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SHARESPACE

Embodied Social Experiences in Hybrid Shared Spaces

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Document Description	This deliverable presents the user requirements for the SHARESPACE system. The requirements include both functional and non-functional aspects.

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Table 1: List of Abbreviations

Term / Abbreviation	Definition
AI	Artificial Intelligence
BSN	Body Sensor Network
SC	Scenario

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This deliverable presents the functional and non-functional requirements for the development of SHARESPACE system. Functional requirements define the key functionality and features that the SHARESPACE system needs to embed, while non-functional requirements define the way this will be achieved, across three stages of prototype iteration in Phase I, and three phases of iteration for Phase II.

1.2 STRUCTURE OF THE DOCUMENT

This document is structured as follows:

- Section 2 presents updated descriptions of the Proof of Principles and SHARESPACE Scenarios.
- Section 3 presents a list of requirements for the SHARESPACE system (general overview and scenarios).
- Section 4 presents a risk assessment for each of the scenarios.
- Section 5 presents envisaged timeline for delivery different prototypes of SHARESPACE system.

2 UPDATED PROOF-OF-PRINCIPLES AND SCENARIO DEFINITIONS

2.1 SHARESPACE PROOF OF PRINCIPLES

Proof of principles will be developed in the WP2 of the SHARESPACE project, which will provide operational principles for core requirements of the SHARESPACE project, related to the embodied interaction between participants and avatars (L1-L3) in a hybrid, multisensory space. This will be established in two tasks looking at the Encoding (T2.1) and Readout (T2.2) of motor primitives, and means of the relaying embodied communication with two different typologies of transmission of amplified or attenuated motor primitives according to the user requirements (T2.3 Kinematic Chinese Whisper – exchange of information in a chain typology; and T2.4 Social Connectedness – exchange of information in open diffusion typologies, such as star or ring alignment between agents). Scenarios presented in this deliverable will provide a test-bed for SHARESPACE vision in real life applications and will unfold in the Phases (I-III).

2.1.1 **PROOF-OF-PRINCIPLE OF AMPLIFICATION***:* KINEMATIC CHINESE WHISPERS

Updated Proposal's description: This proof of principle will use a sensorimotor chain diffusion paradigm to demonstrate the sequential propagation of social information (see Figure 1) from one agent to another across chains of 3-5 individuals. In much the same way as in the children's game 'Chinese Whispers', one seeded expert model will demonstrate a behaviour to a second agent, who will then act as a model for a third agent, and so on along a chain of agents.

In Phase I, the chains tested experimentally will constitute of (L0) human-human interactions in local physical space to extract the first operating principles (i.e., encoding/readout model of social information) and to enable development of later iterations (Phase II in VR space/Phase III in XR space). Phase II (VR) and Phase III (XR) will include Virtual Humans with increasing degrees of autonomy (L1/L2/L3) interspersed within the chain. In the Phase II VR space and Phase III XR space the transmission/propagation of information will be modulated by the *amplification (or attenuation)* of sensorimotor primitives that carry social information in L2 avatars (Phase II and Phase III) and L3 autonomous characters (Phase III only). This paradigm will provide a Proof-of-Principle (PoP) of how the manipulation of sensorimotor primitives will impact the transmission of information in future shared hybrid spaces (Phase III XR space) and how this can be implemented by the SHARESPACE cognitive architecture for the application in Health, Sport and Art scenarios.

Rationale: In this PoP, the social transmission of threat/fear associated with an object will be utilized to study the spread of information in an open chain diffusion paradigm. Fear conditioning studies have indicated threats can be learned by associating a conditioned stimulus (i.e., blue object) with an unpleasant, unconditioned stimulus (US) (i.e., electrical stimulation) and, importantly, this association can be learned by observing another person without directly experiencing the threat (Haaker et al., 2017). We will therefore examine this information transmission by identifying extent to which fear information is encoded in the kinematics of participants (Becchio et al., 2018) and subsequently which of these kinematics features are effectively readout (i.e., intersection information; Patri et al., 2020; Montobbio et al., 2022; Scaliti et al. 2023). These findings will then be used to identify the key sensorimotor primitives which will be used to train the cognitive architecture to amplify and/or attenuate information transmission along the chain (Phase II/Phase III).

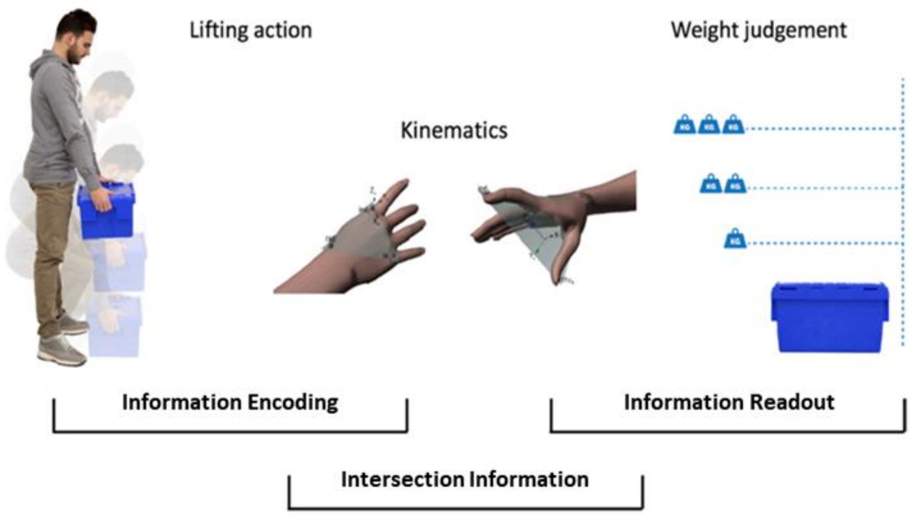

***Figure 1** :*

Schematic describing intersection information. We use the example of one individual lifting a box and using sensorimotor primitives to communicate to another individual information about the weight of the object being lifted. Two operations of information transmission are the encoding of weight information by the lifter's kinematics, and the readout of such information by the observer. Information transmission happens if information encoding and readout intersect, that is, if the readout can extract effectively the weight information encoded by the kinematics. See Scaliti et al. 2023 for a detailed description of the kinematic coding approach.

The Kinematic Chinese Whispers PoP will consist of three phases, a human-to-human interaction (Phase I – a local physical space), a Virtual Reality phase (Phase II – VR), and an Extended Reality phase (Phase III - XR).

PoP Kinematic Chinese Whispers - Phase I, II and III
Goal: Identification of core sensorimotor primitives critical for information transmission during chain diffusion socio-motor interactions in SHS, identification and implementation of key functional requirements of the SHARESPACE cognitive architecture.
Experimental Overview: Groups of 3 participants will take part in each experimental session. During the experiment, we will ask participants to perform sequential "pick and place" movements (see Figure 2) : in each trial, Participant 1 will reach with their right hand towards one of two objects serving as conditioned stimuli (i.e., blue object, yellow object) and pick it and place it on a table in front of participant 2. Participant 2 will then reach and transport the object to a position in front of participant 3. The final participant in each chain will transport the object to a target

space on the table that is not associated with another participant. Only one object will be available in each trial. Before starting the experiment, surface electrodes will be placed on the participants' right-hand palm. Only the first participant in the chain will receive the US, for which the intensity will be individually adjusted to generate an unpleasant (but tolerable) sensation (Haaker et al., 2013). All other participants will not receive US to ensure that information transmission is exclusively driven by readout and transmission of the fear information encoded in the movement kinematics of the first participant. Each experimental session will comprise three phases. In the baseline phase, grasping the objects will not be paired with a US. During the acquisition phase, grasping one of the two objects will be paired with a US in 30% of trials (e.g., blue object, conditioned stimulus paired with US, CS+), while no US will occur when participants grasp the other object (e.g., yellow object, conditioned stimulus not paired with US, CS-). Finally, in the extinction phase, participants will continue performing reach-grasp-place movements, but US will stop occurring. Participants' vision will be occluded so that they can only observe the participant directly preceding them in the chain. Movement kinematics will be recorded to measure information levels at each level of the chain. Galvanic Skin Response (GSR) recorded from the left hand will provide an independent measure of fear transmission.

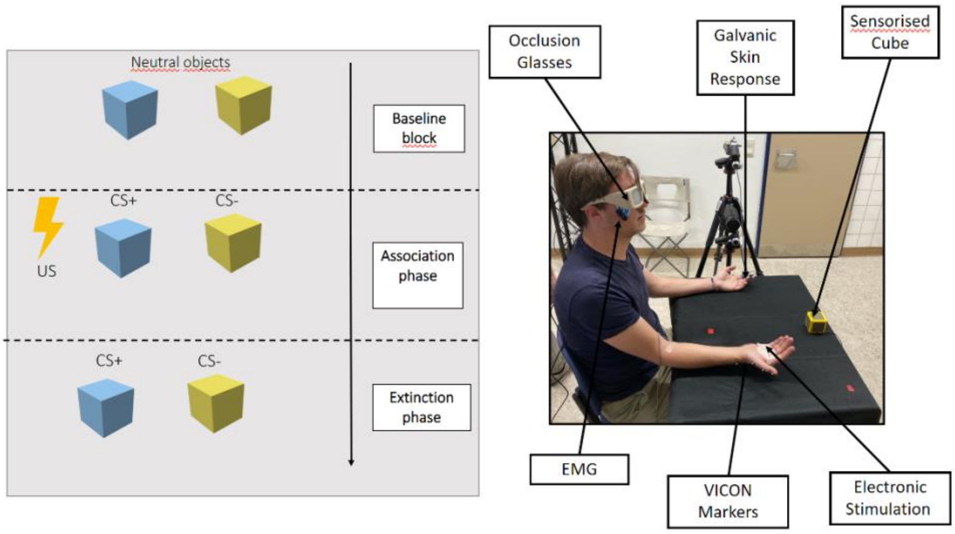

Figure 2 :

Experimental design (left) and setup for the first participant in the chain (right). The participant receives the US (unconditioned stimulus) on the right hand at the time of contact with the sensorized cube. Pick and place movements are tracked using a near-infrared motion capture system. Concurrently, galvanic skin response and eye blink reflex (EMG) are monitored.

Phases:

Phase I (human-human) - L0: All subjects are L0 in the same, local physical space and complete the experimental session as described above. This will condition Participant 1 to be fearful of one object (CS+) through pairing with the US. We will then measure how the fear of the CS+ object is transmitted along the chain. Encoding/Readout analyses will be used to determine the sensorimotor primitives that encode information that is read out (intersection information) and therefore contribute to social transmission. The complete dataset, consisting of movements collected during baseline, acquisition, and extinction, will be made available to train the cognitive architecture for Phase I and Phase II.

Example Participants: $L0_1$-$L0_2$-$L0_3$Phase II (VR) - L1: Follows the same protocol as Phase I but L0 users are now represented as L1 avatars and do not share the same, local physical space, with the chain now nested in VR space and the physical objects are replaced with virtual objects. Encoding/Readout analyses will be used to determine whether the intersection information is successfully reconstructed in VR by the SHARESPACE System Architecture to confirm information transmission occurs similarly in local and virtual interactions.

Example Participants: $L1_1$-$L1_2$-$L1_3$

Phase II (VR) - L2: Follows the same protocol as Phase II (VR) - L1 but one L2 avatar is now placed within the chain. The cognitive architecture will modulate the motor output of the L2 participant to amplify/attenuate information transmission. The cognitive architecture will intervene on a minimal set of kinematic features required to amplify the sensorimotor primitives encoding social information to facilitate the readout by the next human participant in the chain. The number and type of such features (e.g., velocity of the end-effector, position of a joint etc.) will be identified during the Phase 1 experiments. Encoding/Readout analyses will be used to evaluate how well the L2 avatar modulates information transmission.

Example Participants : $L1_1$-$L2_2$-$L1_3$

Phase III (XR) - L1: Follows the same protocol as Phase II - L1. Some users are now sharing the same local physical space, whilst others join remotely and are represented as L1 avatars creating a shared hybrid space. Encoding/Readout analyses will be used to determine whether the intersection information is successfully reconstructed in XR by the SHARESPACE System Architecture to confirm information transmission occurs similarly in hybrid interactions.

Example Participants: $L0_1$-$L1_2$-$L0_3$

Phase III (XR) - L2: Follows the same protocol as Phase III - L1 but one L2 avatar now replaces an L1 avatar within the chain. The cognitive architecture will modulate the motor output of the L2 participant to amplify/attenuate information transmission. The cognitive architecture will intervene based on which object is being moved (e.g., Blue/CS+) and the

desired direction (i.e., amplify). Encoding/Readout analyses will be used to evaluate how well the L2 avatar modulates information transmission in social hybrid spaces. Example Participants : $L0_1$-$L2_2$-$L0_3$ Phase III (XR) - L3: Follows the same protocol as Phase III - L1 but the first participant is now an L3 autonomous virtual character. The cognitive architecture will control the motor output of the L3 autonomous virtual character to produce movements that encode the relevant features that specify fear depending on the object being moved. Encoding/Readout analyses will be used to evaluate how well the information transmission occurs in social hybrid spaces when the origins of the information are simulated (i.e., No human participant ever receives a shock). Example Participants : $L3_1$-$L0_2$-$L1_3$
Participants: L0: Various groups of 3 healthy adults, controlled/balanced for sex, laterality, social disposition and personality (Phase I, Phase II, Phase III); L3 - autonomous virtual character (Phase III XR).
Metrics: Kinematic encoding / readout of fear information to measure information transmission Galvanic Skin Response (GSR) and eye blink reflex (EMG) to assess social fear learning and transmission

2.1.2 PROOF-OF-PRINCIPLE OF SOCIAL CONNECTEDNESS

Updated Proposal's description: This challenge will use a sensorimotor open diffusion paradigm to demonstrate the open diffusion of social information during synchronisation from one agent to another in groups of 5 individuals, across three phases of technological development in the project.

Initially, the chains tested experimentally will constitute of (L0) human-human interactions nested in same, local physical space in Phase I, but later iterations will include Virtual Humans with increasing degrees of autonomy (L1/L2/L3) interspersed in the open chain typology in subsequent phases (Phase II – Phase III). L1 avatars will reconstruct core sensorimotor primitives of human participants (one-to-one tracking to reconstruction; L0 to L1). L2 avatars will use the reference motion of the avatar from the sensorimotor library that best depicts the sensorimotor primitives of the remote participants (one-to-one tracking to reconstruction, with relevant sensorimotor primitives amplified or attenuated to improve synchronisation performance in a group; L0 to L2). L3 virtual humans will continuously adapt their behaviour via our cognitive architecture fueled by data sensed from participants (L0), in order to entrain movement trajectory, phase and frequency, and stabilise group synchronisation (mapping to the sensorimotor library). In later reiterations, the SHARESPACE environment for each participant (L0) will dynamically change to foster meta perception of synchronisation performance with other agents, to maximise the social consequence of the joint movement (i.e., connectedness and cohesion).

Rationale: Moving in unison feels good. Research shows that individuals who have their body (or parts of their body) synchronized in space and time with others during joint action (multi-agent activity in shared physical space, with shared action goal; e.g., playing music, having a conversation, dancing, doing Tai chi, etc.) like each other more. Moving in synchrony increases social features such as: interpersonal attractiveness, empathy, cohesion, and sense of affiliation. The Social Connectedness PoP will afford transfer of currently physically bound sensorimotor group dynamics (in Phase I) to Extended Reality (XR) platform (Phase III) - with interim step of VR Phase II, putting to test AI supported facilitation (or disruption) of inter-agent movement synchronization during collective performance. This will be achieved by the virtue of L1 avatars driven by L0 individuals, L2 avatars driven by L0 individuals, but with semi-autonomous capacities (enriched with input from library), and fully autonomous (intelligent) L3 virtual humans adapting their behaviours in real-time to assist L0 individuals and moderate the group performance. The PoP will identify the core operational features of group synchronization and connectedness to constitute functional bricks of SHARESPACE, further instantiated in the SHARESPACE for Health: Social Low Back Pain scenario; SHARESPACE for Sport: Family Peloton Cycling scenario; SHARESPACE for Art: Shared Creativity scenario.

The Social Connectedness PoP will consist of three phases, a human-to-human interaction (Phase I – a local physical space), a Virtual Reality phase (Phase II – VR), and an Extended Reality phase (Phase III- XR).

PoP Social Connectedness- Phase I, II and III
Goal: Identification of core sensorimotor primitives critical for open diffusion typologies of socio-motor interactions in SHS, identification of key synchronisation and cohesion metrics and other functional requirements for development of SHS.

Situation:

All participants are standing in the same **physical** location (human-to-human) **– Phase I**, or in different locations, with a VR headset on, in a joint VR space (**Phase II**)**;** with a **XR** headset on, in a joint **XR** space (Phase III). They perform in a circle the group synchronization task in the **physical/VR/XR** space with one arm (anteroposterior movement of the arm – Alderisio et al., 2017) and will be asked to move in synchrony with each other (see Figure 3).

In some randomly selected trials, 1 of 5 participants (the same at each iteration) will receive one unique gentle aversive stimulation delivered to their palm (controlling the movement) for 1s during the selected trials. Group will be asked to continue moving together regardless of the event.

Figure 3 :

Panel (A) Illustration of the experimental paradigm. Participants will be asked to stand together (the number of participants is limited to 5). Panel (B) Participants 0-4 will be performing a synchronisation task (anteroposterior movement of the arm). During the task performance, Participant 0 will receive 1s long unpleasant stimulus at the reversal point of the movement to induce movement hesitation.

Tasks:

Phase I - Task 4A (human-human): Move together in the same, local physical space and in time (everyone is doing the same movement in a coordinated way), for series of 1 min trials (see Figure 4 for the breakdown of the experimental design).

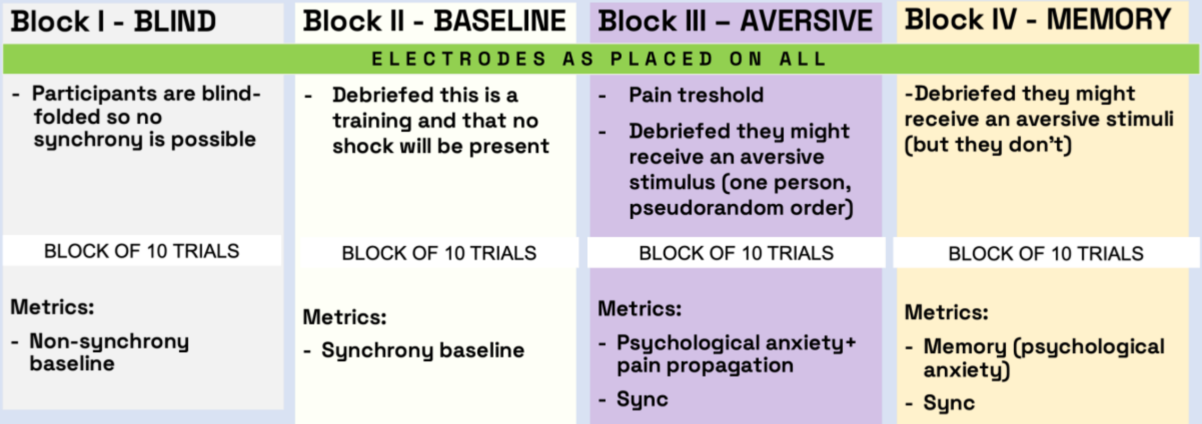

Figure 4 :

Task 4A – Division of the trials into three blocks. Block I – baseline data for social connectedness without synchrony, Block II-collection of the baseline data for the synchrony metrics – without risk of aversive stimuli, without psychological anticipation of fear, Block III – All participants are subjected to the aversive stimuli pain threshold measurement, and debriefed that they might receive aversive stimuli during one of the trials in this block (but only one participant (P0) receives it during forward movement, during randomly selected trials) trials but none aversive stimuli is triggered during trials). Block IV – during this block participants are informed they might receive aversive stimuli, but no participant receives it.

One of the participants – P0 (naïve) receives movement aversive stimulation (1ms light electric shock on their moving hand) at random intervals. They are asked to continue moving regardless of the aversive stimulation. Propagation of pain is measured via self-report, synchrony metrics in Participants (1-4).

Phase II - Task 4B (VR): Move together in VR space and in time (everyone is doing the same movement in a coordinated way – like in Task 4A), for 1 min, with L0 being represented as L1 avatars (they wear VR headsets and move in joint VR space); with L2 avatars are interspersed across the open diffusion network moderating the synchronisation performance of the virtual group by amplification/perturbation of the sensorimotor primitives (optimised as order parameter/local synchronisation index). Some of the participants (naïve) receive movement aversive stimulation (light electric shock on their moving hand) at random intervals. They are asked to continue moving regardless of the aversive stimulation.

Phase III - Task 4C (XR): Move together in XR space and in time (everyone is doing the same movement in a coordinated way – like in Task 4B), for 3 min, with autonomous virtual character L3 and L2 avatars moderating the synchronisation performance of the virtual group by amplification/perturbation of the sensorimotor primitives. All L0 being represented as L1 avatars (they wear XR headsets and move in joint, hybrid XR space). Some of the participants (naïve) receive a movement aversive stimulation (light electric shock on their moving hand) at random intervals. They are asked to continue moving regardless of the aversive stimulation.

Participants:

L0: Various groups of 5 healthy adults, controlled/balanced for sex, laterality, social disposition and personality (Phase I); L1+L3: virtual humans (Phase II); L2+L3: virtual autonomous character (Phase III)
Metrics: Group synchronization: continuous order parameter and variability (GSync), subdivided into synchronisation levels (weak, medium, high). Dyadic synchronization: order parameter and variability in dyads (DSync). This metric is computed between all L0 dyads in human-to-human phase, then between all L1 and L2 dyads, between all L1 and L3 dyads, and between all L2 and L3 dyads, subdivided into synchronisation bands. Individual contribution to group synchronization (ISI – Individual Synchronisation Index – as in Alderiso et al., 2017). This metric evaluates the contribution of each participant to the group synchronization performance. **Time to sync, Time in sync – divided across synchronisation levels (high, medium, weak coupling).** **Perturbation of leadership – (measured as causation entropy, Leadership index – Calabrese et al., 2021) following patterns by social information.** Kinematic Alignment between dyads to assess motor contagion Kinematic encoding of fear information (as a measure propagation of the fear perturbation) Social connectedness metrics (before and after), personal and empathic disposition **Information encoding/readout analysis - Phase I (MoCap/xSense data/Video recordings).** This analysis will be performed at UKE – from the video recordings obtained in TASK 4A, to prepare amplification for Phase II and III. **Pre-screening for empathy related traits:** - Questionnaire of Cognitive and Affective Empathy (QCAE; Brunet-Gouet et al., 2019), the Interpersonal Reactivity Index (IRI; Davis, 1983) and the KinEmp (Koehne et al., 2016) - Autistic (AQ; Allison et al., 2012) and psychopatic traits (SD3; Jones & Paulhus, 2014) **In the lab :**

- Self-reports of affective state (SAM; Bradley & Lang, 1994), pain and vicarious pain (VPQ; Grice-Jackson et al., 2017)
- Self-reports of rapport, social connectedness and ostracism (items adapted from the Williams ostracism needs threat scale, Gerber et al., 2017)
- Self-reports of goal achievement: Perception of being in SYNC or not
- Presence (PQ; Witmer & Singer, 1998) and cybersickness (Kennedy et al., 1993) questionnaires for Phase II and III

Apparatus :

Data will be collected using our Vicon/Qualisys motion capture recording (equipment in the MovLab) recording the movement at the frequency at 120Hz. Participants will have one marker placed on their index finger, one on the wrist, and one on the shoulder. Electrocutaneous stimulation (at an unpleasant, but not painful threshold – US), following guidelines from Londsdorf et al., 2017) will be delivered using electrodes (one on the participant's hand) plugged into the DS71 Digimeter, which is a standardized, commercial method of electric stimulation (EC certified and tested for EMC conformity of medical Devices). DS7A delivers sinus wave pulses (maximal duration = 2 ms), varying in intensity from 1 to maximally 99.99 mA. The US impulse will be released when participants will cross predesignated position (with added variation to prevent learning of the exact location) in the space**.** Session will be captured using two video cameras capturing the movement of participant receiving unpleasant aversive stimuli for potential further analysis of coding of social information (hesitation to move). Societal cohesion will be measured before and after the experimental session using Inclusion of Other in the Self (IOS) Scale (Aron et al., 1992). HRV variability will be measured with Delsys Trigno and two in-house built sensors. In Phase II, participants will also wear a Meta Quest Pro 256GB virtual reality headset, in which they will see a digital version of their interactants performing the oscillatory movement.

Agents:

L0: real agents: $L0_1$-$L0_2$-$L0_3$-$L0_4$-$L0_5$

L1: passive avatars of real agents: $L1_1$-$L1_2$-$L1_3$-$L1_4$-$L1_5$

L2: semi-autonomous avatars of real agents: $L2_1$-$L2_2$-$L2_3$-$L2_4$-$L2_5$

L3: autonomous virtual character: L3 'Sarah'

Functional description of L1-L2-L3 interactions :

Task 4C: Despite the instruction to all move in sync, one L1 (e.g., $L1_1$) is consistently lagging (defined as leaving a pre-set synchronisation band window around GSync). The architecture computes GSync, DSync, and ISI in real time, changes the colour of the arm of the most visible individual in $L1_1$'s field of view (e.g., $L1_4$) to amplify information about dyadic synchronization,

until $L1_1$'s contribution to group performance reaches the pre-designated synchronization band. This can happen multiple times, to multiple individuals during the exercise (as naturally human synchronisation fluctuates on order parameter spectrum across time – from lower to higher value bands). If group's synchronisation performance is below the pre-set threshold, $L1_4$ becomes a semi-avatar $L2_4$, slows down its movement until DSync returns to the desired synchronisation band, and then speeds-up to prompt the pick-up of pace in the group. If not enough, L3 Sarah appears in the group, in the middle of the circle (only in $L1_1$'s field of view), starts mirroring $L1_1$'s movement to establish base level of DSync, and further entrain $L1_1$ towards the desired group synchronisation band performance window.
Amplification/attenuation of primitives will be gradually through Phase II (transitory VR phase), through amplification or attenuation of sensori-motor primitives rendered for L2**, to** be fully **employed for** L3 **in Phase III** (XR phase), **to allow** continuous moderation of group synchronisation performance **in a** predictive fashion by SHARESPACE architecture**.**

2.2 SHARESPACE - REAL WORLD SCENARIOS

2.2.1 SHARESPACE FOR HEALTH: SOCIAL LOW BACK PAIN EXERGAME

2.2.1.1 USE CASE (UPDATED FROM THE PROPOSAL)

Mireia is 42 and Ricardo is 61, they both suffer from chronic low back pain and are outpatients at the Pain Unit in the Vall d'Hebron hospital. Chronic pain has had a profound impact on their lives. Mireia stopped her job one year ago and is supported by her partner. Ricardo is trying to get an early retirement and as he is not able to work right now, he is on prolonged sick leave. Both of them have also significantly reduced their social life and physical activity. They complain of feeling constant pain, fatigue, low mood, and fear of movement. At the hospital they can attend group physical therapy sessions, which helps them, but is difficult to sustain. The rehab sessions are programmed at a fixed time and the hospital is far from their homes. In addition, given the limited resources at the hospital, groups are too large and the physical therapist cannot personalise the exercises. Mireia likes the group sessions, because it is fun to be with other people and she feels more motivated and hopeful. Ricardo would prefer to have more personalised sessions to correct his postures and perform the exercises more effectively.

Phase I (VR): For the first time Mireia and Ricardo can perform the physical therapy sessions from home. They have been enrolled in exercise sessions conducted remotely with Judith (their physical therapist based at the Rehab Unit). Together with other outpatient at the same time (two at once) located in the hospital (with VR headset/sensors/computer units connected to the network), they join the session using the SHARESPACE platform and a VR headset (the other patients are at the hospital and follow the session in the traditional way). During their virtual session Mireia and Ricardo interact with each other and Judith's L1 avatar. The avatar directly reconstructs the movements of the real Judith (L0) in VR (see Figure 5). Judith starts the training by performing the first relatively simple posture to be copied by the patients at the hospital in the traditional way and Mireia and Ricardo in the shared space. A representation of the other patients (and/or L3 autonomous characters, which in Phase I will have basic functionality to couple their movements to L1s) will also be seen in the VR space by Mireia and Ricardo. Mireia feels confident about her movement. The melodic sound accompanying her movements and the change in colour of her avatar, from orange to green, informs her that she performed the movement correctly (Phase I – augmented feedback). She feels good! Ricardo is cautious to start moving. During the next repetition, he tries to mimic the posture better and he sees their chosen avatar changing to green and a pleasant chime as he accomplishes the desired posture. When both Judith and Ricardo successfully copy the desired posture, the individual chimes are binding into a more synchronised melody, enhanced visually by a green halo around all the avatars. That way they feel more socially connected with the rest of the group and have a sense of achievement for reaching the group goal. As the sessions go by, they need fewer repetitions to achieve synchrony with the group, and have the feeling that time flies. It is certainly more fun. They also feel more energy, a sense of self-efficacy, and an improvement in their mood.

Phase II (XR): The platform, adapted to an untethered XR solution, enables Mireia and Ricardo to use their **XR headsets at home**. They enjoy the confidence boost coming from being able to do their exercises as a part of the outpatient community of the Rehab Unit of the Vall d'Hebron hospital. They now have a **personalised training programme**, enjoying the variety of movements proposed by their therapist Luna. **Luna is a L3 autonomous virtual character** which unlike a human, has unlimited attentional resources to devote to each outpatient at the same time. Another innovation of the second phase of the SHARESPACE programme is that **now outpatients can**

participate in the training with enabled L2 avatars (invisible for them, but visible to other participants, who are remote – not in the shared local space). Unlike L1 avatars, L2 avatars are designed to support the group motivation and assist in reward-rich learning of new exercises. L2 avatars amplify the selected movement features, so that in shared hybrid space during virtual session, **everyone performs the task at least as well as group average (mean order parameter of all agents engaged in the task)**, which creates a greater feeling of synchrony and social connectedness between the group members.

Exercises are challenging, but they feel safe about pushing themselves out of their usual comfort zone and enjoying the fluid sense of belonging coming from being in synchronisation with others (see Figure 5). Luna provides exercises chosen from a library according to the outpatients' progress that is being monitored across successive sessions. Luna picks up exercises for each of them to maximise a **'rehabilitation index'** defined as a function of the outpatients' movement kinematics and other factors indicated by their human therapist (Judith). To feel completely at ease, the actual home setting of the outpatient is not visible to the other Participants or the therapist. **Avatars and Luna will be rendered in the safe domestic space chosen by each Participant, in a miniature depiction** (to make them feel less imposing, or threatening to their personal, domestic space). They can also choose to render shared space in a neutral, virtual setting (i.e., imagery of an Alpine meadow or Mediterranean beach). If one of the participants cannot make it to the session that day, they can be simulated in real time as an L3 avatar to keep the same numbers in the group.

Figure 5 :

Simplified visualisation of the Low Back Pain Scenario showing (top) group exercises in VR with L0 patients and their L1 avatars, and (bottom) the AR-version with (L0) patients at two different locations, L1 avatars of other patients, and the L3 autonomous avatar of the therapist.

2.2.2 KPI

Stakeholders involved in evaluation, target 10 patients (for each Phase I – Phase II), 10 healthcare professionals for Scenario 1. 2 XR prototypes (see Figure 6 for the Phase I breakdown and Annex 1 for supplementary information).

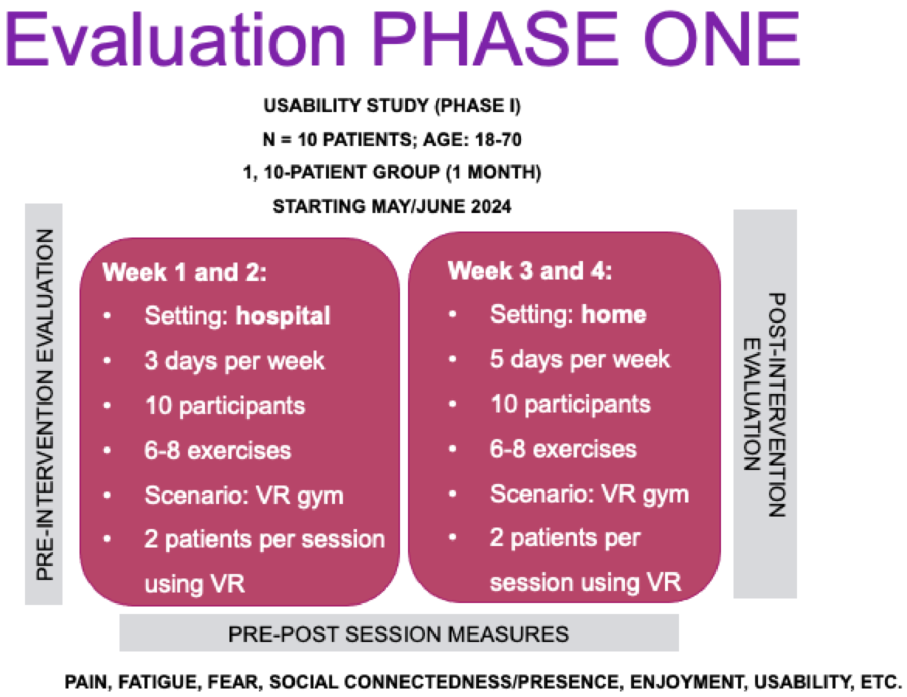

Figure 6 :

Depiction of the Phase I use evaluation planned for the May/June 2024. Participants will start using the system (and familiarise with it; 3 times per week) at the hospital, then bring it home for the fortnight (to have more intense schedule; 5 times per week).

2.2.3 SCENARIO COMPONENTS

Specification of the sensorimotor primitives encoding information (including fear of movement, pain intensity) (T2.1); identification of the sensorimotor primitives to be amplified to assist multisensory information transmission (T2.4); specification and detection of synchronisation patterns[45] during the exercise (T2.3 and T2.5); tracking, reconstruction, and segmentation of patients' posture and arm movements (T3.1-3); L1-L3 avatar animation (T4.2-4); development of semiautonomous (L2) and autonomous (L3) avatars through a cognitive architecture generating their reference arm and postural motion (T5.1-2). Several metrics will be considered, e.g., interpersonal phase relationship, at both body and arm levels, and influence leadership, among others.

Key points :

- Only three VR equipment units working at the same time.
- All participants (N = 10) experience VR at the hospital once and at home twice.
- The practice is done in regular rehab sessions (more ecological).
- Changing from feasibility study to usability study.
- Less interaction of patients with other patients (L3): Effects in social presence, connectedness (to be measured).

For more information, please see Annex 1.

2.3 SHARESPACE FOR SPORT: *PELOTON CYCLING*

2.3.1 USE CASE

The Cycling scenario will focus on PERFORMANCE for cyclists who want to improve their skills to increase their chances of winning races. It uses the SHARESPACE Platform and consists of a Phase I - VR and Phase II - XR. The objective is focused on detecting (and masking) the attack of the peloton. It includes *(i)* learning how to identify the perfect moment to launch an attack (for the attacker) and *(ii)* detecting and reacting quickly to an initiated attack (for the follower) (see Figures 7 and 8).

PERFORMANCE SCENARIO

This scenario is focused on PERFORMANCE, when expert cyclists facing "opportunities of attack" in a peloton.

Phase I (**VR**): Mathieu, Anne, John, and Emma, four experienced cyclists, are at home with their own bikes mounted on Wahoo KickR (home trainer device). Their objective is to enhance their peloton riding skills and train for future races by learning how to detect *(i)* when to initiate an attack while in a breakaway and *(ii)* when a partner is about to launch an attack to follow him promptly. They are all wearing VR glasses and are immersed in a virtual environment (please see Figure 7 top right, panel). Sara, an autonomous character, serves as an opponent in this training session, leading the peloton. The peloton rides on a virtual road at high speed, mimicking the conditions of cycling races, but without traffic. Sara (L3) takes the lead in the group, with Mathieu, Anne, John, and Emma following her. Mathieu, Anne, John, and Emma belong to the same team, and are supposed to help Anne to win the race. As the slope becomes steeper, Sara exhibits signs of fatigue, which can be amplified to make them more detectable by Mathieu, according to the level of expertise of Mathieu. As soon as this latter notices these signs, he is instructed to initiate an attack. The idea is to attack with the aim to make Anne and John and Emma follow him, to benefit from the “pull” effect, due to friction air. The specific variables associated with his attack are amplified at the early stages of the attack (Mathieu’s avatar is L2, driven by the cognitive architecture), for Anne, enabling her to detect and follow Mathieu's move as soon as she can, to benefit from this “pull” effect. When Anne accelerates, John and Emma have to follow her, in the same way. Their avatars are L1. The cognitive architecture enables amplification of Mathieu’s L2 movements to make the relevant anticipatory variables visible for the followers.

In summary, we have the following individuals:

- L0: Mathieu (MA), Anne (AN), John (JO), Emma (EM)
- L1: L1AN, L1JO, L1EM (avatars representing Anne, John, and Emma)
- L2: L2MA (amplified avatar of Mathieu to facilitate perception by Anne, John, and Emma)
- L3: Sara (SA)

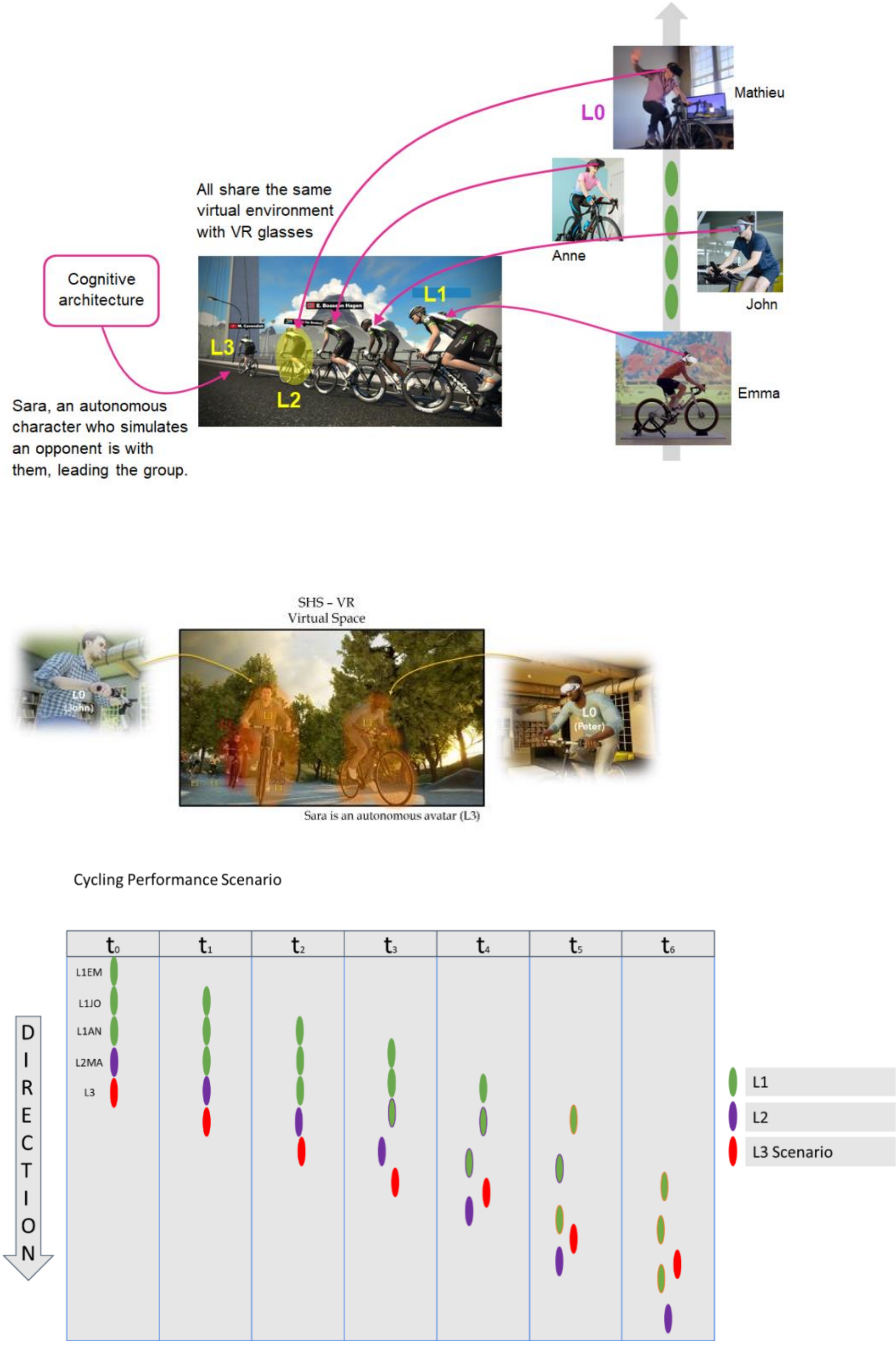

Figure 7:

The VR Phase for the PERFORMANCE version of the cycling scenario. Visual of the virtual scene (left) and temporal dimension of the scenario (right).

Phase II (XR): The aim of the second phase (XR) is to use the skills acquired in the first phase (VR) in a realistic race environment. In a preliminary offline stage, Mathieu, at the wheel of his car on the road, has integrated a set of 360° cameras. He uses this camera to generate a 3D model of the terrain that can be integrated into a navigable virtual environment. After this offline process, Mathieu returned to the road with his bike and SHARESPACE peloton XR (Phase II: AR) equipment. He has invited three trained cyclists to join him remotely for an opposition (race simulation training) on his favorite route, which was previously downloaded to their SHARESPACE peloton XR equipment (Phase I: VR). Using embedded cameras, sensors, and GPS positioning, Mathieu's position is tracked within the navigable model. This allows his avatar to be visible to everyone within their local representation of the terrain (refer to Figure 9). Mathieu and his opponents are thus practicing the acquired skills of cycling in a breakaway during a race, trying to launch an attack when an opportunity arises for Mathieu and quickly following this attack for the rest of the peloton. Their virtual opponent Sara remains present throughout this experience, returning to lead the breakaway after each attack phase and showing again fatigue signs in some steep slopes to induce her follower to create a new attack. Each of Mathieu's friends is eager to share this experience by participating on roads near their own homes and begins utilizing the SHARESPACE peloton XR equipment (Phase II: AR).

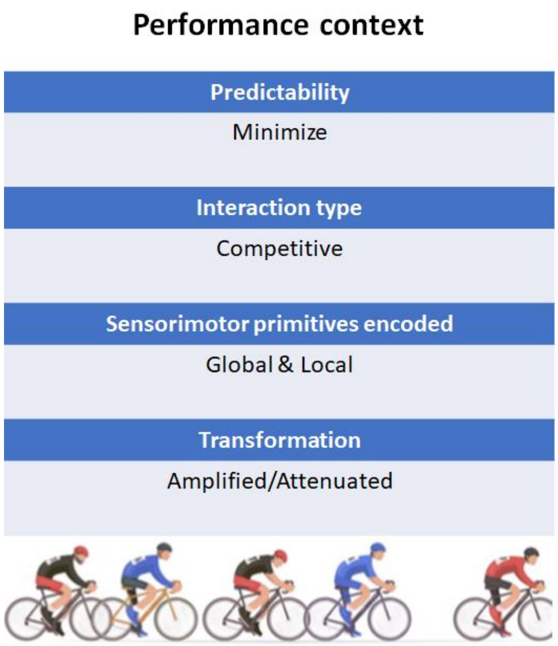

Figure 8 :

Highlights of the socio-motor specifications for SHARESPACE for Sport scenario.

Figure 9 :

Illustration of the XR performance scenario from Third Person Perspective (TPP).

2.3.2 KPI

The evaluation of the Phase I of the scenario is summarized in Figure 10. It consists of a pre- and post-evaluation of cyclists' performance based on the measurement of its key factors. These factors are global cues such as the cyclist's displacement or speed, but also local cues such as head and body orientation, postural changes or handlebar rotation. Pilot experiments involving only L0 cyclists on a real road will be carried out at an earlier stage in order to determine which factors have the greatest influence on the performance of expert cyclists, and therefore which factors need to be amplified.

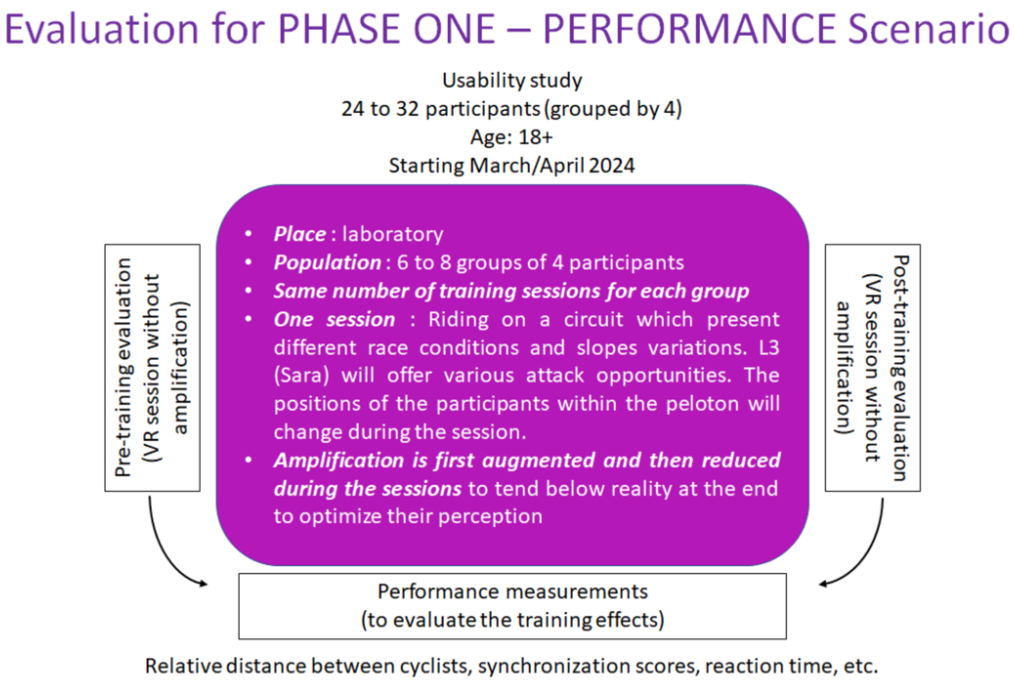

Figure 10:

Evaluation method of the phase 1 (VR) of the PERFORMANCE Scenario

To train the cyclists to focus correctly and perceive the right factors, these will initially be amplified to a large extent and, over the course of the training sessions, they will be amplified less and less until they return to real values without anticipation. Pre- and post-evaluation are of course based on actual performance (without amplification) in order to assess the cyclist's real improvement.

2.3.3 SCENARIO COMPONENTS

Specification and detection of motor intentions and synchronization patterns (WP2); design of the sensor networks embedded in VR and XR versions to capture users' position, motion and velocity (T3.2); prediction of intentions of users based on sensors' outputs (T3.3); scanning of the 3D environment in AR application and transfer offline the 3D reconstructed scene to the other VR users (T3.4, T3.5); realistic reconstruction of 3D motion of the avatar based on sensor information (WP4); design of behavioral models for L3 agents such as Sara or opponents (T5.3). Several metrics will be considered, e.g., relative velocity of peloton and surrounding vehicles, time(s) to collision in the peloton, synchronization patterns (phase and frequency, leadership46), among others. In this scenario (see illustrations below), L0 agents are real individuals, L1 agents are their avatars, L2 agents are amplified, and the L3 agent is Sara.

2.4 SHARESPACE FOR ART: *SHARED CREATIVITY*

2.4.1 USE CASE

Paola (age 32) and her friend Thomas (age 31) are regular visitors to art festivals. This year, they are attending a special event at the Ars Electronica Festival in the Deep Space 8K (refer to Figure 11), developed in the context of the European research project SHARESPACE. This event features a multi-user, hybrid, interactive art performance. The SHARESPACE platform allows remote users (L1-L2 virtual avatars) to join users in the Deep Space 8K (L0 human agents) and interact in real-time to intuitively shape the space through their movements. Paola and Thomas participate as L0 agents. Their position and movements are continuously tracked. Soon, L1 and L2 agents of other remote participants join them through the platform. Thanks to immersive technology, L1 and L2 agents are reproduced in the form of real-size avatars and can interact in real time with L0 users in the Deep Space 8K (please see Figure 11). Together they enjoy the immersive experience of co-creating a new aesthetic form by impacting and influencing what emerges on the virtual stage. The process of co-creation is witnessed by a bewitched audience of 50 people. All of them wear 3D glasses and are thus able to see L1/L2 agents projected in real-size as avatars moving around them.

Figure 11 :

Artistic production in the Deep Space 8K at Ars Electronica Festival (above) and suggestive illustration of Shared Creativity Scenario with L0 humans (white), human driven L1 (yellow), semi-autonomous L2 (pink) and fully autonomous L3 (green avatars).

Within the context of the SHARESPACE project three artworks will be created in Deep Space 8k through a bottom-up fashion. This means that there are no exact requirements from the SHARESPACE consortium towards the artist about what technology needs to be integrated in the artworks, rather, the artist communicates what SHARESPACE technology they want to use for their concept. Furthermore, the development of the art scenario requires the integration of SHARESPACE technology with the systems that are present within Deep Space 8K, which are described in the next section. The clear separation of the art scenario Phase I – VR and Phase II - XR, as is the case in the other two use cases, is less relevant here because the Deep Space 8K is an inherent XR space. However, it is known that the first artwork, which is developed internally by Ars Electronica, will use VR technology developed in Phase I of the project for the remote participants, and the second and third artwork might incorporate the AR technology from Phase II.

Of the three artworks, one of them will be developed internally by the team members of Ars Electronica, and the other two by external artists that are recruited through an open call. The final artworks can be viewed during the Ars Electronica Festivals 2024 and 2025. With multiple showings per artwork over the course of the two festivals plus separate performances, we expect to reach about 1000 on-site visitors with about 100 audience members participating in the performances. The sections below describe the development process in more detail.

Deep Space 8K

Deep Space 8K (please see Figure 12), located in the Ars Electronica Center in Linz, enables immersive XR environments through 3D stereoscopic wall and floor projections (both 16m x 9m). Artworks shown in Deep Space 8K can be made interactive by its laser tracking system PHARUS, which enables the system to determine the 2D position of objects on the floor. Potential 3D positions can be determined by giving visitors an OptiTrack device that tracks the position of their hand. Furthermore, Deep Space 8K has space for a total audience of around 80 spectators on the ground floor behind the floor projection and on the mezzanine in the room.

Figure 12 :

Deep Space 8k, Credit: Ars Electronica

Futurelab Scenario

The internal Ars Electronica Futurelab scenario is the first of the three artworks that will be developed in the context of the art use case. This way the Futurelab team develops tacit knowledge in working with the SHARESPACE technology, which can then be used to aid the subcontracted artists in their development phase. The team consists of an artistic lead, two researchers, and a developer. Currently, the artistic concept is in its development phase. The first draft of the concept will be presented to the SHARESPACE partners during the first in-person consortium meeting after Napels. After incorporating the feedback and engaging in further development, the concept will be presented to the Artistic User Advisory Board (UAB) in January 2024 for a final round of feedback. Full development of the concept will then commence, with the goal to finish this first scenario in June 2024.

2.4.2 SUBCONTRACTED ARTIST SCENARIOS

2.4.2.1 Open call

The other two art scenarios will be developed by two (groups of) artists through a subcontract. Selecting these artists will happen through an open call that is announced at the Ars Electronica Festival 2023. The call includes the following:

- An introduction to the SHARESPACE project and the Deep Space 8K
- A description of the artistic requirements, as they will need to integrate SHARESPACE core concepts such as synchronisation, remote participation, and amplification.

- A description of the technical requirements, as they will need to work with software such as Unreal or Maya.
- A description of all technology available to them for the development of their concept. This includes both the SHARESPACE technology and the technology present in the Deep Space 8K.
- A description of the selection process
- Inquiry about availability (are they available at Ars Electronica 2024, 2025, or both)

Before arriving at the final version of the call, input from both the consortium and the artistic UAB will be incorporated.

2.4.2.2 Selection of the artists

The selection of the artists will be done by the Ars Electronica Futurelab team in collaboration with the artistic UAB. After the call is closed, the Futurelab team makes a shortlist (depending on the number of applications) of artists to be selected for an interview. After the interviews, the final selection will be made by the artistic UAB, which consists of a variety of artistic experts and performers and can therefore provide valuable input.

2.4.3 KPI

5 – 20 on-site participants interacting (wearing 3D glasses) in the Deep Space 8K; up to 80 on-site spectators (wearing 3D glasses) outside of the tracked projection area; 1+ remote(s) user with full or partially body tracking and VR-HMD; 2 external (groups of) artists.

2.4.4 Scenario components

Encoding and readout of social information and synchronisation (WP2); rendering of L1 avatars (WP4); modelling and animation of their behaviours for L2 and L3 avatars (WP3 and WP5).

2.5 DEMONSTRATIONS

2.5.1 Olympic Games, Paris, 26 July –11 August 2024

Olympic games are organized in Paris in 2024, with several satellite events, such as fan zones, general audience communications, and expositions. More specifically, Inria is involved in an event in “Cité des Sciences” in Paris, which aims at exposing cultural and scientific activities associated with the Olympic Games. Inria aims at managing a booth with INSEP (National Institute for Sports) with several demos. We plan to host the demo of the SHARESPACE cycling scenario.

2.5.2 World Pain Conference, Amsterdam, 5-9 August 2024

This is the congress of the most prestigious association in pain research, the Internati onal Association of the Study of Pain, where the consortium plan to present a demonstration of SHARESPACE, concretely a demonstration of the first phase of the health scenario.

SHARESPACE aims to showcase a conference demo of the VR health scenario (depending on the progress of the development at that time). It is not confirmed yet because the application for activities at the conference is not open yet, but the plan is to apply for it.

2.5.3 Ars Electronica Festival 2023, 7 - 10 September

During the Ars Electronica Festival 2023, a panel will be organised where different consortium members and one member of the artistic UAB come to discuss different aspects of the SHARESPACE project. The theme of the Ars Electronica Festival 2023 is ‘Who Owns the Truth?’.

2.5.3.1 Ars Electronica Festival 2024, 5-8 September

During this festival two art scenarios can be presented: the one internally developed by the Ars Electronica Futurelab and the first subcontracted scenario.

2.5.3.2 Ars Electronica Festival 2025, 11-14 September

During this festival the third art scenario, which is also developed by a subcontracted artist, can be presented.

3 Scenarios Requirements

3.1 Introduction / Approach

The description and the findings from the information collected from the relevant stakeholders (researchers, developers, athletes, trainers, medical professionals, artists), among others, indicate that the system's key features include aspects like operational features, usability, privacy, and flexibility.

To create the system in a way that is efficient and well-liked by users, these aspects imply a set of functional and non-functional requirements:

1. **FUNCTIONAL REQUIREMENTS.** Requirements of the **system components and technology** (wearable hardware: Sensors, head-mounted display; Infrastructure: PCs, Internet/Wlan connection, Communication Platform) including the **system features**.

2. **NON-FUNCTIONAL REQUIREMENTS.** Including **Ethics-by-design,** personalisation features, **safety** (data protection and privacy) and **usability (simple and intuitive use, flexibility, tolerance for error)**. Usability/ethics-by-Design and usability requirements have been developed according to GDPR practices, good clinical practice and humanistic principles, focused on the human-centric design of this system (promoting psychological and physical safety).

The requirements have been grouped according to the following categories:

- **CS** - Core system;
- **HW** - Hardware: Sensors (SE), including type of sensors (ST) and sensors' location (SL); Display, such as head-Mounted Display (HMD);
- **DC** - Data Capturing, including Sensors, cameras, offline 3D scanning of the user environment, encoding motion to Motion Library, optical motion capture for ground truth of motion data;
- **DR** - Data Rendering, including Virtual Avatar, executed Movements, Facial Expression, Audio, decoding motion from Motion Library;
- **CA** - Cognitive Architecture;
- **DA** - Data analysis and feedback;
- **MP** - Motion Library and encoding, amplification, attenuation of the Motor Primitives;
- **CP** - Communication platform
- **ED** - Ethics by design.

The requirements of the two Proofs of Principle “Kinematic Chinese Whispers” and “Social Connectedness” represent core operational requirements in the scenario for Health. They are expected to be delivered earlier, in a controlled environment (partners’ labs) and with a smaller set of users.

3.2 USER REQUIREMENTS

3.2.1 Common user requirements for the SHARESPACE System

3.2.1.1 Core System (CS)

Table 2 : Core System Requirements

Code	Type[1]	Requirement name	STATUS[2]	Defined in	Description
CS_01	**F**	System will offer VR and AR capabilities	Approved	T1.4	Both modalities are planned; Phase 1 focus on VR (M18), Phase 2 and final system will include AR.
CS_02	**F**	System will have different versions. SHARESPACE for Health will include: HMD, the whole set of IMU-sensors, an external camera, a PC unit. SHARESPACE for Sport will include: the mobile processing unit, sensors on the bike, cameras. SHARESPACE for Art: Deep Space	Approved	D1.7	The system will include a specific version per scenario, since requirements and tech for tracking, conditions of use (indoor, outdoor) are different.
CS_03	**F**	System will ideally have delay (latency) below 50ms	Approved	T1.4	This requirement might be further split into compound latencies for DC, DR and CP separately.

[1] **F:** Functional; **NF**: Non-functional
[2] Approved, Important (required research/include risk), Optional

CS_04	**NF**	System must comply with the General Data Protection Regulation (GPDR).	Approved	D8.1	The system will implement the appropriate technical and organizational measures to ensure the data protection principles.

3.2.1.2 Hardware (HW)

Table 3 : Hardware requirements

Code	Type	Requirement name	STATUS	Defined in	Description
HW_01	**NF**	Light weight display and wireless	Important	D1.7; D3.8 (T3.4)	Essential for the Health and Sport scenario.
HW_02	**NF**	As little sensors as possible	Important		Essential for all scenarios (along long battery life and plug and play design).
HW_03	**NF**	Multifocal display –less fatigue	Approved		The XR display will provide an innovative multifocal XR display.

3.2.1.3 Data capturing and collection (DC)

Table 4 : Data capture and collection requirements

Code	Type	Requirement name	STATUS	Defined in	Description
DC_01	**F**	System will dynamically monitor the overall body posture	Approved	T3.2	The overall body posture will be measured with the partial BSN and one external camera.
DC_02	**F**	System will collect data about position of specific parts of the body	Approved	T3.2	System will gather relative position of head/neck, trunk/back, arms, hands, legs. Measure of global or absolute positions can't be measured with IMUs. Overall body posture it is composed of different positions in parts of the body (*see DC_01*).
DC_03	**F**	System will localize the users in their virtual/real environment/spa ce.	Approved	T3.3	SC Health: position in the space will be defined with external camera and tracked with partial BSN. SC Sport: tracking of the indoor bike motions in VR-world, tracking of the bike in the real-environment (outdoor scenario).

DC_04	**F**	System will capture the hand kinematics		T3.1	SC Health: required SC Sport optional SC Art: required
DC_04	**F**	System will render facial expression (mouth) in accordance with audio; and eye movements from eye tracking		T3.1	SC Health: required SC Peloton: optional SC Art: required
DC_04	**F**	System will create a 3D model and offer 3D visualization of the local user environment	Approved	T3.3	SC Health: scanning of the room with 360° ToF-camera (DLSR cameras and/or laser scanning as a backup) SC Sport: bike tour (large space), scanning with multiple 360 cameras SC Art: not needed

3.2.1.4 Data Rendering (DR)

Table 5 : Data rendering requirements

Code	**Type**	**Requirement name**	**STATUS**	**Defined in**	**Description**
DR_01	**NF**	System will allow partial personalisation of the Virtual Humans (on a spectrum of physical resemblance to the participant).	Approved.	T4.1; T4.3	Diverse avatars, with some level of personalisation will be available for the users to adopt during the system use.
DR_02	**NF**	Avatars should be realistic	Approved.	T4.5	The avatars will have realistic features.
DR_03	**NF**	Personalisable features of scene rendering for XR (especially the SHARESPACE for HEALTH scenario – choice of the backdrop for the sessions).	Approved	T4.4	In SHARESPACE for Health – scene rendering will be personalisable for Phase II use test.

3.2.1.5 Cognitive Architecture (CA)

Table 6 : Cognitive Architecture requirements

Code	**Type**	**Requirement name**	**STATUS**	**Defined in**	**Description**
CA_01	**F**	L1 accurately replicates motion	Approved.	T5.1	The L1 virtual human associated to a participant replicates the motion of that

					person, in the shared space, with the minimal alteration required for the correct operation of the whole system.
CA_02	**F**	L1 does not follow scenario-specific goals	Approved.	T5.1	The L1 virtual human associated to a participant does not alter the motion of that person with the aim of achieving a goal associated to a scenario.
CA_03	**F**	L2 alters motion to achieve goals	Approved.	T5.1	The L2 virtual human associated to a participant produces a motion that is an altered version of the motion of that person, with the aim of striking a balance between improving some scenario-specific metrics of interest and remaining true to the motion of the participant.
CA_04	**F**	L3 produces human-like motion	Approved.	T5.2	A L3 virtual human produces a motion that most people would deem similar to what a person would do.
CA_05	**F**	L3 produces original goal-oriented motion	Approved.	T5.2	A L3 virtual human produces a motion that is not the alteration of that of any single human in the shared space. However, it is possible that L3 virtual humans are trained to perform motion that is similar to those of other people in other contexts. Additionally, the motion is chosen so as to improve some scenario-specific metrics of interest.

3.2.1.6 Encoding of the motor primitives (MP)

Table 7 : Encoding of the motor primitives requirements

Code	**Type**	**Requirement name**	**STATUS**	**Defined in**	**Description**
MP_01	**F**	Movements represented as kinematic data will be segmented to identify socially relevant information	Approved.	T2.1	Tracked body motion of human participants, interacting in social spaces, will be segmented and single-trial information analysis will be applied to identify primitives that encode social information
MP_02	**F**	A movement primitive abstraction will be created to identify or generate motion	Approved.	T2.1	Movement primitives will be created as adaptable abstraction of the human movements and represented in lower-dimensional space (lower as compared to the

		via a lower dimensional space.			dimension of kinematic data). They can be used to identify movements or combined to generate complex motion.
MP_03	**F**	Movement primitive encoding, extended with additional information/ features / sensor inputs will be used to represent a library of sensory motor primitives to identify, generate and modify movements.	Approved.	T2.1, T4.3, T5.1	An abstract movement description (like the movement primitives) and sensory inputs / features / additional information derived e.g. from an interaction or surrounding, will be used to create a mapping between sensory inputs and motion outputs, enabling the description and identification of socially relevant sensory motor primitives.

3.2.1.7 Communication Platform (CP)

Table 8 : Communication platform requirements

Code	**Type**	**Requirement name**	**STATUS**	**Defined in**	**Description**
CP_01	**F**	System will route and distribute sensorimotors primitives to registered endpoints	Approved.	T1.4; T5.3,	Endpoints being different clients – participants of session in the the shared hybrid space.
CP_02	**F**	System will synchronize multimedia streams with avatars animations	Approved.	T5.3	Once session is launched no additional participant can enter (SHARESPACE v1.0) - more flexible in Sharepsace v2.0
CP_03	**F**	System will handle network impairment to ensure avatar synchronization and animation	Approved.	T5.3	
CP_04	**F**	System will allow flexible number of participants during the session	Approved.		For the second prototype (SHARESPACE v2.0).

3.2.1.8 Ethics by Design

Table 9 : Ethics by Design requirements

Code	Type	Requirement name	STATUS	Defined in	Description
ED_01	**NF**	**Privacy:** Data protection	Approved.	T1.5/T8.2	Data sharing and storage will be GDPR compliant (i.e., protecting privacy and restricting sharing data with external stakeholders), and specified in the Data Management Plan. -consent from participants for use of in pseudo realistic avatar representation and rendering. -collecting demographic information from participants. Administering surveys, and interviews. Pseudo anonymisation. -privacy and data protection of health participants in home scenarios constrained to render specific movements of bodily interaction segment (e.g., flexing, shuffling, squatting) -consent for video and audio recording, sharing and distributing images or their use externally for academic or relevant publications. Audio to facial animation mapping. All scenarios. -GDPR compliant software for processing data. -privacy rights protected, the right to withdraw within a specified time-frame.
ED_02	**NF**	**Safety:** Physical injuries	Approved.	T1.5/T1.4 /	Design of the experiment will consider possible physical discomfort (i.e., cybersickness, eye strain); injuries (i.e., encountering physical obstacles).

ED_03	**NF**	**Safety** Psychological safety	Approved.	T1.4, T1.5	Design of the experiment will consider and minimise possible psychological harmful consequences such escapism/addictive behaviours; leveraging attachment style (by for example excessive attention bombing), dysmorphophobic tendencies (i.e., alteration of body representation)
ED_04	**NF**	**Usability**	Approved.	T1.5, T8.2	Data collected during this project will comply with the FAIR principles (Findable, Accessible, Interoperable, Reusable).
ED_05	**NF**	**Transparency related to L2 and L3 avatars**	Approved.	T1.5, T6.4	Participants will be informed and will be asked for consent to have their data exploited by and movements amplified by the cognitive architecture to increase the social connectedness and engagement in the interaction with other agents. Participants will be informed when interacting with AI systems, using non jargon terms and idioms.
ED_06	**NF**	**Acceptability/Participatory Design –** Design (the users have the possibility to configure the avatar appearance and the scene)	Approved.	T1.5, T4.1	The project will ensure participants' dignity by avoiding manipulation of avatar representation increasing sexualisation, gender differences and minorities representation. Avatar rendering will avoid objectifying and sexist, racist and classist stereotyping. Avatars should be reasonable (moderately realistic) diverse to allow a choice from the participants, they could identify with as their representation. No public access to stored avatar renderings.

ED_07	**NF**	Dignity of **Human Subjects**	Approved.	T1.5, T6.4	Scenarios will work with human subjects - no children (where extra regulatory conditions apply (safeguarding) and adults in pain scenarios), of which the dignity has to be protected.

3.2.2 Scenario specific user requirements

3.2.3 SHARESPACE FOR HEALTH

Future, mobile 'home rehab' systems could address the hospital rehab clinic overload [(inadequate and insufficient number of therapist/care-providers/physicians) versus the number of outpatients seeking access to pain management services] in two ways:

+ provide additional, low-cost services to increase the number of overall sessions on top of hospital sessions (high demand, lack of care providers)

+ prevent passiveness of outpatient at home - difficult to perform the rehab exercises at home. Interference with daily life routines (work, household, family care, etc.) and less motivation of doing the exercises without the guidance of the therapist and the company of other patients.

+ allow for communication and monitoring of a patient remotely - SHARESPACE could help to overcome the barriers pointed out in the previous point (remote guide, feeling accompanied).

+ provide quantitative data for more precise tracking of rehabilitation progress - the accurate monitoring of objective and subjective measures can help for a better assessment of the patient's state and progress.

+ provide personalized rehabilitation programs adapted to the needs and pace of each person - the data gathered by SHARESPACE a personalized exercise program can be planned for each patient.

(In Phase II – Luna (L3 therapist) provides exercises chosen from a library according to the outpatients' progress that is being monitored across successive sessions. Luna picks up exercises for each of them to maximize a 'rehabilitation index' defined as a function of the outpatients’ movement kinematics and other factors indicated by their human therapist (Judith).

Therapist therefore can be only: L1(Phase I) or L3 (Phase II)

+ remove the need for outpatients to commute to the hospital for every session - logistics barriers are sometimes an important problem for patients who need to go to the pain units or rehab units at hospitals far away from their homes. Being able to conduct rehab sessions at home (guided by therapist and feeling accompanied by other patients remotely) can save time and money.

+ address the psychosocial underpinnings of pain experience via:

- XR amplified synchronous movement with other Virtual Humans (with preliminary scientific evidence showing that moving in unison increases the pain threshold);
- Decoupling of the learnt association between pain and movement via XR amplification of movement.

There is an important relationship between pain and movement. Behavioral synchrony has been linked to endorphin activity (Cohen et al., 2010; Sullivan and Rickers, 2013; Sullivan et al., 2014, 2015 ; Tarr et al., 2015, 2015; Weinstein et al., 2016).

Table 10 : Scenario specific requirements: SHARESPACE for Health

Scenario specific user requirements		**HEALTH**	Description
	Number of participants		In the Phase I, VR 10, 2 at once plus therapist.
RH_01	Shared physical space	In the final weeks, participants (2) will connect from home	Yes, with the reconstructed scene being a gym or other. The immersion in the ‘shared space’ needs to be displayed and streamed remotely to the HMD via wireless connection.
RH_02	Distance between physical users	(use metric system and describe if it is going to fluctuate)	Lie in the gym 1,5-2m between participants.

RH_03	Remote shared space	3 participants at once (2 patients, 1 therapist, rest emulated as L3)	For Phase I, for Phase II for 10 at once.
RH_04	Example of movement/range of motion	Hip sways, lateral sways, squats	Relevant body parts: upper leg + hip + lower back
Criticial usability features			
RH_05	Acceptable latency	Ideally under 50ms	To avoid cybersickness and compromised embodied experience.
RH_06	Plug and play	YES/NO	Phase I (VR headmounted) – System will be set- up by the technican/researcher (one or different ones, instructional video will be provided by the consortium), participants will be in approximate physical space – in a hospital Vall d'Hebron, different gym rooms. Participants will be encouraged to launch the application themselves, but assistance will be provided. Phase II (XR untethered) - System needs to be low-cost and plug and play, easy to set up by a non-technical person, the calibration has to include movements that are relatively easy to execute even for a person with movement limitations (demo needs to be provided or an instructor to demonstrate the set up) S/he is at home, and attaches the sensors with elastic bands over the knee (upper leg), pelvis (clip-sensor or belt), and at the top of the spine (clip-sensor) S/he starts the Laptop-App and the camera.
RH_07	Calibration procedure	YES/NO	YES for each participant
RH_08	Set up time		Few minutes, sensors need to be attached by Velcro to strap. Clear instruction needs to be provided where to place them on the body and how to close them
RH_09	Weight and battery life of sensors		As light as possible, easy to put on with straps Battery lifetime of at least 4, ideally 8 hours; easy to re-charge (e.g. standard usb-charger, similar to a smartphone charging)
RH_10	Number of sensors	5	Four sensors: upper legs, pelvis and neck (spine). If more detailed monitoring of the spine is required, one additional sensor should be foreseen (middle of the spine). If the user wears a head-display, one additional sensor will be available Motion prediction of body segments which do not have IMU sensors (info from cameras). Fusion of the IMU information with the information of a camera image from a laptop/smartphone or the head-mounted display.
RH_11	Weight of HMD		Head-mounted display (Phase I and Phase II) should be small, lightweight, and wireless and easy to connect to the processing unit (laptop or smartphone)
RH_12	Wireless	YES/NO	YES, The AR LIGHTSPACE display has to allow for the freedom of head movement with convergence issues or motion sickness.
RH_13	Video camera	YES/NO	YES
RH_14	Other specify:	the "processing unit" should be provided; ´mini-pc or laptop with a camera in Phase I (maybe a smartphone in Phase II)	
Data capture			
RH_15	Mocap full body	YES/NO	YES
RH_16	Hands orientation	YES/NO	YES

RH_17	Eye tracking	YES/NO	YES
RH_18	Physiological	YES/NO	YES
RH_19	Sound	YES/NO	YES
RH_20	Key candidate MPs	(i.e., smoothness, vigour, amplitude, frequency, speed of execution)	Amplitude, speed, smoothness- > rehabilitation index.
RH_21	Inter-apparatus synchronisation requirements	YES/NO	NO
SHARESPACE typology:			
RH_22	Verbal comms in hybrid space	YES/NO	YES
RH_23	Leader-follower (one-to-one)	YES/NO	YES
RH_24	Complete graph – open diffusion, all agents can see each other in the shared hybrid space	YES/NO	YES
RH_25	Chain	YES/NO	yes - gym like set-up, the rest is following the leader.
RH_26	Personalised feedback to user about performance	YES/NO	YES
RH_27	Sound rendering 3D to increase immersion	YES/NO	YES – Phase II

Other requirements (from Q&A) session		
RH_28	Fun	To ensure that the patient performs the exercises is the first priority (so the motivation to/fear of exercise -> make the available exercise sets 'easy', 'doable', 'fun', 'engaging', 'challenging') – the system needs to offer a variety of movement options at different levels of difficulty, there must be a balance between the variety of movements and the exercises needed to perform (selected by therapists). The precision of exercises in comparison to the template needs to be monitored, but is secondary-> system needs to track and render the execution versus the template. Most important is that participant performst he exercises.
RH_29	Wide and versatile portfolio of exercises	The system should support/provide most exercises usually done in a session at the hospital (lying on a bed or on the floor, leaning against the wall) - 8-10 exercises, duration of the session 45-60 minutes (with breaks included if participant needs breaks). Piloting will test the exercises that are feasible to perform – and define whether patients can stand or need to be seated (not defined at this stage).
RH_30	Social	The remote patient should get the feeling of being part of the group and performs the exercises with the group (rendering of 6 L3 in Phase I).
RH_31	Diverse	It is possible to include patients with different demographics (sex, age)

RH_32	Privacy and confidentiality	The data transmitted to the hospital are only movement primitives and on request a live video stream for video conferencing. The functionality of blurring the background should be provided. The data transmitted to the hospital are only movement primitives and on request a live video stream for video conferencing.
RH_33	VR Gym personalisation	Participants will choose whether they would like the shared space to be rendered and overlay their home surroundings or some neutral space (i.e., Alpine meadow, Mediterranean beach – week 3 and week 4 – Phase I).
RH_34	Rendering personalisation	Participants will be able to choose the space where the other Participants and Therapist will be rendered. They will also be able to define their 'size' to feel more comfortable with their presence in the Mixed Reality of their home and AR display
RH_35	Miniature scaling of other participants	L1/L2 Avatars and L3 Therapist will be rendered in a safe space chosen by Participant, in a miniature depiction (to make them feel less imposing, or threatening to their personal, domestic space*).*
RH_36	Amplification – multitude rendering	Participants will be informed that in Phase II their movements will be 'amplified' to support their learning/motivation to exercise and that the L3 therapist will encourage the exercise adapted to the needs and possibilities of each patient separately. To achieve this, the Cognitive Architecture needs to manage the dissonance between FPP of L0 movements and L2 rendering, and TPP view of others. Note: We expect that Phase II SHARESPACE platform will be more efficient than home-based exercises performed by Participants without supervision (not more efficacious than hospital-based gym sessions – although that would be a great result – that could be attributed to the 'social connectedness' and personalized approached of L3 Therapists, with one-to-one attention given to each patient).

3.2.4 SHARESPACE FOR SPORT

Table 11 : Scenario specific requirements: SHARESPACE for Sport

Scenario specific user requirements		**SPORT**	Description
	Number of participants (L0)	4	The scenario involves 4 participants
RS_01	Shared physical space	Yes, partly	In Phase 1 (VR), cyclists has VR device and can share the same physical space. In phase 2 (XR), it is the same except for the cyclist on real road.
RS_02	Distance between physical users	At least 1m	For the cyclists using VR devices, the distance between them can be only 1m since they are on ergocycles. It can be more if they are using mobile platforms that allow them to bend a little.
RS_03	Remote shared space	Always	In Phase 1 (VR), all cyclists are sharing a virtual road. In Phase 2 (XR), this virtual road is reconstructed from the real physical one the cyclist in XR is riding on
RS_04	Example of movement/range of motion	Cycling movements (stationary posture, rhythmic limb motion)	Cyclist in VR: Stationary ride on a home trainer Cyclists in AR: dynamic ride on a real bike and on road

CRITICIAL USABILITY FEATURES			
RS_05	Acceptable latency	Ideally under 50ms	End To end Latency – to avoid the impact on performance (Morice et al., 2008), while threshold of 60-70ms increases cybersickness.
RS_06	Plug and play	YES/NO	The system is based on commercial VR device easy to setup in Phase I. In Phase II XR device will allow this functionality. All the software can be started easily, not only by the PhD student or researcher.
RS_07	Calibration procedure	YES/NO	YES
RS_08	Set up time	10 minutes	Less if possible
RS_09	Weight of sensors		Should be lightweight (as much as possible) particularly for sensors on the head, hands and feet. They should not induce fatigue or pain to participants because of their weight
RS_10	Number of sensors	8	6 on participants (2 feet, 1 pelvis, 1 head, 2 hands) 2 on bike, to determine direction (1 on saddle, 1 on handlebar). The one on saddle will also determine if cyclist is sitting or standing.
RS_11	Weight of HMD		HMD should be lightweight (for VR and AR) because cyclist leans forward, too much weight can cause neck fatigue or pain.
RS_12	Wireless	YES/NO	YES VR: preferable but not mandatory. XR: Necessary, for safety
RS_13	Video camera	YES/NO	NO
Data capture			
RS_14	Mocap full body	YES/NO	YES
RS_15	Hands orientation	YES/NO	YES
RS_16	Eye tracking	YES/NO	NO
RS_17	Physiological	YES/NO	NO
RS_18	Sound	YES/NO	YES (a background soundscape to increase fidelity)
RS_19	Key candidate MPs	(i.e., smoothness, vigour, amplitude, frequency, speed of execution)	Will be determined by a preliminary study but based on biomechanical data such as trunk flexion, handlebar orientation, cyclist bending, speed, cycling frequency...
RS_20	Inter-apparatus synchronisation requirements	YES/NO	YES Synchronization between 4 bikers and their virtual spaces.
SHARESPACE typology:			
RS_21	Verbal comms in hybrid space	NO	NO
RS_22	Leader-follower (one-to-one)	YES/NO	YES
RS_23	Complete graph	YES/NO	Maybe
RS_24	Chain	YES/NO	YES
RS_25	Personalised feedback to user about performance	YES/NO	YES
RS_26	Sound rendering 3D to increase immersion	YES/NO	YES
Additional			
RS_27	Position in the global frame	For AR, we need to know the position of the participant in the global frame to be coherent with the virtual elements.	

3.2.5 SHARESPACE FOR ART

In this scenario, two main parts exist. First the shared co-located physical projections space Deep Space 8K (will be referred as on-site) and second VR or XR remote users (will be referred as remote). On-site users and remote users share the same shared hybrid space.

On-site users will be present in the Deep Space 8K and mainly be tracked by a 2D LiDAR tracking system (PHARUS). This positional tracking will potentially be augmented by optical markers (OptiTrack). They will be held by the users and allow further control of the avatar. Avatars will be semi-autonomous (L2).

Remote users will be equipped with a partial or full body tracking system and wear VR-HMDs. Remote users will be represented as L1 Avatars.

Depending on details of the artistic concept. Autonomous avatars (L3) may also be present.

Goal of the art scenario is to encourage collaboration between all users, on-site users and remote users, in a shared hybrid space. A strong sense of connectedness between the users and social presence is desired.

Table 12 : Scenario specific requirements: SHARESPACE for Art

Scenario specific user requirements		**ART**	Description
	Number of participants	5 - 20 co-located 1+ remote	Visitors of the performance will be present in the Deep Space 8K. They are tracked by tracking systems within the Deep Space 8K and their avatars are projected on the floor and wall. Remote users are wearing (full/partial) body tracking and a VR HMD. 1st (AE internal) pilot: ~10 co-located users and 1 remote user. 2nd and 3rd (subcontracted artist) pilots: TBD
RA_01	Shared physical space	Deep Space 8K	5 - 20 users
RA_02	Distance between physical users	(use metric system and describe if it is going to fluctuate)	
RA_03	Remote shared space		1st pilot: 1 user with VR gear. In the same LAN. 2nd and 3rd: TBD
RA_04	Example of movement/range of motion	On-site: walking (2D LiDAR tracked). +optional: picking, painting, waving, swinging (one had beeing tracked). Remote: free (full/partial body tracking)	

CRITICAL USABILITY FEATURES			
RA_05	Acceptable latency	Ideally under 50 ms	If not reachable by SHARESPACE system artist will need to adapt their interaction concepts in their artworks
RA_06	Plug and play	YES/NO	YES
RA_07	Calibration procedure	YES/NO	On-site users: no for (potenially yes, for hand tracking) remote users: Yes)
RA_08	Set up time		On-site: no setup time Remote: less than 10 min
RA_09	Weight of sensors		NA - using DeepSpace
RA_10	Number of sensors		NA – using Deep Space
RA_11	Weight of HMD		NA- using Deep Space
RA_12	Wireless	YES/NO	On-site: naturally yes Remote: preferable
RA_13	Video camera	YES/NO	NO
Data capture			
RA_14	Mocap full body	YES/NO	Remote: Yes
RA_15	Hands orientation	YES/NO	Remote: Yes
RA_16	Eye tracking	YES/NO	Remote: Yes
RA_17	Physiological	YES/NO	No
RA_18	Sound	YES/NO	Remote: Yes
RA_19	Key candidate MPs	(i.e., smoothness, vigour, amplitude, frequency, speed of exectution)	As it is not known right now, what will be necessary for the external artist projects, we would like to make all existing ones available.
RA_20	Inter-apparatus synchronisation requirements	YES/NO	YES
SHARESPACE typology:			
RA_20	Verbal comms in hybrid space	YES/NO	Remote: Yes
RA_21	Leader-follower (one-to-one)	YES/NO	Yes
RA_22	Complete graph	YES/NO	
RA_23	Chain	YES/NO	
RA_24	Personalised feedback to user about performance	YES/NO	Yes
RA_25	Sound rendering 3D to increase immersion	YES/NO	Yes, but most likely not possible to implement.
Additional:			
RA_26	Multiple avatars on one instance	All avatars of on-site users are controlled by the same game instance/machine (2 cluster machines). This means that, in contrast to the typical setup, data from multiple avatars needs to be streamed from that instance.	
RA_27	2D LiDAR tracking input data	On-site users are tracked by a 2D-LiDAR system. Therefore, their avatars positional input is the 2D position in the Deep Space 8K.	
RA_28	3D position tracking extension	Associating a single OptiTrack	An avatar is then controlled by the position of a user and the tracked marker in one hand.

		marker with a user to allow more interaction.	
RA_29	Syncing avatars between render machines	In the Deep Space 8K the wall and floor projection are rendered by two separate PCs (and therefore Unreal instances). The contents need to be synchronized.	That is important because an avatar can be visible on the both projections simultaneously. E.g.: The feet and legs are visible on the floor projection, and the rest is visible on the wall projection. In Unreal, to render scenes on multiple synchronized display devices nDisplay is used. Where simple objects, like a cube, can be synchronized easily, we need to take care of proper synchronization of the avatars. One PC (e.g. the one which renders the wall projection) serves as primary node, the other one as secondary. Only the primary node connects to Rainbow. The data (avatar position, pose, ...) is then synced by a dedicated plugin (which uses nDisplay).
RA_30	Integration of tracking hardware	As described in RA_27 and RA_28, custom tracking hardware will be utilized in the art scenario.	Furthermore, it is considered to use an existing body tracking system. This allows to provide BVH data.
RA_31	Development toolkit for the artists	Artists must be able to work on their projects – also when they are not in the Deep Space 8K. A working development environment and toolkit which allows using or simulating all crucial components are necessary. Including simulation of Deep Space 8D, Tracking, and accessibility to Crucial SHARESPACE components such as avatar animation.	
RA_32	Licensing for artists	The subcontracted artists need to have access to necessary licenses for relevant software products.	
RA_33	Training of AI/Cognitive Architecture (CA)	For the scenarios (especially the 3rd scenario, which is presented at the AE Festival 2025) custom training of the CA and AI behavior might be of interest. There should be a process that facilitates this. The addition of further MPs should also be possible.	

4 CHALLENGES/RISK ASSESSMENT

The implementation of new systems and technologies introduces certain risks that need to be carefully evaluated and mitigated. Risk assessment presented below followed a systematic process to identify, analyze, and prioritize potential risks associated with the implementation of SHARESPACE technology in the three different scenarios (SHARESPACE for Health, Sport and Art).

By examining these risks, we identified the potential challenges and uncertainties that may arise during the implementation process and help them develop effective risk management strategies as a part of the user requirements and technical safety rules.

4.1 SHARESPACE FOR HEALTH

Table 13 : Risk assessment SHARESPACE for Health

Risk	SEVERITY	LIKELIHOOD	RISK IMPACT	Preventative/ recovery measures
Low acceptability of hardware devices by patients.	UNACCEPTABLE	POSSIBLE	HIGH	Testing of hardware with patients during development: patients at the hospital and members of user advisory board
Fatigue in patients while using VR/AR devices.	TOLERABLE	PROBABLE	MEDIUM	Testing of hardware with patients during development: patients at the hospital and members of user advisory board. Programming of sessions including breaks.
Low acceptability of VR/AR use from health professionals.	UNACCEPTABLE	POSSIBLE	MEDIUM	Inclusion of health professionals in user advisory board to get feedback during development
Access to patients willing to participate in testing of the scenario.	TOLERABLE	NOT LIKELY	LOW	VHIR partner is a hospital with pain and rehab units with easy access to patients
Difficulty of performing rehabilitation exercises with VR/AR devices.	TOLERABLE	POSSIBLE	MEDIUM	Selection of exercises balancing clinical efficacy and easiness to perform with VR/AR devices (testing with patients during development)
Difficulty for patients to use VR/AR equipment at home.	TOLERABLE	PROBABLE	HIGH	Performing VR/AR sessions first at hospital for training. At least first VR/AR session with research assistant.
Low social presence and other social indicators) during VR/AR sessions.	TOLERABLE	PROBABLE	HIGH	Testing of different types of avatars, L1, L2, L3 and their influence in social indicators. Testing of different amplification cues and their influence in social indicators
Rejection from patients of using VR/AR at home for fear of privacy breach.	UNACCEPTABLE	POSSIBLE	HIGH	The data transmitted to the hospital are only movement primitives and on request a live video stream for video conferencing. The functionality of blurring the background should be provided. The data transmitted to the hospital are only movement primitives and on request a live video stream for video conferencing.

4.2 SHARESPACE FOR SPORT

Table 14 : Risk assessment SHARESPACE for Sport

Risk	SEVERITY	LIKELIHOOD	RISK IMPACT	Preventative/ recovery measures
Cybersickness caused by the discovery of new sensory-motor relations (VR is not usual for most individuals)	UNACCEPTABLE	POSSIBLE	HIGH	Insert a substantial familiarization period + Avoid sharp turns at high speed (and possibly moderate speed) which can be very disturbing, even with practice

Cybersickness caused by HMD device and more specifically related to the delay between the head movement and display update	UNACCEPTABLE	POSSIBLE	HIGH	Select the right HMD with optimal refresh rate to have an acceptable delay between image update and head movements
Eyestrain caused by the HMD device	TOLERABLE	POSSIBLE	MEDIUM	Limit session time to be acceptable
Fall off the bike in VR:	UNACCEPTABLE	POSSIBLE	HIGH	Avoid sharp turns at high speed (and possibly moderate speed) to prevent the user from wanting to tilt too much. When we ride a bike in the real world, we lean when we turn. This inclination depends on the radius of curvature of the turn and the speed of the bicycle. Users well immersed in the virtual environment will tend to tilt the bike as in the real world to turn. However, the home trainer having a limited degree of lateral freedom, this can surprise the user who can lean his body excessively and fall off the bike. Pay attention to the home trainer stability : - For basic set-up: the home-trainer should be placed on a flat surface, in its most stable configuration. - For a set-up using a platform allowing tilting: the platform should be placed on a flat surface and the home-trainer should be well fixed to the platform in its most stable configuration. Solution: The system has to be safeguarded not to tip to the side.
AR: Accident, due to traffic (e.g., other bicycles, cars, pedestrians, etc...) or presence of obstacles (e.g. rock, barrier, etc...).	UNACCEPTABLE	PROBABLE	HIGH	If this risk is present in real life, it is increased by using AR technology. Indeed, the virtual elements that will appear in the field of vision of the user can mask the dangers of the real world (e.g. a virtual avatar can mask a real rock or car in the field of vision of the cyclist). Solution: Stay on bike paths and safe roads, with no traffic and no obstacles.

4.3 SHARESPACE FOR ART

Table 15 : Risk assessment SHARESPACE for Art

RISK	SEVERITY	LIKELIHOOD	RISK IMPACT	PREVENTATIVE/ RECOVERY MEASURES
On-site users in the Deep Space 8K				
Visitors do not relate with their avatar.	TOLERABLE	POSSIBLE	HIGH	Early and continuous testing of the concept. Also with less or not involved people.
Artistic concept is misunderstood by the on-site participant, affecting the execution.	TOLERABLE	POSSIBLE	MEDIUM	Early and continuous evaluation of the concept.

The interaction concept is misunderstood or too complicated.	UNACCEPTABLE	NOT LIKELY	HIGH	Early and continuous evaluation of the interaction design.
Cyber sickness due to moving virtual world/environment (e.g. could occur if the virtual camera performs movements).	UNACCEPTABLE	NOT LIKELY	HIGH	Early and continuous evaluation of the concept.
A delay of tracking and/or avatar behavior causes a feeling of detachment or inhibits the interaction.	UNACCEPTABLE	NOT LIKELY	HIGH	Early and continuous evaluation of the interaction design. If it cannot be solved or mitigated enough technically, the interaction design needs to be adapted.
REMOTE VR USERS				
The interaction feels cumbersome or too difficult.	UNACCEPTABLE	POSSIBLE	MEDIUM	Early and continuous evaluation of the interaction design. Adaptation of the interaction design.
Low social presence.	TOLERABLE	POSSIBLE	MEDIUM	Early and continuous evaluation of the interaction design. Evaluating different avatars and interaction/control strategies.
Cyber sickness.	UNACCEPTABLE	POSSIBLE	MEDIUM	Early and continuous evaluation of the system. If it cannot be solved or mitigated enough technically, the interaction design needs to be adapted.
Delay of communication inhibits interaction	UNACCEPTABLE	POSSIBLE	HIGH	Early and continuous evaluation of the interaction design. If it cannot be solved or mitigated enough technically, the interaction design needs to be adapted.

5 DELIVERY ROADMAP

The research delivery roadmap will be produced for both PoPs and SHARESPACE scenarios to monitor delivery. The template below (Figure 13) is a starting point, which will be developed of M7 of the project, and updated on monthly basis to monitor stable progression of the project and requirements being met at different iteration points of each prototypes of SHARESPACE system.

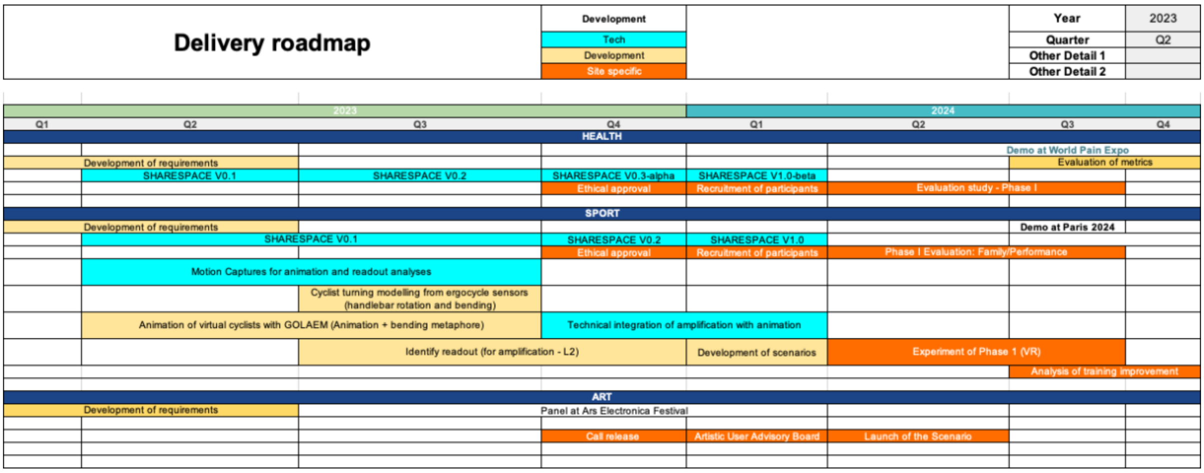

Figure 13 :

Template for the delivery of the two prototypes of the SHARESPACE system across different Phases of delivery (I-III for PoPs, and I-II for SHARESPACE: for Health, for Sport and for Art).

6 CONCLUSIONS

This deliverable has presented the functional and non-functional requirements to feed in the system developments described in the D1.7 System Architecture. Three conclusive elements are important to underly here:

6.1. DIFFUSION OF THE SHARESPACE BLUEPRINT ACROSS PROOFS OF PRINCIPLE (POP) AND SCENARIOS

Some requirements reviewed above are specific to a system component or scenario (e.g., 3.2.1, 3.2.3 or 3.2.4), while others are applicable across all project activities (e.g., ethics-by-design, safety, transparency) or are globally identical (e.g., amplification of primitives) but instantiated differently based on the scenario. It is important to note that we do not intend to establish a one-to-one mapping between all requirements and scenarios, as this would be unrealistic. Instead, through the proposed (many-to-many) mapping, we ensure that the original SHARESPACE blueprint, such as the encoding-amplified-readout of social information, is present in all PoPs and scenarios but can be adapted to specific contexts and tasks that will be implemented.

6.2. TIMELINE FOR THE IMPLEMENTATION OF THE REQUIREMENTS OVER DIFFERENT ITERATIONS OF THE PROTOTYPES

The deliverable D1.7 System Architecture presents in detail the stages of introduction of different requirements (compiled herein) at various iterations of the SHARESPACE system, driven by the time estimates pertinent to the technical development and research delivery. The envisaged roadmap (here, presented as a template in Section 5) for SHARESPACE system development consists of three iterations per prototype, providing a structured framework for progressive system enhancement from facilitating socio-motor interaction in VR (Phase I) to embodied XR experience (in Phase II). This iterative approach allows us to incorporate new functionalities, and enable us to adapt and refine the system based on the changing technological solutions and stakeholder expectations from three scenarios. Through this approach, we are confident in delivering a robust and future-proof SHARESPACE system that will deliver new multi-modal hybrid XR technology at the forefront of European innovation.

6.3. Possible requirement revision for the future AR/XR phase

While the descriptions and requirements for the first phase (Phase I - VR) have been delineated precisely, some requirements related to the second phase (Phase II – AR/XR) are currently somewhat generic. This is because we need the results from Phase I to validate certain components for Phase II, such as the amplified information or the specifics of the cognitive architecture. As Phase I is progressively evaluated and we obtain the initial results, we will be able to refine some of the requirements and potentially make modifications based on the findings. Therefore, we anticipate revising this document around M16-M18 when preparing for Phase II.

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ANNEX 1

More information regarding planning of the SHARESPACE for Health: Social Low Back Pain Scenario.

Evaluation Phase ONE

First week (VR at hospital):
Session 1: Rehab session without VR. Show use of VR devices to all patients.
Session 2: Two patients use VR in different rooms (P1, P2).
Session 3: Two other patients use VR in different rooms (P3, P4).

Second week (VR at hospital):
Session 1: Two other patients use VR in different rooms (P5, P6).
Session 2: Two other patients use VR in different rooms (P7, P8).
Session 3: Two other patientes use VR in different rooms (P9, P10).

Third week (VR at home):
Session 1: Two patients use VR at home (P1, P2).
Session 2: Two other patients use VR at home (P3, P4).
Session 3: Two other patients use VR at home (P5, P6).
Session 4: Two other patients use VR at home (P7, P8).
Session 5: Two other patients use VR at home (P9, P10).

Fourth week (VR at home):
Session 1: Two patients use VR at home (P1, P2).
Session 2: Two other patients use VR at home (P3, P4).
Session 3: Two other patients use VR at home (P5, P6).
Session 4: Two other patients use VR at home (P7, P8).
Session 5: Two other patients use VR at home (P9, P10).

Important steps :

- Opinion of user advisory board.
- Coordination with proof-of-concept experiments.
- Define evaluation protocol (pre-post intervention; pre-post session, objective and subjective measures).
- Define exercises (considering wearing HMD).
- Pilot testing of sensors, devices, etc. with patients at the hospital.