayed the inactivity alert to her doctor who had previously agreed to being contacted this way. Soon after she received another call from her doctor. They rapidly scheduled an appointment so that the doctor could check what was going on and adjust the medication accordingly to deal with the pain, fatigue and depression. This was really helpful and as soon as it got better, she started walking regularly again.

**Upper limb monitoring**

When he got back home, as Paul was heavily helped by his wife for all the daily tasks, and without the regular pushing of therapists, he stopped using regularly his injured upper limb. He got used to doing things with his functional arm and for the tasks requiring assistance such as cutting his meat, his wife is always by his side ready to help. It has even strengthened their bond in some ways so he enjoys it. However recently, he started feeling some pain that he reported to his physiotherapist. Noticing also the rapid decline in the upper arm mobility, his physiotherapist encouraged him to use the STARR system to help reduce the pain by monitoring his activity, providing some motivation and raising some alerts for too prolonged inactivity. He didn’t have to rely less on his wife or change fully his habits, just exercise his upper limb more.

Therefore, he bought the STARR wristband that he wears every day. The wearable also displays time, so it acts as an enhanced watch and thus it does not bother him too much. He paired the wristband to his smartphone quite easily and he only needs to upload the data into the STARR application once a week, i.e. the application automatically loads the raw data from the wristband when it is connected and performs the analysis for the statistics. However as he quite like the activity statistics provided by STARR and the goals that it provides, he uploads it more frequently. These statistics display general information about how much he has moved his upper limb in terms of duration and frequency. The goals are set by his physiotherapist so he gets excited when he reaches them. As the STARR system also includes input information from the other risk factors (such as weight, blood pressure, etc.), he also sees some information about the impact that the activity of his upper limb has on reducing the risk of having another stroke. He realizes how all the risk factors are linked and the importance of physical activity.

When his physiotherapist comes, in addition to the usual session, they take a few minutes to look at the activity provided by STARR. The physiotherapist has access to the raw data and thus filters out the information in ways that Paul does not have access to. It gives them both new insights about things to improve and the new goals to set. When he goes to the doctor once a month, the doctor also has a look at the general data provided by STARR, and assists with inputting medical data about other risk factors (blood pressure, blood sugar, etc.) to keep an accurate picture of the evaluation of risk factors. It helps the doctor adjust the medical treatment and inform Paul about the general picture of the evolution of his post-stroke injuries.

### 5. Challenges

- Wearables adapted to and accepted by stroke survivors and integrated into a monitoring platform
- Wearables measuring slow dynamic
- Easy instrumentation of everyday wearable accessories (e.g. cane or orthosis) adapted to stroke survivors to monitor moving about (walking / standing) and upper limb activity
• Linking of physical activity to the risk factors
• Raising of alerts to prevent hospitalisation

6. Link with Risk Factors
As stated in [5], recognised recommendations state that all adults should accumulate 30 minutes of moderate activity on most days of the week. This scenario will enable to monitor whether such a level is achieved. Inactivity or cardiovascular deconditioning can have dire impacts on the risk factors and daily living. For example, a decline in walking abilities and upper limb motor function can have an impact on autonomy, grooming, dressing, performing daily activities and pain. These in turn can impact the risk factors, such as diet, weight, smoking or drinking abusively and the emotional state through depression, which can increase the risk of having a recurrent stroke. As previously described for Scenario 1, Section 6. Link with Risk Factors, various studies have shown the importance of performing regular physical activity to lower risk factors as physical activity has an impact on cardiovascular parameters and depression.

7. Privacy Implications
The data measured (see Section 3 Technical Requirements) will be first stored locally on the wearable device and then on the device running the STARR application after upload, so there should be no privacy infringement. The same applies to the data inputted into the system regarding the risk factors and profile of the stroke survivor (age, medical history, weight, etc.).

Privacy will be at stake with the data to be shared with the therapists concerning the inactivity and overall walking activity indicators. To ensure privacy is respected, this data should only be shared upon agreement of the stroke survivor thus defining the mode of transmission (either the participants show themselves the local data to the therapists on their device or it can be sent automatically through the secure STARR system servers). Together with the therapists and the carer, the stroke survivor will also provide agreement on the type of data that can be shown with the corresponding information: raw (enables performing other operations and adjusting more precisely the treatment), just post-processed data (limits the privacy infringement but also limits the data analysis that can be performed to gain information for adjusting the treatment), a mix of raw and post-processed data depending on the parameters, etc.). Data security measures will be implemented to ensure privacy in the collection, storage and sharing of data as advised in the work conducted in WP8, and in particular in the deliverables D8.2 and D8.3.

III. Indoor and outdoor exercising

1. Cardiovascular training
   1.1. Scenario Objective
The goal for this scenario is to encourage daily exercising through a cardiovascular training program suited to the stroke survivor’s profile and taking into account the perceived effort and the climatic conditions. Indeed, the aerobic exercises workouts proposed by the system both indoors and outdoors will be adapted according to the goals achieved and perceived effort. Additionally, information about the geographic terrain along with the climatic conditions will be collected to adapt the training to enable the stroke survivor to exercise in an efficient and effective way anywhere in the world. Therefore, the training
program will be adapted to the stroke survivor’s condition and the environment in real time, similar to having a coach at home.

### 1.2. Target Users
- Stroke survivors cognitively able to integrate information.
- Stroke survivors with a minimum capacity of ambulation FAC 2

Similarly to scenario 1 and 2 focusing on the upper and lower limbs movements, this sub scenario also aims to target disabilities related to movement. Indeed, in the UK, 80% of stroke survivors have their general movement affected [2]. More recent statistics in the UK listed that 77% of stroke survivors suffer from upper limb/arm weakness and 72% from lower limb/leg weakness (the highest in the list of disabilities) [2]. In Australia, impairment in the ability to undertake physical activities was the most common impairment for people who experienced impairment as a result of a stroke (close to 60% of the stroke survivors affected) [3]. Difficulties using arms or fingers, gripping or holding things and using feet or legs were also frequently experienced problems.

### 1.3. Technical Requirements

**Possible Apparatus**

A wearable or wearable device(s) including a:

- Heart Rate Monitor
- GPS to assess distances, terrain, altitude
- Accelerometer for measuring the number of steps
- Access to an application or online site with weather data
- A computer / tablet / smartphone with the STARR application

**Measures**

- Heart Rate
- Distance travelled
- Training time
- Number of steps
- Length of steps (feasibility to be investigated)
- Walking speed
- Geographic elevations, terrain topography
- Temperature and relative humidity
- Perceived exertion scale: New Borg Scale (see Figure 6)
- Emotional status (e.g. the Goldberg scales Figure 7)
Table 5.2B: The category-ratio scale of perceived exertion—the new Borg Scale

<table>
<thead>
<tr>
<th>Rating</th>
<th>Perception of effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Nothing at all</td>
</tr>
<tr>
<td>0.5</td>
<td>Very, very weak (just noticeable)</td>
</tr>
<tr>
<td>1</td>
<td>Very weak</td>
</tr>
<tr>
<td>2</td>
<td>Weak</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Somewhat strong</td>
</tr>
<tr>
<td>5</td>
<td>Strong (heavy)</td>
</tr>
<tr>
<td>6</td>
<td>Very strong</td>
</tr>
<tr>
<td>7</td>
<td>Very, very strong (almost maximal)</td>
</tr>
<tr>
<td>&gt;10</td>
<td>(any number)</td>
</tr>
</tbody>
</table>

From BJ Nolte et al. (1983, p. 122), © by Lippincott, Williams & Wilkins. Adapted by permission.

Figure 6: The new Borg Scale

Depression. Think about how you have been feeling recently:

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you been lacking in energy?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you lost interest in things?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you lost confidence in yourself?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you felt hopeless?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you had difficulty concentrating?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you lost weight (due to poor appetite)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you been waking early?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you felt slowed up?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you tended to feel worse in the morning?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Anxiety. Think about how you have been feeling recently:

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you felt keyed up or on edge?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you been worrying a lot?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you been irritable?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you had difficulty relaxing?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you been sleeping poorly?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you had headaches or neckaches?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you had any of the following: trembling, tingling, dizzy spells,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sweating, diarrhea, or needing to pass water more often than usual?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you been worrying about your health?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you had difficulty falling asleep?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7: The Goldberg Depression and Anxiety Scales
Analysis
The measurements would focus on measuring the heart rate and the related effort through the collection of distance travelled, speed, step length, training time, accumulated slope, altitude at which the activity is performed, temperature and humidity. The analysis of these measures would focus on correlating the variation of the heart rate with the effort. It would also be compared to the effort perceived by the stroke survivor through the delivery of the modified Borg scale (see Figure 2). The Goldberg depression and anxiety scales administered regularly would enable to monitor the link between the emotional status and the realisation of the training, i.e. the influence that the emotional status can have on exercising and vice versa, whether exercising has an impact on improving this status.

Measures related to the weather and the state of the terrain would also enable adjusting the training program in function of the stroke survivors’ ability in such conditions. The STARR application will help the stroke survivor organise the moment of the training depending on the weather and geographical conditions (in fact it is not the same to walk at 40° with 90% humidity than during dry weather). Such a tailored training program, adjusting in real time to geographic conditions, can motivate the stroke survivor to exercise. Improvement in any of the collected measures, either objective or subjective, will be monitored and be a valuable source of data for the therapist to assess the stroke survivor’s evolution but also check for possible error or deficiencies in the training sessions.

The evolution between the training sessions will be analysed and displayed to the stroke survivor. For example, the step length and walking speed will be monitored to inform the stroke survivor and his/her carer of any significant decline, thus raising alerts that could lead to an increased risk of falls.

The overall data about physical activity and emotional status would be regularly inputted to the main STARR system to update the predictive risk factor modelling and the self-management program.

Display
Before starting the training, the wristband or STARR application could display the weather and geographical situation and depending on the climatic conditions propose a cardiovascular exercise tailored to the stroke survivor’s profile.

In real time, the wristband could display the following information so that the stroke survivor can adjust his pace or know when to stop the exercise:

- The heart rate
- The distance walked
- The weather
- The number of steps
- The walking speed
- The altitude
- The elevation gain
- The temperature / humidity
At the end of the cardiovascular activity, the modified Borg scale will appear to be filled out. The different measures will enable the computations of the relationship between the heart rate variation and the perceived exertion and walking performance. General statistics about those will be displayed for information, such as evolution between sessions for the various walking parameters (e.g. step length, distance and duration).

1.4. Scenario
Adrian has always been very fit before his stroke, exercising was quite important to him so he used to run several miles, cycle and swim. He still wonders why someone fit like him was affected by a stroke. After his stroke, it was difficult to regain the same physical abilities, he could not run or jump anymore, or even swim. At least, he could still go out for walks. As he was rather depressed when he came out of the rehabilitation center because he thought he would have been able to regain most of his abilities, his therapists advised him to use the STARR application with the cardiovascular training module. Coupled with a wearable, it would help him exercise safely with his “new” abilities, all the while providing achievable goals that adapt in real time according to the climatic conditions. As he did not want to give up on all the things that use to matter to him, he decided to try.

He installed the STARR application on his tablet and bought the corresponding smartwatch. After inputting general information about his profile (stroke and medical history), together with the physiotherapist and doctor, he established a training program with weekly minimal periods of training time including minimal distance to walk and the minimal effort to perceive without exceeding a submaximal heart rate. After that, Adrian was in charge of his own training and adapting it according to the weather and terrain though the STARR application was always providing some suggestions and some goals.

With varying altitude, temperature and humidity levels, the goals would adapt in order to perform an efficient activity, i.e. maintaining the heart rate and sense of perceived effort long enough in a range of acceptable values (i.e. less than the established submaximal heart rate and more than the minimum levels defined). It was quite motivating as the goal was never the same and adapting to the forecast or the place he was staying at. Moreover, as the STARR application was collecting various information and regularly enquiring also about this emotional status, in particular related to depression and anxiety, he felt like the program was always adapted to him but also trying to push him a little to walk regularly.

1.5. Challenges
- Monitor the influence of exercising on risk factors
- Monitor the influence of personalisation and self-management of cardiovascular exercise on the therapeutic success
- Integration of physical effort subjective and objective data collected during cardiovascular exercise to achieve success in training
- Monitor the influence of emotional aspects in performing training and the effect of training on improving the emotional status
- Providing information to the stroke survivor based on their walking performance to reduce the risk of falls
2. Encouraging mobility through gaming

2.1. Scenario Objective
The goal for this use case scenario is to encourage daily mobility through gaming with possible collaborative participation. The recent popularity of Pokémon GO\(^3\) shows that an augmented reality (AR) game can be a powerful motivator for moving. Similarly, the objective of such a game for this scenario would be to find some sort of “treasure” but also to collect steps to unlock new features or items. The game could also involve hiding treasures for others – friends and/or family. The game needs to be carefully designed for the user group, and any challenges within the game should be adapted to the user group. The game should be possible to play both indoors and outdoors, and involve different levels of physical activity and skill. The overarching goal of the game is to encourage moving around – both indoors and outdoors – as well as social interaction around the “treasures”. The game should also allow the stroke survivor to see the level of activity he/she performed, for example by showing how much he/she has moved (steps, or similar).

2.2. Target Users
This scenario targets stroke survivors who are able to walk unassisted or with assistance (level 3-4 minimum on the FAC see Table 2 and level 3 on Rankin scale) and also stroke survivors in wheelchairs but able to action it themselves.

Similarly to scenarios 1 and 2 focusing on the upper and lower limbs movements, this sub scenario also aims to target impairment related to movement and the related physical activity. Indeed, in the UK, 80% of stroke survivors have their general movement affected [2]. More recent statistics in the UK listed that 77 % of stroke survivors suffer from upper limb/arm weakness and 72% from lower limb/leg weakness (the highest in the list of disabilities) [2]. In Australia, impairment in the ability to undertake physical activities was the most common impairment for people who experienced impairment as a result of a stroke (close to 60% of the stroke survivors affected, Figure 1) [3]. Difficulties using arms or fingers, gripping or holding things and using feet or legs were also frequently experienced problems.

2.3. Technical Requirements

Possible Apparatus
- Smartphone
- (and/or) smartwatch or activity wristband
- AR games (e.g. treasure hunts)

Measures

*Automatic recording:*
- Activity level: duration, frequency
- Step count or distance
- Movement: localization
- Level in the game

\(^3\) http://www.pokemongo.com/en-uk/
Analysis & Display
The measurements would focus on measuring the overall moving about activity during the game (duration, frequency, steps). The collected data would be fused with the data collected in the other scenarios involving measurements related to physical activity, i.e. Scenarios 1, 2, 3 (depending on the data available / devices used) to form an aggregated picture of the global level of physical activity. The aggregated data as indicated in Scenario 2 would be sent to carers to inform them about the stroke survivors and to therapists to get data about the overall level of physical activity performed once at home but also to raise alerts in cases of inactivity.

This game would encourage stroke survivors to be more active through enjoyable gaming with rewards, reminders and motivational messages and could be an initial countermeasure to alerts raised in Scenario 2 to motivate stroke survivors to engage in physical activity. The data collected relative to the game (e.g. localization) would be displayed through the gaming interface and used in real time whereas the overall activity data (e.g. duration, frequency, distance or step count) would be computed with post-processing and inputted into the main STARR system to update the health dashboard with the relevant activity statistics as well as the predictive risk factor modelling and the self-management program.

2.4. Scenario
Ada uses an electric wheelchair outside. Inside the house she tries to challenge herself to move between different rooms, but often finds that she forgets to do this. A friend tells her about the treasure hunt game, and she decides to try it out. She got help to make the initial settings (goals, play area, play time, maximum play session length etc.) from that friend. Since that setup, the game sends her regular messages when treasures appear in a room, so that she can go there to pick it up. Having read about “Pokemon Go” she thinks her game is a bit similar, and also feels quite “cool” at being able to play something similar to a game so many other people enjoy. She tells Hans about this game, another stroke survivor she met at the rehabilitation center. Hans is able to walk, and often takes slow walks outside to get fresh air. Unfortunately, the area where he lives has fairly dull walking areas so it isn’t very motivating. Upon Ada’s suggestion, he decides to try out the game as a means to spice up his daily walks. He already tried Pokemon Go, but found it too difficult to play – the on screen gesture was too complicated. Hans also needs to time his walks so that he gets home before he gets too tired, but this feature was not available in Pokemon Go. He got help from the local stroke organisation in how to set up the games and enter the maximum durations for his walks (as well as other settings needed to personalise the game). Playing the game is fun, and after a while he notices that he no longer uses poor weather as an excuse for staying indoors. He enjoys the way he can talk to other players about his progress, and treasures he finds; they even started a friendly competition with Ada. He also likes that the game tracks his steps, so that when he visits the healthcare he can show how active he is.

Thanks to the game both Ada and Hans became more active and also keep better track of their overall level of activity. The STARR application that the game is linked to not only provides them about general evolution about their activity and the risk of having a second stroke but also links to other similar games adapted to them that they could play. Before trying new games, Ada and Hans usually talk about it in the STARR forum.
to see if it really matches their interest. This gaming feature really brought them together with other stroke survivors.

2.5. Challenges
- Wearables adapted to and accepted by stroke survivors and integrated into a monitoring platform
- User interface suited to stroke survivors
- Cardiovascular exercises adapting to climate and environmental conditions as well as to the stroke survivor’s profile
- Game design involving motivational and engaging aspects as well as collaborative / social components usable and accepted by stroke survivors
- Linking of physical activity to the risk factors

3. Possible flow diagram
The diagram (Figure 8) shows a common interaction flow for the global scenario of outdoor exercising (i.e. the two subscenarios with the cardiac coached training and the treasure hunting game) that relates the different elements of the proposed STARR system in D6.1 and which will enable a final technical discussion at the end of this deliverable to input technical functionalities to help WP6 in the architecture design and implementation.
4. Link with Risk Factors

As previously stated in Scenario 1, inactivity or cardiovascular deconditioning has an impact on risk factors. For example, a decline in walking abilities can have an impact on the stroke recurrence or appearance of complications through for example a reduced functional ability, reduced autonomy and pain. These in turn can impact the diet, the weight, the bad habits such as smoking or drinking abusively and the emotional state through depression. Hence, lifelong participation in programs of exercise after stroke should be encouraged [5]. Recognised national recommendations state that all adults should accumulate 30 minutes of moderate activity on most days of the week. Indeed, exercising generally produces positive effects even though there is still insufficient evidence due to the size of studies. Some studies for example, as reported in [5] have demonstrated positive effects from cardiovascular training on gait speed, stair climbing, human activity profile, motor function, workload and exercise time. Jennings et al. [6] demonstrated that a regular moderate exercise leads to a clinically significant fall in resting blood pressure associated with a fall in peripheral resistance and an increase in cardiac output. They conclude that “increased physical activity in young sedentary normal subjects has effects that should reduce the possibility of subsequent development of cardiovascular disease” and that “30 min of bicycle exercise at 60% to 70% of Wmax three times weekly is sufficient for most of the beneficial hemodynamic and metabolic effects to occur”. Although these results were obtained for young normal participants, they also add that similar mechanisms would occur with
“more protracted comparable activity, or in older subjects”. These various studies show the importance of performing regular physical activity to lower risk factors.

5. Privacy Implications
The data measured (see Section 1.3 and 2.3 Technical Requirements) will be first stored locally on the wearable device and then on the device running the STARR application after upload, so there should be no privacy infringement. The same applies to the data inputted into the system regarding the risk factors and profile of stroke survivor (age, medical history, weight, etc.).

Concerning the data collected and displayed in real time, the localization data will not be shared with others in a way that strangers or non-agreed people can see where the stroke survivor is. To ensure privacy is respected, the stroke survivor will be able to choose who the localization data and performance statistics can be shared with (i.e. only with family members or for the gaming sub scenario public collaborative gaming) and the data will be stored safely online. Data security measures will be implemented to ensure privacy as advised from the work conducted in WP8, and in particular in the deliverables D8.2 and D8.3.

IV. Spasticity monitoring
1. Scenario Objective
The goal here is to monitor contraindicated positions of the hand or foot due to high levels of spasticity. Spastic individuals often wear orthoses but they can suffer from very high spasticity which manifests either through their limb folding back into a contraindicated position with no longer any contact with all of the orthosis surface or exerting too much pressure on the orthosis through hyper-tonus (see Figure 9 and Figure 10). The idea is to equip the orthosis with some pressure sensors in order to monitor the points of contact and pressure exerted to avoid both of these situations and alert the carers and therapists in the event of such situations. Indeed aggravated spasticity can lead to painful pathogenic complications (e.g. contractures, skin ulcers, ingrown nail or complications involving surgery, Figure 10).

Figure 9: Examples of upper limb spasticity with a flexed elbow, a bent wrist or closed fist

4 From http://texasneurology.com/spasticity/
2. **Target Users**
This scenario aims to target stroke survivors with spastic limbs as spasticity affects a large number of stroke survivors and is one of the most common post-stroke conditions\(^5\). Indeed, in the UK, 19-38% of stroke survivors are affected [2]. The spasticity alliance states that up to 43% of stroke survivors report spasticity [8].

3. **Technical Requirements**
**Possible Apparatus (Figure 11)**
- Pressure sensors that can be patched onto the orthosis or pressure sensitive insoles or shoes
- Tablet / Smartphone / computer to display the STARR interface and communicate with the smart orthoses or shoes/insoles

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Requirements

- The embedded sensors and processing unit should have an acceptable autonomy (e.g. a week), as the recharging can be associated to the various weekly routines such as preparing medication.
- The system should be easily embeddable/attached to the orthosis.
- The pressure sensitive insole (or the pressure sensitive shoe which insole) should not be more than 7mm so the heel stays in the shoe.

Measures

- Lack of contact with the orthosis (limb folding back)
- Too much pressure exerted (hyper tonus)

NB: spasticity increases automatically during physical activity such as walking, but should be reducing in the following hours.

Analysis

The measurements would focus on the spasticity through measurements of pressure applied on the orthosis, either through overly applied pressure or on the opposite the lack of it at certain contact points. The collected data would be analysed to identify aggravated spasticity as it could generate complications and surgical interventions and also have an impact on depression and hence motivation to remain active. The goal is to raise the appropriate alerts to the carers in a first instance and if the situation keeps declining, after validation from the STARR call centre, alert the therapists.

Possible flow diagram

The diagram (Figure 12) shows a common interaction flow for the general scenario that relates the different elements of the proposed STARR system in D6.1 and which will enable a final technical discussion at the end of this deliverable to input technical functionalities to help WP6 in the architecture design and implementation.

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Figure 11: Possible apparatus by equipping orthoses or shoes with pressure sensors

Image of the leg orthosis taken from: [http://www.msmedical.net/le-pied-semelles/703-releveur-de-pied-dorsalex-neut.html](http://www.msmedical.net/le-pied-semelles/703-releveur-de-pied-dorsalex-neut.html)
4. Scenario

Joseph has never been motivated much by exercising. It was already difficult at the rehabilitation center, but it is even more so the case at home. At least at the rehabilitation center, the therapists were pushing him and moving themselves his spastic hand. Knowing him all too well, he’s been advised to get the smart orthosis from the STARR system to monitor his spasticity and raise appropriate alerts to avoid medical complications. He bought it just before leaving the center and thus the therapists helped him with the installation and pairing with his portable computer. Aside from the installation, all that was left to do was to upload the data every now and then into the application, which wasn’t too difficult. The dashboard provides general statistics about his spasticity along with some movements and exercises that he should be doing. Sometimes he does them a little but the motivation is often not there.

Once he started to feel some pain for a prolonged time, his hand had gone into hyper tonus. However the STARR system raised an alert and notified him to contact his doctor. Somehow he was scared to call the doctor about it and did not do anything further. He then received a call from his son who had received the same alert the next day and his son decided to schedule together an appointment with the doctor. In some
ways, he felt relieved his son was dealing with it. During the visit, the doctor adjusted the medication with stronger muscle relaxants which really helped with the pain and strongly recommended to do some little exercises to relax the hand, the same ones provided by the STARR application. He is not so sure he’ll do them, but he’s glad that the instructions are available at hand on his computer through the STARR application and that in case the situation gets really bad again, the system will alert his son again.

5. Challenges
- Smart orthosis or smart insoles/shoes (with pressure sensors) tailored to stroke survivors and accepted
- Raising of alerts to prevent complications/hospitalisation

6. Link with Risk Factors
High levels of spasticity leads to major complications consisting in muscle contractions, which have an impact on:
- Posture and functional ability (walking, grasping)
- Autonomy
- Grooming
- Dressing
- Difficulty sleeping
- And the major risk of bedsores and pain (low back pain, contractures)
These risks concern all stroke survivors exhibiting a high level of spasticity.

For stroke survivors demonstrating sufficient motor skills, spasticity may also hinder the expression of motor skills from the antagonists, e.g., upper limb wrist and fingers extensors or foot lifters for the lower limb.
The vibrations can be in itself a cause of great discomfort or imbalance.
Finally, spasticity is directly responsible for pain by:
- Prolonged muscle contractions
- Secondary tendinopathies,
- Joint hypertension and subluxations,
- Or bad positions.

Gillard et al. have shown that statistical and clinical meaningful differences in health-related quality of life (HRQoL) exist between stroke survivors with and without spasticity [9]. They also report that in addition to impacting self-care and ambulation, spasticity also leads to psychological and emotional issues, such as depression and poor self-image, which are important risk factors.

7. Privacy Implications
The data measured (see Section 3. Technical Requirements) will be first stored locally on the wearable device attached to the orthosis and then on the device running the STARR system after upload, so there should be no privacy infringement. The same applies to the data inputted into the system regarding the risk factors and profile of the stroke survivor (age, medical history, weight, etc.).
Privacy will be at stake with the data to be shared in cases of alerts concerning the contraindicated postures. To ensure privacy is respected, this data should only be shared upon agreement of the stroke survivor by choosing who can be alerted. A standard mode of operation would be alerting the stroke survivor and his/her carer first, and if the high level of spasticity persists or even declines, an alert should be sent through the STARR system, which would be verified by the STARR call center before alerting the therapist for further contact and visit. The stroke survivor could also provide agreement on the level of data shared, i.e. raw data or simple alerts with some thresholds with proper information about what can each option enable the therapist to do. The data would be transiting through secure servers and data protection measures would be implemented as advised from the work conducted in WP8, and in particular in the deliverables D8.2 and D8.3.

V. General self-management

1. Scenario Objective
The goal here is to provide an intuitive application with services to deal with the self-management of stroke. This application would generally include information about stroke for the stroke survivors and carers, recommendations for dealing with stroke injuries, a social platform, setups that are available for training or monitoring, reminders for medical and physical treatment and user inputs about medical measurements related to risk factors to monitor the risk of a second stroke. It would also propose the related services associated the scenarios described previously (i.e. setups for exercising and monitoring, information about state evolution, communication with carers and therapists).

This application would be customised to each stroke survivor upon fulfilling initial profile information to deliver tailored information concerning the stroke survivor.

2. Target Users
This scenario targets all the chronic stroke survivors except those suffering from severe cognitive or physical impairments, which would prevent them from being able to use the application.

In particular, this scenario encompasses the target users from the previous scenarios (1, 2, 3 and 4) as well as stroke survivors interested in managing other related lifestyle factors such as smoking, diet, etc.

3. Technical Requirements
Possible Apparatus
- Tablet / smartphone / computer

Measures
In this scenario all the possible modifiable risk factors are measured\(^7\) [1], directly or indirectly, and mostly by user input either by the stroke survivor himself/herself or the carer or in some cases the therapists:

- General profile information (for the setup): age, gender, medical history, information about the carer(s) and therapists
- Diet input: for example a scale indicating if the food intake over the week has been healthy and balanced or input of roughly how many times unhealthy food has been eaten

\(^7\) http://ontariostrokennetwork.ca/information-about-stroke/stroke-stats-and-facts/
- Blood sugar, with the possibility to get the information from connected apparatus
- Blood pressure
- Alcohol intake: scale to rate how reasonable the user has been
- Smoking: scale to rate how reasonable the user has been
- Weight, with the possibility to get the information from connected scales
- Physical activity with the possibility to get input from the other peripherals from the STARR system (cf. scenarios 1 to 4)
- Emotional status: through different scales, e.g. Figure 7: the goldberg depression and anxiety scales
- Medical compliance: through reminders if needed

Data about general lifestyle and other aspects of daily living that could have an impact on these measures could be enquired about through standard questionnaires, for example the Post-Stroke Checklist\(^8\).

**Analysis**

All the regular measures of the risk factors will enable to update the risk factor model(s) used in the STARR system and thus update the outputted risk of having a second stroke. This will be computed on a regular basis when the information is updated but will be delivered in a non-stigmatizing form to the stroke survivor. For example, recommendations will be provided to reduce that risk related to the factors elevating that risk. A health dashboard that aggregates all the data will show the evolution in terms of diet, medical measures, physical activity, etc. and focus on improvements. The iterative studies in WP3 and WP5 will help design a usable, intuitive and acceptable STARR application.

**Display**

The display will deliver summaries of the evolution of the state of the stroke survivor as well as links to information and a social platform for discussion. The information should cover aspects important to the stroke survivor and his/her caregiver. For example, as reported in [5], the five most important issues identified by patients and carers looking for information include:

- Medical Information
- Consequences of stroke
- Experiences of other patients and caregivers
- Home recovery
- Advice for the partner and the social circle

The STARR application could for example include or link to the MyStrokeGuide from TSA which already includes extensive material related to such topics of information as well as a social platform (see Figure 13 and Figure 14).

![General Interface of My Stroke Guide](image1)

**Figure 13: General Interface of My Stroke Guide**

![Section Advice on Clothes and Dressing of My Stroke Guide](image2)

**Figure 14: Section Advice on Clothes and Dressing of My Stroke Guide**

The design of the other elements such as the way to deliver results from the games and the health dashboard along with the link to the predictive risk modelling will be iterated upon in WP3 and WP5.
The display of the application could be based on behavioural models, for example the FRAMES behavioural change model to provide the order of items to display or query about, see Table 4 below.

**Table 4: The FRAMES model of behavioural change (explained in [5], Section 12)**

<table>
<thead>
<tr>
<th>Feedback</th>
<th>patient receives information about current status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsibility</td>
<td>patient assumes responsibility for change</td>
</tr>
<tr>
<td>Advice</td>
<td>patient receives suggestions that will help him or her in the change process</td>
</tr>
<tr>
<td>Menu</td>
<td>patient receives a number of alternative strategies for modifying the problem behavior</td>
</tr>
<tr>
<td>Empathy</td>
<td>patient receives warm support and respect</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>patient develops an “I can do this” attitude</td>
</tr>
</tbody>
</table>

Patients should be encouraged to take responsibility for their own health and be supported to identify, prioritise, and manage their risk factors.

### 4. Scenario

**Support for the caregiver**

Since her husband Jonathan has returned home after his stroke, Mary has been feeling a bit overwhelmed. One of the main sequels Jonathan suffers from is dysphagia, i.e. difficulty in swallowing, which apparently is quite common and affects 1/3 of stroke survivors. She has to be very careful about what she cooks for him and she is always worried he may choke and die because of her. Luckily, seeing how anxious she was, the therapists have suggested her to use the STARR application which is a gold mine for information and various tutorials. For example, it reminded her that she should not speak to him while he is eating so he can focus on the swallowing and that she shouldn’t use food with both types, i.e. solid and liquid food with some examples of recommended meals. As she entered the various information concerning Jonathan in the application, she often gets reminders and tips on how to deal with dysphagia and suggestions on meals for the week related to a healthy diet not to increase the risk of a second stroke. She also subscribed to the forum where she joined a group of carers who also have to deal with dysphagia. Here they often exchange recipes and discuss daily issues. Mary feels she has easy access to information and peer support. She still worries about Jonathan obviously but she feels like she has all the tools she needs to provide the care she can provide.

**Connected objects**

Annie loves good food so she has been having various excesses since she got back home after rehabilitation, like falling for good chocolate desserts or dishes with rich sauces. Before leaving, both her physiotherapist and occupational therapists told her to watch out for her weight as it could aggravate her mobility and hence require additional structural changes in her small flat. She lives alone since her husband passed away a few years ago. She gets occasional help from her kids but she has to take care of herself mostly on her own. To help her watch out for her weight and do some exercises, she invested in a connected scale, a connected activity wristband and the STARR application which contains various exercises.
she can do indoors and outdoors. The STARR application manages to get the information from the scale every time she weighs herself as well as the general level of physical activity from the connected wristband on a regular basis. In addition, at the end of the week, she also updates the diet input with a general evaluation of how healthy her diet was overall and the excesses she has had and their type (e.g. sweet or fat). Inputting the information is not the most exciting part but based on the evolution of her weight, her physical activity and her diet, the application gives her recommendations and tips about her weight and related exercises in a nice way with nice graphics and funny motivating messages. Sometimes it also tells her how to be able to keep eating food that she loves without it impacting her weight in a serious way. She feels like she has a life coach that still lets her have some guilty pleasures in a balanced way.

5. Challenges
- Self-management interface integrated in a platform with several peripherals for input
- Motivating system for long-term use
- Intuitive, acceptable and usable design of the user interface

6. Link with Risk Factors
Hackman and Nelson [10] demonstrated that a combination of 5 key strategies (namely 3 medications, exercising and diet) reduces the risk of recurrent vascular events by >80% in stroke survivors with a history of stroke or TIA and underlined the importance of a comprehensive and multifactorial approach. Therefore, a self-management program that tackles all the modifiable risk factors, including the 5 mentioned in the previous study, is a promising approach to reducing stroke recurrence. Moreover, a recent review collated evidence that self-management programs improved quality of life and self efficacy in people with stroke compared with usual care. The authors also found individual studies that reported benefits for health-related behaviours such as reduced use of health services, smoking, and alcohol intake, as well as improved diet and attitude.

In this scenario, both the dynamic measures collected during the exercises or through the daily monitoring described in the previous scenarios will be combined with the user inputted information (profile, diet, blood pressure) to update the models with all modifiable and available factors to provide as best as possible a dynamic picture on risk factors.

For example, the Zuum health tracker application, as described in deliverable D2.1, not only calculates the risk of various diseases but also adds a dynamic aspect linked to behavior change with the “What if” section (see Figure 16). For example, a smoker can see the update on his risk if he stopped smoking. Something similar could be implemented with the risk factors linked to stroke and based on the data collected regularly. Moreover advice about risk factors can be delivered in a similar way as depicted in Figure 16.
**Figure 15: Overview of the Zuum Health Tracker**
7. Privacy Implications
The data inputted by the users (age, medical history, etc.) or possibly measured through connected smart home objects/appliances (weight, blood sugar, etc.) (see Section 3. Technical Requirements) will be stored locally on the device running the password connected STARR application thus limiting any risk of privacy infringement.

Privacy will be at stake with the data chosen to be shared with the carer(s) or the therapists. To ensure privacy is respected, this data should only be shared upon agreement of the stroke survivor concerning the type of data to be shared, the type of transmission and the person to disclose it to, with the corresponding explanations so that the stroke survivor can make informed decisions. In the case of sharing, data will be stored securely on the STARR servers until reception by the therapists. Data security measures will be implemented to ensure privacy as advised from the work conducted in WP8, and in particular in the deliverables D8.2 and D8.3.

VI. Technical discussion
A detailed analysis of the different scenarios and their workflows highlight important technical functionalities that shape the future development of the STARR system. Scenarios can be split in two main domains: indoor and outdoor activities (Figure 17). These domains intrinsically define the type of devices that suit each activity. The scenarios indicate the need of using television for rehabilitation gaming activities, which seems the best user interface for this purpose. Likewise, activities related to monitoring daily routines and providing feedback like reminders, alerts and rewarding messages can be found in indoors and outdoors scenarios. For this purpose, either a tablet or a smartphone communication seems to be the right device to enable these activities, preferentially smartphone for outdoors. There seems to be a
clear separation of functionalities between the rehabilitation gaming scenario, which will require a specific system to handle the 3D sensors and the image processing to provide smartness and adaptation functionalities to the rehabilitation program. The rest of the services including the cardiovascular rehabilitation program, the spasticity and regular activity monitoring plus the different self-management services could be integrated as a part of a mobile application presented in both tablets and smartphones. These applications would be connected to the STARR platform to provide summary reports of the activities, to enable professionals to follow-up these reports and in turn, the platform would provide smart feedback (i.e. alerts, recommendations, reminders) as a result of the post-processing carried out in the decision support system (DSS). In turn, professionals will have also means to provide feedback assisted by the recommendations received by the DSS.

**Figure 17: overview of the scenarios**

Some different common functional requirements have been noted throughout the different scenarios presented as follows:

1. **Security**: The communication between either the Gaming System or the Telehealth client agent with the STARR platform must be secured. The STARR platform must provide functionalities to ensure authentication and authorization and privacy when communication is established between these devices and the remote STARR platform.
2. **Storage**: Applications should be able to work without network connection and therefore, should be able to store taken measurements and send them to the STARR platform when necessary. In turn, the STARR platform should provide a centralized secure mean to store this information to enable other elements.
3. **Post-processing**: The STARR platform should provide post-processing routines that analyze the gathered information and assess in the decision support providing smart recommendations, advices, alerts, etc., to both carers and stroke survivors and in some relevant agreed instances, the professionals.
4. Data visualization: The system should enable functions and user interfaces to get information reports showing relevant trends from measures taken both from stroke survivors and professionals.

Following the indication of D6.1, the STARR platform is composed of three main elements: the middleware, the decision support system and health services. This analysis recommends that security and storage functions are kept in the middleware, while post-processing is performed by the decision support system. The health services should enable the visualisation of the information for professionals as well as other potential application that can exploit the information exposed by the middleware and the DSS. On the stroke survivor side, the main application used in indoors and outdoors scenarios should be able to integrate different sensors (i.e. the telehealth client agent), store information locally and even having a first level of intelligence that can detect when measurements are out of normal. Furthermore, it must provide a friendly user interface as defined in WP3 and secure communication with the STARR platform. A first attempt to show a global functional system putting emphasis on the client side is presented in the Figure 18 below.

**Figure 18: overview of the global system**

This is the result of the coordination work between WP4 and WP6. The STARR telehealth client agent should develop different connectors to integrate the sensors, which are under selection in WP4. A broker should manage the incoming information and offering local storage to be able to show data when the user interface is asking for it. Therefore, a small database will be required for these purposes. Furthermore, this will be necessary to have a light rule engine that is able to apply local rules and give a first prompt level of smartsness to the client agent. Finally, the client agent will keep communication with the STARR platform by
using web services by using a clear API, which is under development in WP6 and is proposing REST services under JSON or SOAP messages. The first to intercept the messages will be the middleware, which will make communications secure and expose the information to the DSS and the professional user interfaces (a full description of the STARR architecture can be found in D6.1).

**Conclusion**

This deliverable presented possible scenarios that will be considered for the rest of the project. All these scenarios aim at enabling the stroke survivor to self-manage once he/she returned home to not only maintain the level of physical activity reached at the end of the rehabilitation but also to provide him/her and his/her carers with relevant information to keep a healthy lifestyle and avoid various consequences post-stroke (depression, feeling of isolation, aggravated state) and thus reduce the risk of a recurrent stroke.

All these scenarios cover the different aspects of the self-management once the stroke survivor has returned home through various exercising and monitoring use cases. They combine two aspects: a voluntary participation from the stroke survivor with the exercises indoors or outdoors and inputting information about other risk factors in the application; and a more “invisible” or involuntary participation with the inclusion of sensors in the environment and in worn objects or wearables for daily monitoring.

These scenarios provide:

- **At least 3 physical and cognitive rehabilitation exercises to be performed at home:** with serious games, balance games (e.g. in Scenario 1) and indoor/outdoor mobility games (in Scenario 3) that can be played alone or collaboratively with family members and also a training cardiovascular program (Scenario 3)

- **At least 3 self-management services for stroke survivors and other stakeholders:** with general risk factor management with user inputted information by the stroke survivor or his/her carer (in Scenario 5), a health dashboard informing the stroke survivor and his/her carer about the evolution of his/her state with appropriate reminders and alerts (e.g. in Scenarios 1, 2, 3 and 5), a self-management motivational program adjustable by therapists that will be setup in Scenario 5 for other scenarios (Scenarios 1 and 3) and spasticity monitoring (Scenario 4).

- **At least 2 services for peer support and collaboration:** with a link to the MyStrokeGuide from TSA and other resources with recommendations and information with tutorials for support and a forum for collaboration (e.g. in Scenario 5).

These scenarios will be further refined and possibly expanded or reduced along with the collection of needs in WP3 and the definition of the self-management services in WP5. Amongst these scenarios, all or some of them will be implemented and tested at different sites and a few of them will be selected for the final evaluation of the overall STARR system at the end of the project for WP7.
References