# Requirements, Specification and System Design for MIMICS

## Deliverable D1.1

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# 1. Lokomat

## 1.1. User Needs

*What do researchers, therapists and patients need, when applying VR to Lokomat therapy?*

### 1.1.1. Improve Rehabilitation:

- System should improve recovery after stroke and other pathologies.
- Movements should be therapeutically meaningful (relevant for ADL).
- Required movements should support “Repetition without repetition”
- Behaviour should be trained through the reinforcement of successive approximations (“Shaping”).

### 1.1.2. Use and acceptance by therapists and patients:

- Ensure safety for patients and therapists.
- System can be adjusted to every patient.
- System supports variable training intensities.
- Level of difficulty can be adjusted to the patients motor/cognitive impairments.
- Therapist can start and adapt the exercises to each patient.
- Easy operation for the therapists to support everyday clinical use.

### 1.1.3. Patient motivation:

- System provides engaging and motivating training scenarios.
- Scenarios make the patient happier.
- Scenarios increase concentration, endurance, etc.
- System allows patient exercise with maximal effort and involvement.
- System automatically adjusts to the demands and abilities of the patient.
- Patient should not get bored.
- Scenarios should be fun and motivating.

### 1.1.4. Rehabilitation Costs:

- System leads to a reduction of therapy duration and costs (in the long run).

## 1.2. Requirements

*Which technical functions are required to fulfil the user needs? Which technical functions should be comprised within the different virtual scenarios with its various tasks? How should the Lokomat be controlled and adapted to the patient?*

### 1.2.1. Requirements for the scenarios

- The movement must be repeatable, e.g. on well defined movement trajectory (e.g. path over an obstacle, virtual tunnels, not necessarily presented as a tunnel, the reference trajectory can be indicated by another virtual character).
- Predictable movement timing (movement start/stop commands are given by system trigger not by the patient)
- Predictable forces and direction of forces (e.g., when soccer ball is kicked in order to be able to support the patient and to compare patient's performance to requirements and to be able to discern movement artifacts – unwanted movements)
- Therapeutically meaningful movements lead to well-defined ROM, force, coordination, speed and ADL tasks.
- Socially engaging environment: haptic, visual and acoustic communication with other virtual characters; virtual characters should be able to show various moods by facial expressions, gestures and speech; Task should allow competition within or between individuals.
- For patients with sufficient cognitive and sensorimotor functions the scenario allows and encourages patients to influence the walking pattern and speed. For other patients, the speed is set by the therapist.
- Situations within a task or the entire task must change in certain moments in order to keep the patient engaged and motivated in an adequate way (changing partner behavior, "awakening" effects, surprises, etc.).
- The scenarios should include scoring systems (game character) to allow competition with him/herself or among individuals to engage patients.
- Scenarios include elements of shaping (e. g. obstacles getting higher, when successfully overcome by the patient).
- The scenarios and tasks should be adaptable to different levels of neurocognitive, biomechanical and sensorimotor impairment.

### 1.2.2. Adaptable guidance in the Lokomat

- Position control (for normal walking with 100% guidance force)
- Path control (e.g. for friction forces, for walking with increased difficulty)
- Walking speed (variable between 0 – 3.2 km/h)
    - Gait speed constant, but adjusted by therapist
    - Voluntary speed changes by the patient (automatically)

### 1.2.3. Requirements to modalities

- Haptic display
  - Allows soft contacts like soccer ball
  - Allows hard objects like wall, obstacle
  - Allow force fields
- Graphic: Adaptive environment that include
  - 2D and 3D display
  - Adaptive avatars (e.g., adaptive appearance, characters…)
  - Adaptive environments, background (e.g., nature, houses, objects…)
  - Functional objects (e.g., soccer ball, obstacles, humans that interact with patient, moving objects, …)
  - Adaptive daytime, weather, number of people
  - visual effects of velocity (optical flow)
- Audio
  - Enable directional sound (surround sound system)
  - Sound must be realistic (not too synthetic)
  - Enable conversations, talking to avatars
  - Cheering sounds/applause for amplification of positive results
  - Speech must be multi-lingual (German and perhaps English, Spanish)
- Wind produced by a fan

### 1.2.4. Safety

- Lokomat must not reach an instable state.
- Lokomat must switch off, when forces or position deviations become too large.
- Scenario must stop or change as soon as patient gets into a psychologically or physiologically instable situation (e.g., panic attack).
- Safety mechanisms deemed necessary by the subsequent risk analysis during the implementation.

### 1.2.5. Adaptability

- Adaptable to different patient handicaps
  - Online measurement of performance of patient
  - Online adaptation of the difficulty level
  - Different sizes of objects for patients with visual impairments
  - Different Loudness for patients with auditory impairments
- “Repetition without repetition” respectively “Repetition with variation” to reinforce/enhance motor learning
- “Shaping”, i.e. repetition with increasing difficulty to take into account that patient learns
- Different levels in order to switch to different motivation and engagement levels
- Different virtual characters behaviors

## 1.3. Lower Extremity Scenario: Walk through virtual environment

*How does the virtual environment and the tasks to be solved look like in order to fulfil the user needs, while meeting the technical requirements?*

The patient walks possibly together with other virtual characters (partner, opponent) through a virtual environment, such as a city or forest. Positive feedback is given, when patient successfully fulfils tasks (quality of walking over obstacle, touching an object to collect, reaching a target in a given time, etc.). This can be realized by “positive” sound, increasing score, entering next level, receiving a virtual present, object, supporting tool, etc. Negative feedback can be given, when quality of movement is poor, touching an object involuntarily, walking too slow etc. This can be realized by playing a negative sound, giving haptic feedback, decreasing the score, etc. However, feedback after a failed task can also be “positive” in the way to motivate the patient (support him with instructions, show how to perform better, show him where he failed, cheer, etc.). Note that if there is too much negative feedback patients will loose interest in solving tasks.

### 1.3.1. Sub-scenarios:

- The patient joins a guided city tour where he has to walk in a small group of people. Some of those might want to talk with him/her.
- Similar as in Shenmue*, the scenario can have a “Free Quest” mode where the patient can explore the whole city on his own (ADL), or a “Quest” mode where the patient has to talk to people and search for and collect things in order to solve puzzles and help the citizens (repeatable and social). For example, the patient has to find an ancient building in the city and ask for directions.
- Patient walks on a parcour, where he or she has to solve different motor and cognitive tasks. Such tasks will include
  - Crossing a traffic lights, pedestrian walks, tram crossing
  - Stepping over obstacles or holes
  - Walking through water puddles with increased friction
  - Walking over narrow bridge or narrow path
  - Kicking a ball or another moving obstacle
  - Mirroring the motor behavior of another person or the partner
- Find as many “friendly” items as possible (search, find, approach) and collect them. Try to avoid that other “enemy objects” are touched.
  - Collecting: If the patient is at the same virtual location as an object in the VE, a positive sound is played, the object is hidden in the VE and an entry is made in the patient’s inventory list.
  - Avoidance: If the patient is at the same virtual location as an enemy object, a negative auditory feedback is given, the patient looses one or more items from his inventory list (permanent loss), the patient drops one or more items from the inventory list (reversible loss, have to be collected again). Movements of the avatar result from the movements of the subject in the Lokomat. Virtual speed depends (i) on the real treadmill speed or (ii) on the

* http://en.wikipedia.org/wiki/Shenmue

walking performance of the subject (measured by biofeedback). Heading directions are calculated from kinematic and kinetic measurements of the subject. The patients can influence their virtual heading by varying their stride length while in the Lokomat (a larger step with the left and a smaller with the right leg will cause a turn to the right).

- Play soccer: The subject hast to kick a ball, into a goal or just in a predefined direction, e.g. before a competitor arrives at the ball. Further characters (soccer players) demonstrate how to kick, give comments and feedback. The patient can "run" towards a ball. The patient can change his walking speed (and direction) voluntarily. He/she feels the haptic interaction when kicking.

### 1.3.2. Social Challenges

While performing the task(s) within one of above sub-scenarios, the patient is confronted with a social challenge:

- Being addressed by a person and choosing between (more details)
  - Following that person
  - Running away from that person
- Discover what other people stare at and choosing between
  - Investigating what everyone looks at
  - Decide not to look
- Being asked to mimic another person
- Find sites of interest, e.g. specific buildings within city
  - Ask another characters for directions and decide to trust them or not.

### 1.3.3. Expected performance values

- Biomechanical and physiological reactions
  - Biomechanical comparisons between patient and partner avatar (e.g. distance)
  - Change walking speed
  - Motion when overstepping obstacles (no. of obstacle hits, foot clearance)
  - Voluntary stopping at street crossing
  - Walking speed during increased friction
  - Number of collected objects, goals scored, other scores
  - Time execution (e.g., when collecting)
  - Gait symmetry
  - Movement coordination
  - Endurance
  - Contact force when colliding with obstacle or kicking a ball
  - Energy consumption
  - Heart rate and heart rate variability
  - Spasticity, e.g. Modified Ashworth Scale
  - Voluntary force, e.g. MRC motor score
- Cognitive behavior
  - Coordination (accuracy, e.g. when hitting the ball)
  - Actively change the walking speed
  - Kind of collected objects
  - Quality of path chosen for collection of objects

    - General behavior (webcam analysis)
- Psychological reactions
    - Curiosity induced by a small crowd staring at something
    - Social fear when being addressed by a stranger
    - Stress induced by negative comments of characters (e.g. other players)
    - Stress from opponent taking the ball
    - Happiness induced by a successful task (e.g. goal)?

## 1.4. Technical Specifications (Design, Setup)

*Which hardware and software components will be implemented in the first maximal configuration in order to realize above-mentioned scenarios and tasks?*
*Hardware and software components include Lokomat, audiovisual displays, other displays, biomechanicals sensors, physiological measurement systems, computers, software algorithms, etc.*

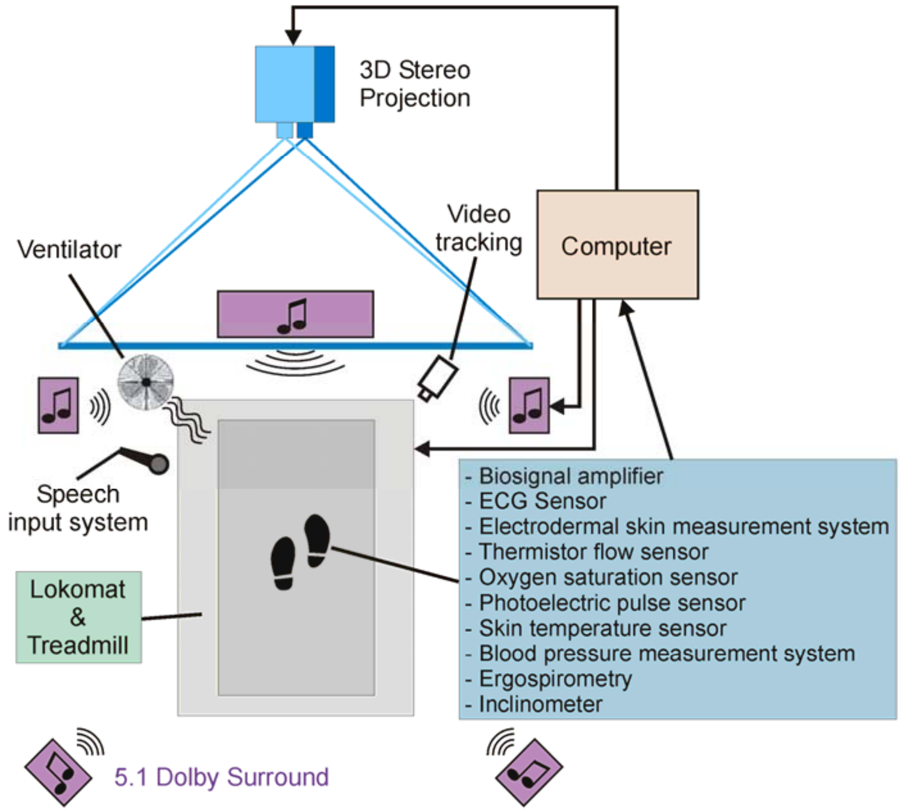


Figure 1 Sketch of MIMICS system for lower extremities (top view)

| Hardware | |
|---|---|
| Lokomat system | |
| Lokomat® Pro | Hocoma AG |
| instrumented treadmill with built-in force plates (Kistler) | h/p/cosmos |
| Lokocontrol (PC) | Standard component of Lokomat system |
| Lokomaster | Standard component of Lokomat system |
| Audiovisual displays (Stereoscopic back-projection system) | |
| Back-projection screen (2.0m x 2.7m) | |
| 2 Projectors | Panasonic PT-D3500E |
| Graphic Computer | Dell Precision 390; Intel Core 2 CPU 6600 (2.4 GHz, 2 GB RAM) |
| Graphic board | NVIDIA Quadro FX 3500 |
| Sound system | Dolby Surround 5.1 (Creative) |

| Physiological measurement system | |
|---|---|
| Biosignal amplifier | g.tec: g.USBamp Developer System |
| ECG Sensors | g.tec (Heart rate, Heart rate variability) |
| Electrodermal skin measurement system | g.tec: gGSRsensor (Skin conductance response, Amplitude of electrodermal response) |
| Thermistor flow sensor | g.tec: g.FLOWsens (Respiration) |
| Oxygen saturation sensor | g.OXYGENsensor (Peripheral blood flow) |
| Photoelectric Pulse Sensor | g.PULSEsensor (Heart rate, Peripheral blood flow) |
| Sensor for changes in skin temperature | g.TEMPsensor (Peripheral blood flow, Indicator for emotional stress) |
| Head tracking: | Intersense: Wireless InertiaCube3<br>IS-900 Systems |
| Blood pressure measurement system | CNSystems: CNAP™ Monitor 500 |
| Ergospirometry | Cortex: MetaLyzer 3B (Assessing work load) |
| Inclinometer | MicroStrain or other (Assessing ankle power in combination with treadmill force plates) |
| Video tracking<br>(for off line analysis) | Standard camcorder (Somatomotor activity) |
| Speech input system | Software: Microsoft Speech SDK 5.1;<br>Hw: standard or voice INTER connect (vicCONTROL) |
| Computer for recordings | Standard PC (with USB 2.0) |
| Software | |
| Online Data Processing Software | g.tec: g.USBamp SIMULINK HIGH-SPEED ONLINE Processing |
| Data recording software | g.tec: g.USBamp recording software |

*Lokomat system and hardware already present or will internal founded.*

## 1.5. Validation and Optimisation

*How must the setup and scenarios be validated in order to reduce the maximum configuration to an "optimal" configuration? How will we show that presence, motivation and therapy outcome will improve? We will try to answer most of the questions in case studies on healthy subjects and single stroke patients.*

### 1.5.1. Sense of presence

- Test visual display: effect of screen size and 2D/3D function
- Test auditory display: Surround sound/stereo/or mono?, Loudness?
- Is haptic feedback needed at all (contact force after object collision)?
- Test Lokomat adjustments for optimal presence: walking speed, guidance force
- Test scenario with objects and virtual characters and there effect on sense of presence
- Test which physiological measures show signs of change at all, if the scenarios, tasks and difficulty levels are being changed? Which measures comprise signs of change in presence (arousal, stress)?
- Test involvement, breaks in presence and overt behavior.

### 1.5.2. Increase motivation/engagement

- Haptic effects: Test how walking speed and controller adjustments (guidance force) can affect motivation /engagement.
- Audiovisual effects: Test how sudden audiovisual surprises (e.g. approaching car, hole on ground, another (un)attractive character approaching) can increase motivation/engagement
- Test visual display: effect of screen size and 2D/3D function
- Test auditory display: Surround sound, stereo or mono? Loudness?
- How can a change of task or task difficulty level increase motivation/ engagement?
- Social engagements: Test which social challenges affect concentration of patient.
- Intrinsic motivation inventory

### 1.5.3. Increase therapeutic outcome (NKBA)

- Ergonomic issues (ease of use, donning, doffing) tested in pre-studies
- Primary outcome measure: walking ability measured with Functional Ambulatory Category (FAC) and the 10 m walking test
- Secondary outcome measures: gait parameters measured by EMG, energy expenditure, endurance, efficiency, biomechanical parameters, physiological measures, etc.

# 2. Haptic Master

## 2.1. User Needs

What do researchers, therapists and patients need when applying VR to Haptic Master therapy?

### 2.1.1. Improve Rehabilitation

- The system should improve motor/cognitive functionalities of upper extremities after stroke and other pathologies.
- Movements should be therapeutically meaningful (relevant for ADL).
- Required movements should support “Repetition without repetition”.
- Behaviour should be trained through the reinforcement of successive approximations (“Shaping”).

### 2.1.2. Use and acceptance by therapists and patients

- The system should ensure safety for patients and therapists.
- The system should be adaptive to conform to particular patient.
- The system should support adaptive training intensities.
- The level of difficulty should be adjusted to conform to motor/cognitive abilities of particular patient.

### 2.1.3. Patient motivation

- The system should provide engaging and motivating training scenarios.
- The system should automatically adjust the exercise to the demands and abilities of the patient.
- Scenarios should be fun, attractive and motivating.
- Scenarios should stimulate emotional responses (e.g. laughter, contentment...).
- Scenarios should increase concentration and endurance.

### 2.1.4. Rehabilitation costs

- In the long run the system should reduce the therapy time frame and costs.

## 2.2. Requirements

*Which technical functions are required to fulfil the user needs? Which technical functions should be comprised within the different virtual scenarios with its various tasks? How should the HapticMaster be controlled and adapted to the patient?*

### 2.2.1. Requirements for the scenarios

- The task must be repeatable, e.g. determined via well defined movement trajectory (virtual tunnels, not necessarily presented as a tunnel, the reference trajectory can be indicated by another virtual character).
- Predictable movement timing (movement start/stop commands are given by system trigger not by the patient)
- Predictable forces and direction of forces (in order to be able to support the patient and to compare patient's performance to requirements and to be able to discern movement artifacts – unwanted movements)
- The patient must exercise therapeutically meaningful movements (with respect to ROM, force, coordination, max speed).
- Socially engaging environment (haptic, visual and acoustic communication with other virtual characters); Task should allow competition within or between individuals. Scoring system should be implemented.
- Situations within a task must change in certain moments in order to keep the patient engaged and motivated.
- The scenarios and tasks should be adaptable to different levels of neurocognitive, biomechanical and sensorymotor impairment.
- The task should be adjusted in a way to maintain patients engagement and motivation (e.g. communication with virtual character, commendation,…).
- Virtual characters should be able to provide facial expressions, emotional responses, gestures and speech.

### 2.2.2. Adaptable guidance in the Haptic master

- Position control (for guided movements)
- Support as needed (for goal directed movements)
- Optional gravity compensation of arm
- Additional weight or force perturbations during arm movements

### 2.2.3. Requirements to the modalities

- Haptic display
    - Admittance control for all scenarios
    - Gravity compensation
    - Grasping
    - Tactile display for indicating touch
- Graphic
    - 2D and 3D projection display
    - Adaptive avatar (e.g., changing appearance, facial responses, moving lips during speaking)
    - Predominantly static environment (the subject is sitting)
    - Adaptive virtual characters

    - Backgrounds (rooms, furniture, objects…)
    - Functional objects (e.g. cubes, cylinders, balls, table, …)
- Audio
    - Directional sound (surround sound system)
    - Sound must be realistic (not too synthetic)
    - Talking of other avatars (e.g. stimulating, commendation…)
    - Multi-lingual speech (Slovene & English, perhaps German)
- Safety
    - Haptic Master cannot reach an instable state.
    - Haptic Master must switch off, when forces or position deviations become too large.
    - Dead-man switch and other “standard” safety components (emergency buttons, mechanical end stops, etc.)
    - Safety mechanisms deemed necessary by the subsequent risk analysis during the implementation.
- Adaptability
    - To different patient handicaps
    - Online measurement of performance of patient
    - Online adaptation of the difficulty level
    - Different sizes of objects for patients with visual impairments
    - Different Loudness for patients with auditory impairments
    - “Repetition without repetition” in order to enhance motor learning
    - “Shaping”, i.e. repetition with increase in difficulty to take into account that patient learns
    - Different task levels: passive movement, active resistance, etc.
    - Different levels in order to switch to different motivation and engagement levels

## 2.3. Upper Extremity Scenario: For internal dissemination only

Since this section contains confidential intellectual property, it has been removed from the public version of the deliverable.

## 2.4. Technical Specifications (Design, Setup)

*Which hardware and software components will be implemented in the first maximal configuration in order to realize above-mentioned scenarios and tasks?*
*Hardware and software components include Haptic Master, audiovisual displays, biomechanicals sensors, physiological measurement systems, computers, software algorithms, etc.*

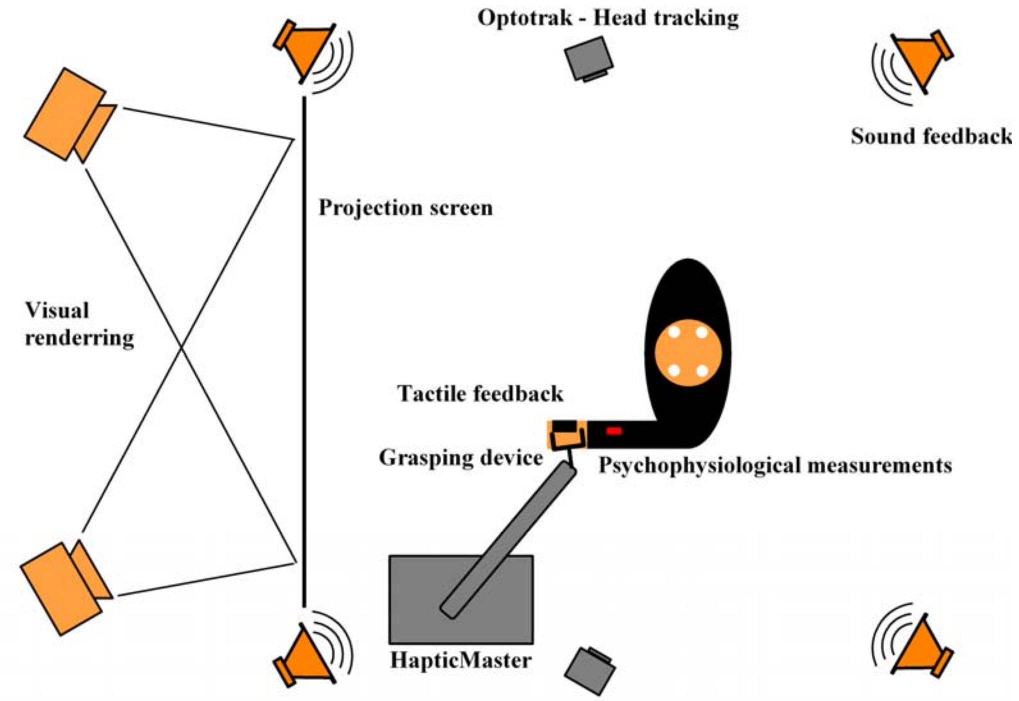


Figure 2 Sketch of MIMICS system for upper extremities (top view)

| | |
|---|---|
| Hardware | |
| HapticMaster system | |
| HapticMaster robot | |
| HapticMaster control unit | |
| Personal computer | Standard PC |
| Audiovisual displays (Stereoscopic back-projection system) | |
| Back-projection screen | |
| 2 Projectors with polarizing filters | |
| Graphic Computer | Standard PC |
| Head tracking: | Optotrak system |
| Personal computer | Standard PC |

| | |
|---|---|
| Sound system | Dolby Surround 5.1 |
| Tactile feedback | |
| Vibrating/Stimulating unit | |
| Physiological measurement system | |
| Biosignal amplifier | g.tec: g.USBamp Developer System |
| ECG Sensors | g.tec (Heart rate, Heart rate variability) |
| Electrodermal skin measurement system | g.tec: gGSRsensor (Skin conductance response, Amplitude of electrodermal response) |
| Thermistor flow sensor | g.tec: g.FLOWsens (Respiration) |
| Oxygen saturation sensor | g.OXYGENsensor (Peripheral blood flow) |
| Photoelectric Pulse Sensor | g.PULSEsensor (Heart rate, Peripheral blood flow) |
| Sensor for changes in skin temperature | g.TEMPsensor (Peripheral blood flow, Indicator for emotional stress) |
| Video tracking (for off line analysis) | Standard camcorder (Somatomotor activity) |
| Speech input system | Software: Microsoft Speech SDK 5.1 or Dragon Naturally Speaking; Hw: standard or voice INTER connect (vicCONTROL) |
| Computer for recordings | Standard PC (with USB 2.0) |
| Software | |
| Online Data Processing Software | g.tec: g.USBamp SIMULINK HIGH-SPEED ONLINE Processing |

## 2.5. Validation and Optimisation

*How must the setup and scenarios be validated in order to reduce the maximum configuration to an "optimal" configuration? How will we show that presence, motivation and therapy outcome will improve? We will try to answer these questions in a series of case studies on healthy subjects and stroke patients. A large clinical study would be required to provide statistically significant answers, but such study is beyond the scope of the MIMICS project.*

### 2.5.1. Sense of presence

- Test visual display: effect of screen size and 2D/3D function
- Test auditory display: Surround sound/stereo/or mono? Loudness?
- Is haptic feedback needed at all (the value of actively supporting movements and generating active resistance)?
- Test scenario with social and non-social implementation. Does social interaction have an effect on sense of presence?
- Test which physiological measures comprise signs of change in presence (arousal, stress)? Are physiological measurements needed at all?
- Test involvement, breaks in presence and overt behavior

### 2.5.2. Increase motivation/engagement

- Haptic effects:
  - Test how physical interaction with the virtual environment changes motivation/ engagement.
- Audiovisual effects:

    - Test how sudden audiovisual surprises can increase motivation/ engagement
    - Test visual display: effect of screen size and 2D/3D function
    - Test auditory display: Surround sound, stereo or mono? Loudness?
- How can a change of task or task difficulty level increase motivation/ engagement?
- Social engagements: Test which social challenges affect concentration of patient.
- Intrinsic motivation inventory

### 2.5.3. Increase therapeutic outcome (NKBA)

- Primary outcome measurements by the Wolf Motor Function Test, Motor Activity Log and Stroke Impact Scale
- Measures for assess motor impairment, abnormal joint synergies and biomechanical function by the Fugl-Meyer and Ashworth Score