D2.5

EVALUATION OF ASSESSMENT RIG

Grant Agreement nr	**856998**
Project title	Personalised recovery through a multi-user environment: Virtual Reality for Rehabilitation
Project Acronym	PRIME-VR2
Start day of project (dur.)	October 1st 2019 (3 years)
Document Reference	PRIME-VR2_D_WP2_UOS/UOP_D2.5 RIG EVALUATION_final
Type of Report	PUBLIC
Document due date	31/12/2020
Actual date of delivery	30/12/2020
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Document status	FINAL

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 856998

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EXECUTIVE SUMMARY

This document is an evaluation of the assessment rig developed within D2.2/3. The material presented here can be seen as a partner document in which the fundamental functionality of the rig is tested, evaluated and discussed.

Firstly, a brief overview of the finished prototypes is presented with a description of the overall vision for the scanning procedures. The overall rig is designed to provide a comprehensive biomechanical profile unique to each person that uses it. The prototypes for the rig were fabricated at the University of Pisa (UOP) and the University of Strathclyde (UOS). UOP focused on the development of the "hoop" module that comprises the anatomical scanning and the motion capture devices. UOS focused on the force assessment module which comprised the hand dynamometer, pinch gauge and torque gauge. The collected information from the devices will interface directly with the core design work for the PRIME-VR2 bespoke controllers within WP3 as they are intended to be designed on individual users and tailored around their therapeutic needs. WP7 is also influenced heavily as the nature of the injury or disability will be understood partly through this scanning system. With respect to this, the overall protocol for use of the scanning rig is summarised but is more extensively presented in D2.2/3 as this document is more focused on the core functionality of the rig.

Following this, the main evaluation material is presented. This is split into the three scanning categories and the feedback for each Living Lab is presented within each section. The three Living Labs – Global Disability Innovation Hub (GDIH), St James Hospital (STJH), Kinisiforo & NICOMED Rehabilitation Centre (KNRC) – all provided feedback to varying degrees allowing WP2 to make an initial evaluation on the success of the design. The evaluation was principally conducted through video analysis and survey methods. In general, the devices and the systems were shown to work successfully – they could be assembled and operated at all of the Living Labs and initial patient reporting provided significant insight. Utilising this information, considering all the positives and negatives observed, an experience map was created designed to map an "idealised" scan procedure. This will essentially act as a datum moving forward where we can focus on key areas to improve following a human-centred design (HCD) paradigm.

Lastly, these results are discussed with a view to targeting specific design changes to the rig and changes to the overall procedure that will improve the overall experience for facilitators and patients. Several redesign proposals are identified to further improve the procedure and, by extension, advance the overarching aims of PRIME-VR2.

BACKGROUND

One of the objectives of PRIME-VR2 is to produce bespoke controllers that are designed to replicate particular therapeutic and clinical exercises. To this end, the anatomy and capabilities of each patient must be understood. Three methods have been developed in order to create a comprehensive biomechanical profile: anatomical scanning, motion capture and force assessment. Each assessment type is facilitated by a different device mounted onto an integrated prototype or "rig" the development of which is extensively described in D2.2/3. Presented here is the evaluation work that was done on the first prototypes of the rig. This evaluation is important as it will influence how the acquisitions are performed on the final participants and the information articulates with many other work packages. The main work packages that interface with the activities set out in this document are:

- WP3 – utilisation of the user data scanned by the demonstrator for generation of bespoke controller designs
- WP6 – utilisation of the user data scanned by the demonstrator for use in designing appropriate VR games
- WP7 – incorporation of feedback from clinicians and end users to ensure that the configuration and experience of the scanning demonstrator is appropriate.

1 INTRODUCTION

1.1. Main objective and goal

The document relates directly to the work carried out during tasks 2.1, 2.2. and 2.3 in which the methods of patient measurement are elucidated. This includes, the anatomical scanning, motion capture and force assessment. These different methods have been amalgamated into one specially designed testing rig in which all the devices are mounted and can be used for data capture. The rig was designed to be adaptable and accessible to both clinicians facilitating the scanning process and participants, meeting their needs for comfort and a non-invasive procedure. With respect to this, the purpose of this evaluation is to understand the initial rig prototypes in greater detail: how effectively they are working and how easily they can be deployed and used. Additionally, it is to examine the *experience* of use, by the participants being scanned – how comfortable they are, how easy they find the process. And also, by the facilitators – how easy the process is to facilitate, how effective are the procedures for capturing data.

This document will set out the findings from the initial evaluations which explore these questions. After an introduction to the status of the assessment rig following the development process documented in D2.2/3 and a presentation of the fully developed prototype, the evaluations will be explored. An evaluation has been performed for each stage of the process, starting with the anatomical scanning, followed by the motion capturing then the force assessment. Each section describes the effectiveness of the acquisitions in terms of participant and facilitator experience. This is then used as a framework to build an experience map of an "idealised" scanning experience using the knowledge gained about the scanning process realities. Following this, discussion is presented on the critical areas that require more attention for the scanning process with a number of proposals on how it can be improved for future tests.

1.2. Terminology

Table 1: Critical terminology used within document

Term	***Definition***
3D reconstruction	*The capturing of the shape and appearance of real-world objects in computer graphics*
Anatomical scanning	*Capturing the geometric make-up of body parts through computer graphics and visulisations technology*
Biomechanics	*The science of movement of a living body, including how muscles, bones, tendons, and ligaments work together to produce movement*
Cloud Registration	*The alignment of two 3D point clouds basing on the overlap region*
Computer-aided-design (CAD)	*The use of computers to aid in the creation, modification, analysis, or optimization of a design*
Data acquisition	*The capturing and compiling of different forms of data*
Dynamometer	*Device that can measure linear forces*
Force assessment	*A structured study to examine the forces applied within a given domain or set of conditions*
Gauge	*Device that can measure forces*

Human-centred-design (HCD)	*Commonly used in design and management frameworks that develops solutions to problems by involving the human perspective in all steps of the problem-solving process*
Motion capturing	*Process by which the motion of an object is captured through computer-based sensing and visualization technology*
Range-of-motion (ROM)	*The extent of movement of a joint, measured in the degrees of a circle. NOTE – a wider definition would include distance-based measurement*
Rehabilitation	*The action of restoring someone to health or normal life through training and therapy after or during illness or injury*
Rig	*Prototype configuration combining three data capture modules: anatomical scanner, motion capture and force assessment module*

2 OVERVIEW OF ASSESSMENT RIG

The assessment rig is designed to capture three key information types from patients involved with the PRIME-VR2 project. As part of the requirements for tasks 2.1, 2.2 and 2.3 where the scanning specifications are described in the proposal documentation as follows - "a total scan time of 30 minutes will be used as the maximum acceptable limit for all tests to be completed. The target for the final scanning and testing setup will be to conduct this under 20 minutes and to ensure a score of 8/10 in patient comfort while doing so" – it is desirable that the system is integrated to ensure a maximum level of efficiency and operational smoothness. The data acquired from the scanning rig will be fundamental for the design work moving forward. Critically, the design work planned for M18-24 when the algorithms are developed, allowing for the tailoring of the VR controllers around a patient's biomechanical profile (D3.4). The data gathered from the scanning rig design presented here will form the basis for this biomechanical profile.

2.1. System integration

Figure 1 illustrates the overall scanning process at work to understand how this can be effectively managed. There are multiple factors present that an integrated system needs to accommodate. This includes the different actors interacting in the process, the chronology of activities, and their inputs and outputs at each stage:

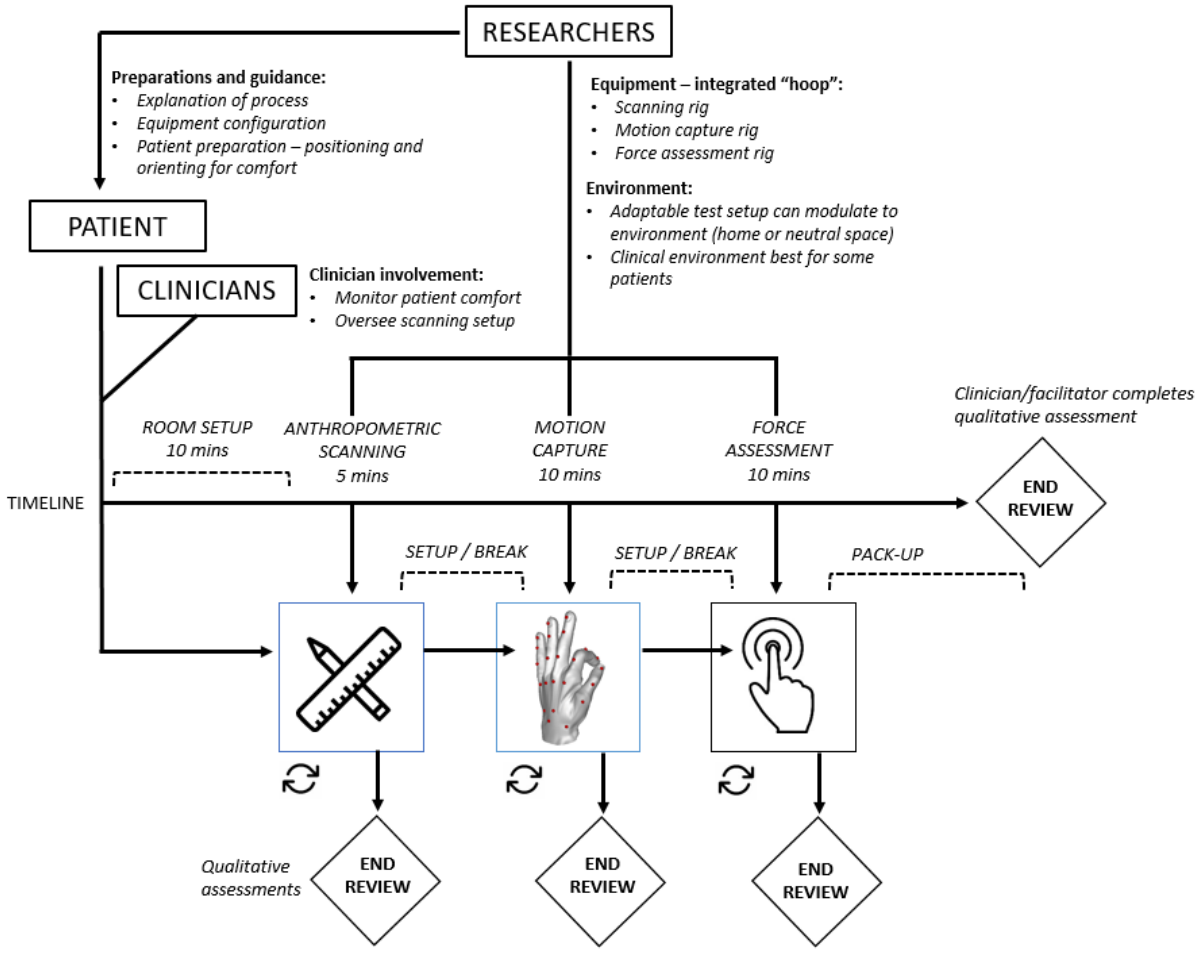


Figure 1: High-level map of scanning process including actors, timescales and processes

2.2. Integrated prototype

The scanning rig was designed to be flexible for both the patients and the clinicians utilising the scanning system. To this end, the integrated prototype was developed to allow for a wide range of use contexts. With this flexibility in mind, all of the elements of the scanning rig can be moved around – the hoop can be freely unmounted from the stand as can the force module - to best suit the context of use and the needs of the individual being scanned. D2.2/3 details the rationale behind producing the assessment rig in this way more fully and has detailed schematics and images of the initial device prototypes. As this is a public document, images of the final device are either in schematic form or have been edited to hide key elements.

2.2.1. Environment views

Additionally, we can consider the environment in which the integrated rig will be used. While this cannot be absolutely defined at this stage due to testing limitations, we can however present a rough vision of a testing setup: the rig place squarely on a table with a chair either side, differentiating two testing "zones" – one for anatomical scanning and motion capturing, the other for force assessment (Figure 2).

Figure 2: Environment views, with ergonomic swivel chairs (left). Final prototype with dummy elements (right)

2.2.2. Anatomical scanning and motion capture “hoop”

Presented in D2.2/3 is the anatomic scanning and motion capturing “hoop” developed at the University of Pisa. The hoop contains the RealSense 3D scanners and the Leap motion capturing scanners mounted on to a bespoke ring. The hoop is designed to be lightweight whereby the acquisition can either be made by placing the hand and arm through the hoop or the hoop is held by the facilitator and it is rotated around the subject. No image has been provided for intellectual property reasons but the confidential document D2.2/3 (p.50, Fig 36) contains images of the final prototype.

2.2.3. Force assessment module

Presented below in Figure 3 is the force assessment module developed by the University of Strathclyde, the details of the design and development of which are detailed in D2.2/2.3. The module contains a hand dynamometer, a pinch gauge and a torque gauge all mounted on to a bespoke shelf. The system is designed to be flexible for the user whereby the devices can be arranged in a way that best suits the requirements for the person.

Figure 3: Overview of force assessment module

2.2.4. Full prototype (dummy hoop)

These two core elements are combined in the full integrated prototype. Due to the current travel limitations, a dummy hoop was locally prototyped at UOS in order to verify the physical dimensions and visual presentation of the rig. While it contains all of the force assessment equipment, the 3D and motion capture scanners are absent. This does however provide a good picture of how the final prototype will appear. As shown, the hoop and the force module are mounted in brackets and stands that present the user with a coherent and integrated system.

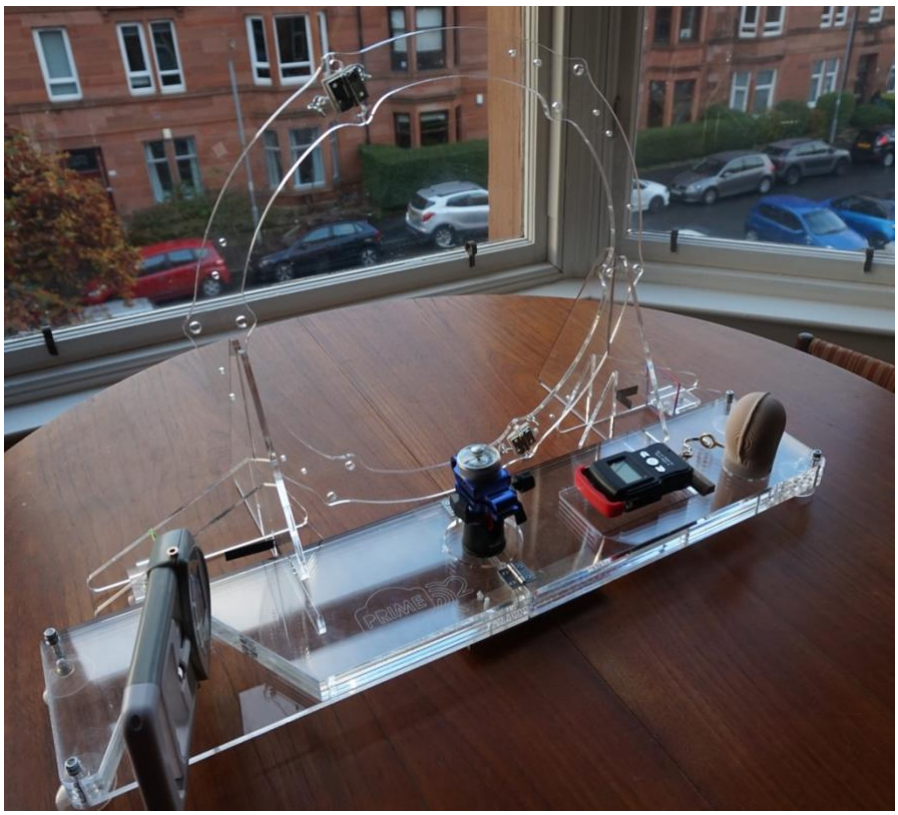


Figure 4: Assembled assessment rig with dummy hoop

2.2.5. Protocol and instructions for use of rig and devices

A set of simple instructions has been developed for each stage of the assessment process as well as a document that instructs the user how to build and assemble the rig, step by step presented in D2.2/3 appendices. Firstly, the "protocol and instructions" have been formulated in a visual format that is easily digestible for the facilitator of the process. The protocol also contains a useful illustrations of device setup, guidelines for device use and assessment approach and a guide to timings for each stage. A sample of the protocol is shown in Figure 5 where the first stage of the force assessment (pinch test) is described step by step. The full illustrated protocol for all three assessments can be viewed in the appendices (section 9.1).

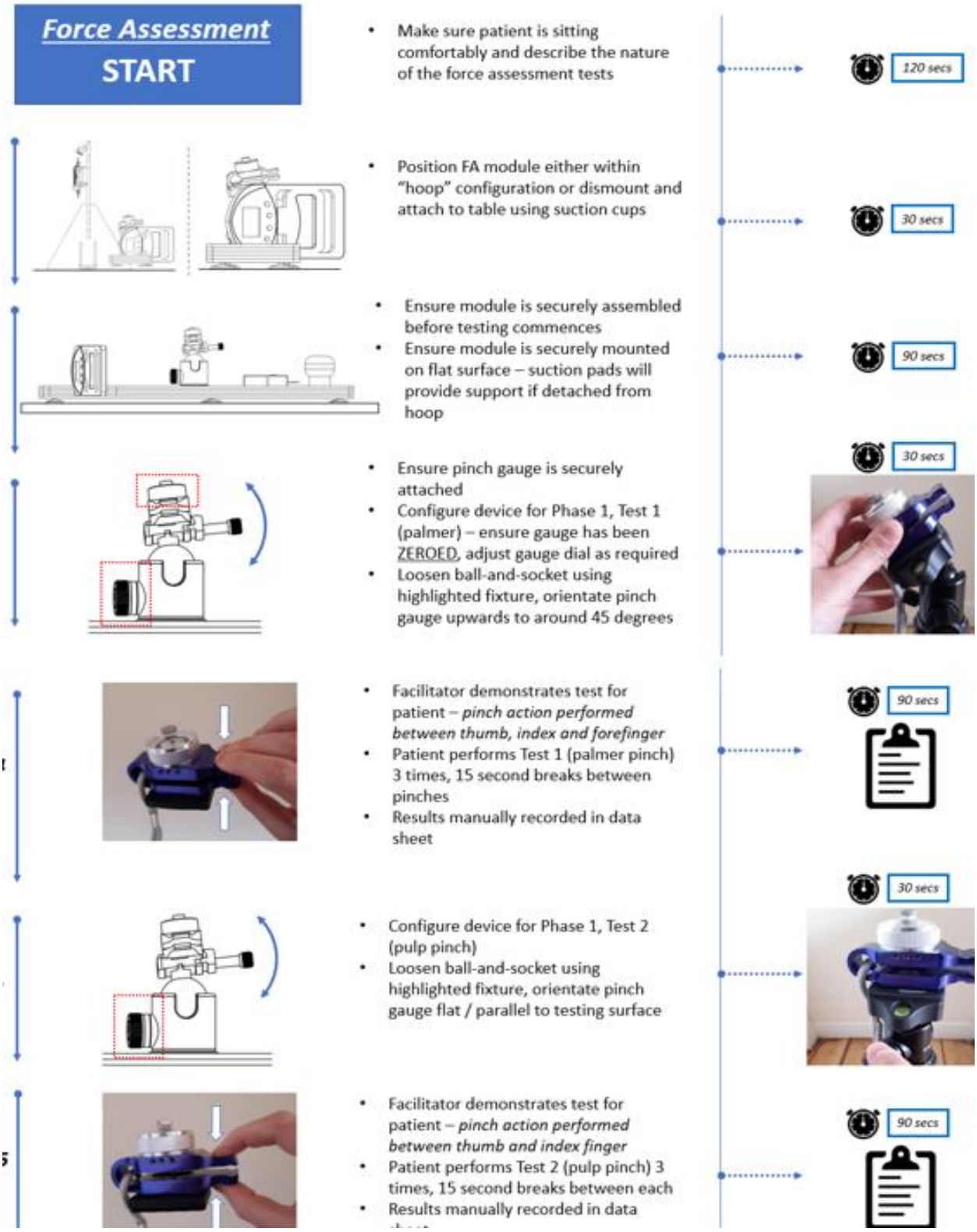


Figure 5: Illustrated protocol for force assessment pinch test (full protocol in the appendices)

3 APPROACH FOR EVALUATION OF SCANNING RIG

3.1. Qualitative assessment

There is a requirement to achieve a minimum of an 80% level of patient comfort during the scans. Qualitative assessments, within the context of user testing, are designed to scrutinize the subjective and experiential facets of a product or system and establish how people feel about particular features of it. For example, the subjective enjoyment of drinking coffee might be changed by the receptacle it is consumed from. Designing a structured qualitative assessment can help PRIME-VR2 improve the experience mapping and assessment experience at large and subsequently enhance the outcomes of the wider platform.

3.1.1. Aims of the assessment

Assessments of this kind can take various forms but the starting point for any such assessment is to define what the aims of the assessment are. In the broadest terms, we aim to improve the experience of the assessment procedure by scrutinizing any procedural problems that may manifest in a subjectively negative emotional experience for the patient and the facilitator of the process. This must however be defined more closely and narrowly – there are a number of questions that can help to define the aims:

- What exactly must be established from the qualitative assessments?
- What kind of information do we want?
- What format would the qualitative assessment take?
- What are the metrics used within the assessment?
- How will the data gathered be used to understand or improve aspects of the procedure?
- Can existing protocol be used to inform the assessment?

With respect to these questions, a more systematic approach can be developed. The assessment procedures are designed to probe biomechanical information that will be used to establish design domains for bespoke VR controllers. With respect to this, there must be an expectation that the quality of the procedure and the quality of the data remain consistent. Consistency of data acquisition can be affected by a variety of factors including the mood of the patient or the usability of the devices used to collect the data. By examining both properties of patient comfort while carrying out the testing procedures and also how easily the tasks can be completed and administered, we will gain a subjective picture of how efficacious the procedures are. Improving aspects of efficiency or comfort, may lead to improvements in the quality of data output. This goal is distinctly practical, meaning that the qualitative assessment should be formulated to address high-level practical concerns in the workflow of the procedures. With respect to what kind of information we want, it could be something more reflective or something more immediate. More reflective information means that the participant must think about the question for some period of time “sleeping on it” – obviously this has logistical complexities in having to arrange the communication and return of the data for example. Something more immediate is a first impression or a “gut feeling” and can be done directly after the procedure is complete. For the purposes of PRIME-VR2, the latter option is more desirable from both an information processing perspective (the data can be captured

immediately) and patient comfort perspective (the patient is not required to perform any more tasks outside of the procedural time slot).

In functional terms, qualitative assessments are most easily administered as variations on the questionnaire format in which normative and/or Likert scale-based questions are answered. This format also facilitates easy recording and processing of data. Some complexity is introduced however with respect to the design of the questions: biases or leading questions should be avoided. This also relates to the question of metrics – normative scales may ask for the extent of a subjective feeling using number scales to establish this ("to what extent do you feel X?" – 1 not at all, 10 a lot). Likert scales may ask for levels of agreement for a given statement although sometimes "agreement" is not an appropriate metric or indicator in which to frame a question so the scale should be changed accordingly. Likert scales offer more direct agency in the framing of the questions by asking for direct opinions. While processing of the data may need more analysis, it is likely the information gained will be more useful for making informed decisions regarding changes to the assessment procedures.

3.1.2. Structuring of questions

A number of important factors must be considered when structuring and formulating questions for a qualitative assessment of this kind, critically – how long will the questions take? And how will they be administered? This section will look at these factors in more detail. It was deemed sensible to review the opinions of both the patients and the facilitators of the process. The two different perspectives provide a two-pronged approach for potential improvement.

In the interests of testing efficiency, a shorter testing model was favoured – one that could be easily administered after each phase of the testing or completed at the end. It is possible this could be left to the preference of the patient or the facilitator. Furthermore, as mentioned earlier, the goal of the qualitative assessment in not so much a detailed analysis but a broader tool that will identify potentially larger structural problems with the assessment platform or approach. Other already existing assessment methodologies were examined in order to inform this including the Canadian Occupational Performance Measure [1] which uses a client-centred approach to review therapy and the Individually Prioritised Problem Assessment [2], which is technology focused, but these were not used as a direct reference. With respect to these, the questions have been formulated to examine several key factors: *subjective comfort of the patient during the process, experienced difficulties completing tasks and interactions between the actors and the actors and the technologies.*

Firstly, we can look at the questions that have been formulated for the patient review. In line with the requirements for WP2 and task 2.1, the questions were structured around examining the subjective comfort of the patient during the process. The three questions presented can be reformulated for each of the assessment procedures. (Three questions for each phase with an additional comment questions totals 10 – 8 out of 10 positively answered questions satisfy the procedural requirements of an 80% patient comfort level for task 2.1). The choice of answers was formulated in a Likert scale e.g. very comfortable to uncomfortable with the option to add additional comments at each question:

1) To what extent do you rate your comfort during the scanning process?

2) How difficult would you rate the experience of following the instructions of those directing the scanning process?
3) To what extent was the setup of the scanning device intrusive for you?
4) Additional comment on process

While the questions are simple, they allow the project team to identify larger more general problems with the procedures. Secondly, we can consider the questions formulated for the facilitator of the process. Structures similarly to the patient's questions, they differ in targeting understanding of procedural efficiency i.e. how easy or difficult the process is to administer with respect to technological setup and patient comfort:

1) How difficult would you rate your experience of setting up the scanning equipment?
2) How difficult did you find your experience directing the participant in completing the scanning?
3) How comfortable did you feel the participant was during this stage of the assessment?
4) Additional comments on process

Again, the questions can be reformulated for each stage of the assessment and allow for major procedural problems to be identified.

3.1.3. Layout of the questionnaire

The layout of the questionnaires is presented in Figure 6 and can be seen in full in the appendices (section 9.3). It is designed to be easy to read and to fill in. Procedurally, the facilitator of the process will orally present the questions to the patient marking the relevant box and filling in any relevant additional comments. The facilitator will do the same for themselves after the end of the full procedure – these procedural elements are both highlighted in the experience maps.

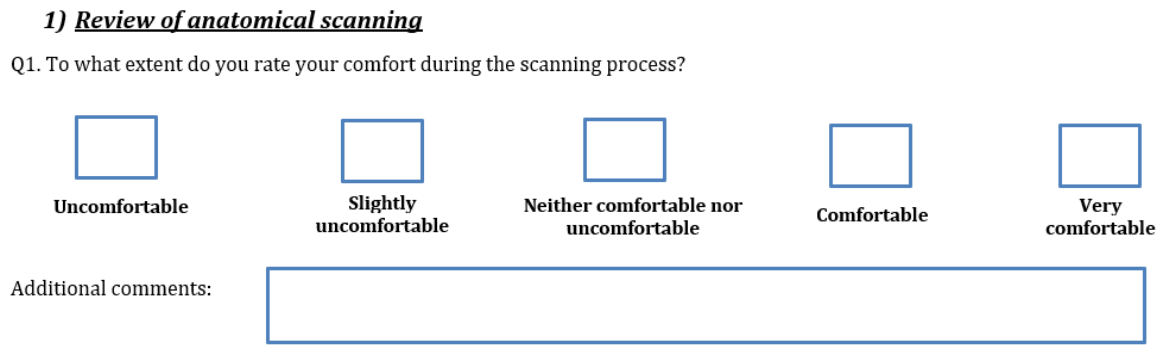


Figure 6: Layout of questionnaire with tick-boxes and addition comment box

The "final comment" section is intentionally open-ended, allowing the participant and the facilitators to offer improvement suggestions with respect to the procedures they have completed.

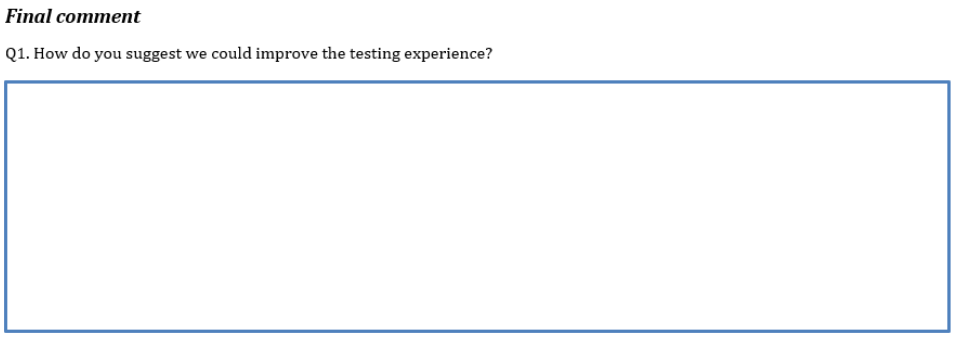


Figure 7: Layout of questionnaire final comment box

3.1.4. Number of participants

There were intrinsic limitations on how many participants we could recruit for the evaluations due to the nature of the conditions of the three use cases, however, but a target of 5-10 participants at each Living Lab was agreed as being both logistically feasible and methodologically sufficient. Ideally, these participants would have comprised individuals from each of the three clinical contexts associated with the three Living Labs though this was not possible in all cases. The next section will describe the evaluations that took place and how the results were analysed.

4 EVALUATIONS OF SCANNING SYSTEMS

4.1. Introduction

The last section detailed how the evaluation of the various scanning systems would take place. This section will now report upon the results of these evaluations. The assessment of the scanning and motion capturing involved both an evaluation of the effectiveness of the data acquisition and an evaluation of the procedure – this was principally undertaken at STJH. The force assessment module was principally assessed at GDIH with partial assessments from STJH and KNRC. Due to ethics protocol at GDIH, any acquisition information that was taken from participants cannot be presented in this report. Where acquisition material is not available to present, indicative data has been presented in its place, derived from tests conducted during the development of the overall system.

4.2. Assessments of anatomical scanning

The developed scanning system undertook several verification steps. Firstly, the device was tested at UOP: the system developers performed several acquisitions of healthy people to assess the functionality of hardware and software, the usability of the system, the effectiveness of the measurement and the training time needed to become confident with the equipment. To this extent, three different researchers performed a complete scan of each other arms. This first assessment also allowed to verify the scanning outcome with respect to anthropometric measurements taken through rulers. These preliminary tests demonstrated that, after about five trials, each researcher was able to perform a successful complete scanning of the human arm. Figure 8 shows the scanning results for one of the researchers, from different perspectives. The figure highlights that the full 360° acquisition was achieved, with no gaps or relevant holes in arm and forearm geometry. Some noise and surface holes can be noted between the fingers, which are the most challenging region to be acquired. Nevertheless, arm and forearm surfaces are smooth. After the training trials, all the researchers could complete the acquisition procedure in less than 60 s.

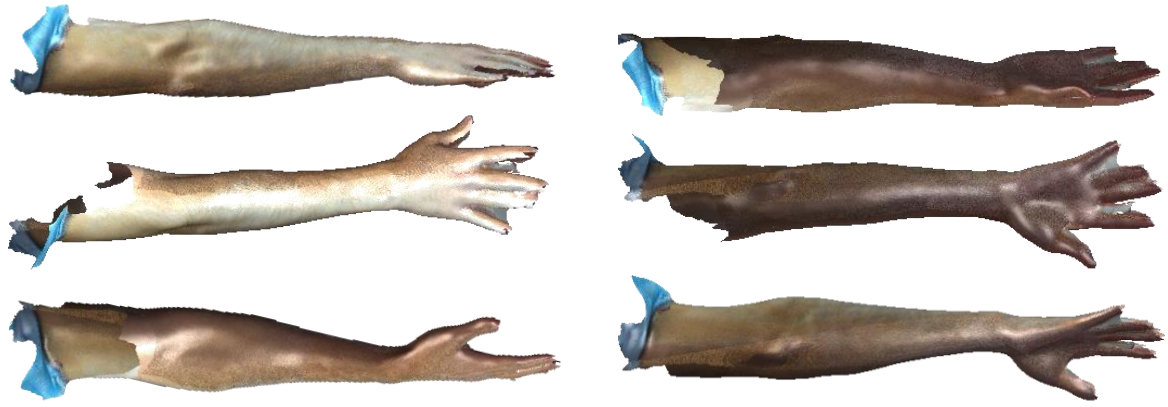
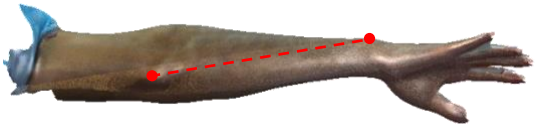
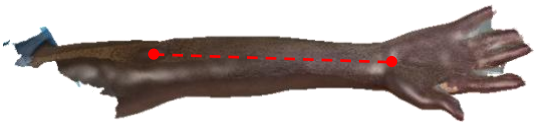


Figure 8: Example of 3D scanning outcomes at UOP: 360° view of the patient arm

The good qualitative results of Figure 8 were quantitatively evaluated by comparing the measurement of some key points of the arm on the 3D scanning and on the actual arm. The comparison results are shown in Table 2 the first column shows an image of the performed measurements, the second column reports the measurement value as

obtained from the 3D scanning (rounded to the nearest unit), the third column reports the mean value of the corresponding measurement taken through a tape with five repetitions, the fourth columns shows the standard deviation of the tape measurement, while the fifth column reports the percentual difference between 3D scan and tape measurements.

Table 2: Anthropometric measurements for scanning validation

Measurement	Scanning (mm)	Tape (mm)	Tape σ	Diff. %
	286	275	8	3.8
	94	97	4	3.2
	56	58	2	3.6
	179	181	7	1.1
	309	294	12	4.8

The assessment at UOP produced promising results concerning the usability and reliability of the system. It is worth noting that a high standard deviation was found concerning the tape measurements, due to high difficulties for the operator to repeatedly select the proper measurement point on the arm. This also justifies the discrepancies in the absolute measurement, which are to be ascribed to uncertainty in the tape measurement.

Nevertheless, the actual system validation is to be performed at Living Labs, by measuring non-healthy patients. Thus, two full prototypes were shipped to STJH and KNRC, and the rig structure (without the sensors) was sent to GDIH for additional testing. Due to covid-19 restrictions, the developing team from UOP could not travel with the system, to install and train the clinicians. All the setup procedure was remotely supervised by UOP and succeeded in installing the system in both Living Labs, providing some feedback concerning the usability of the system by non-technical users. After a training session on the use of the device, the Living Labs proceeded to measure actual patients with the system. The equipment's overall performance was comparable to the trials performed at UOP on healthy people, demonstrating the usability of the system for such measurements.

4.2.1. Sports injury patients

In this section, the scanning results achieved at STJH on nine patients after sports injury are presented. It is worth noting that no sensitive data are recorded during the acquisition, since only the 3D point clouds are recorded, along with the corresponding RGB images (which do not show the patient face). Additionally, the saved files are named using a Patient number instead of the patient's name.

Two examples of acquired patients are provided in Figure 9, showing six different views of the scanned arms. As can be noted, the scanning quality is comparable to the results shown in Figure 8, which were obtained by the developer team on healthy people. Additionally, the measurements performed with closed fingers strongly reduced the noise in between the fingers. This confirms that the system is usable, even with a short remote-training time. STJH confirmed that the scanning procedure took less than 60 s for all the patients.

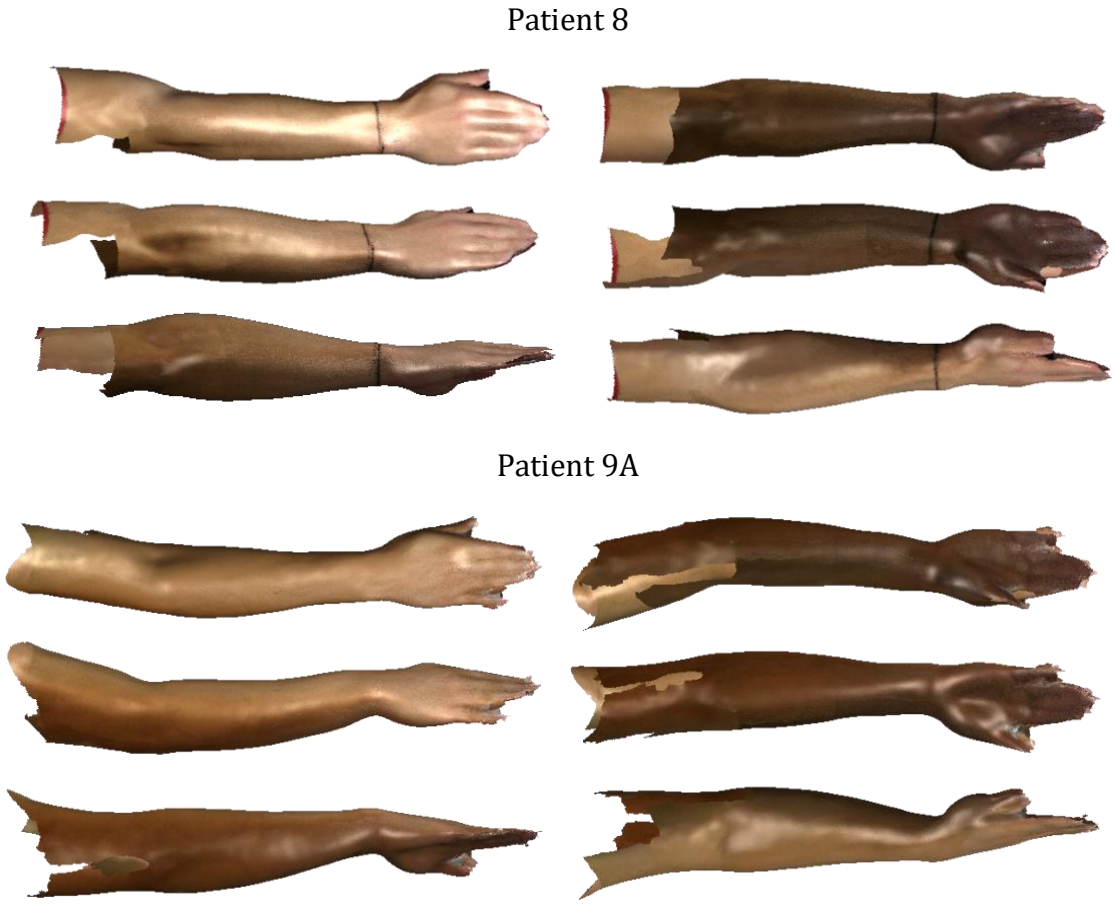


Figure 9: Example of 3D scanning outcomes at STJH: 360° view of two patients' arm

On the other hand, data processing in one case (Patient 4) highlighted an acquisition issue, since the last two frames of the scanning showed a wrist movement. Indeed, the patient slightly changed the angle between the hand and the forearm during the acquisition step, as denoted in Figure 10, thus impairing the registration process. Nevertheless, two separate surfaces could be defined, which can be processed separately for the controller design. Indeed, even if the last two views could not be aligned with the previous, all the frames were successfully acquired, meaning that no sides of the arm are missing in the acquisition. Thus, the arm geometry's 360° information is still preserved, if the two

separate clouds are considered. It is worth noting that this issue was found only in one acquisition out of nine: since the acquisition time is short, the patients can generally stay still for the needed time. Nevertheless, the risk of data loss could be mitigated by repeating the acquisition twice, giving an adequate resting time to the patient between repeated acquisitions.

Patient 4

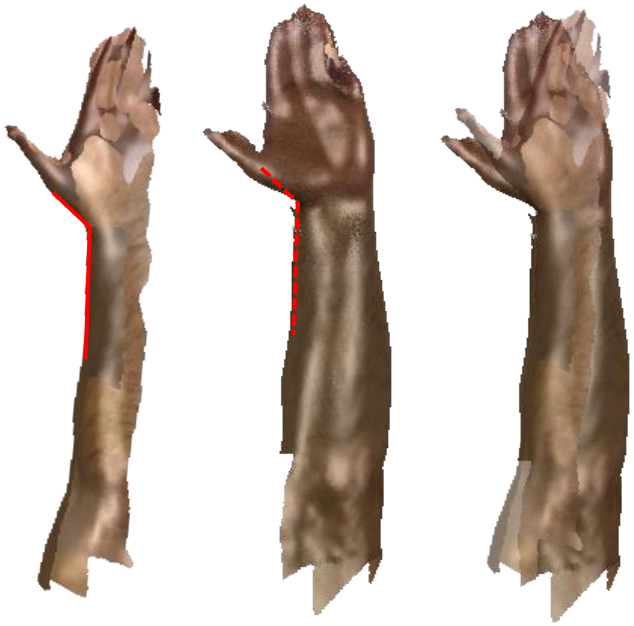
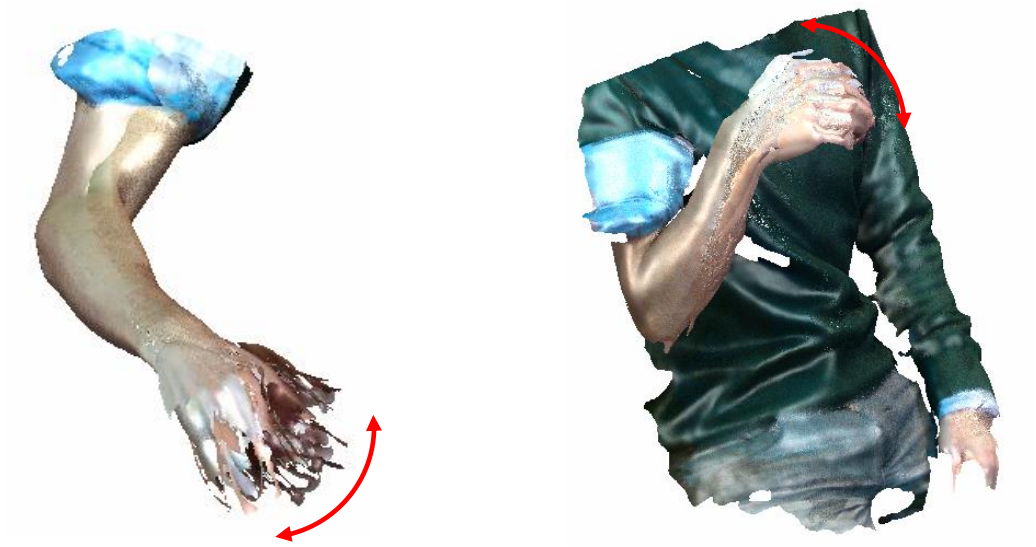


Figure 10: Example of partial 3D scanning: the wrist angle changed during the acquisition

4.2.2. **Dystonia patients**

The trials of the 3D scanning device were also planned at GDIH, which treats dystonia patients. Due to a delay in the ethics committee's approval of the measurement protocol, they were not allowed to perform an actual acquisition. On the other hand, they were allowed to test a dummy device, i.e. a ring without the sensors, to evaluate the feasibility of the measurement procedure with their patient group. The trials revealed that only a small group of patients, affected by mild dystonia disorder, can hold the acquisition pose for the needed time (i.e. 40-60 s). Thus, only this small portion of the population could be assessed with a 360° scan. In any case, even if they could stretch their arm long enough, they could not stay still during the acquisition, thus it is unlikely to achieve a proper registration of the clouds coming from different viewpoints (similarly to the example reported in Figure 10). Concerning the more severe dystonia cases, their possibility of stretching the arm and staying still is even more limited. Thus, only a few viewpoints can be acquired for these patients. Even if the actual scan was not performed on this patient group, the obtained feedback is not promising. It suggested that a different solution will probably be needed for this patient group, such as taking a few anthropometric measurements to use for scaling a template parametric model. These measurements could be taken directly on the patient, using rulers, or extracted from the partial scans obtained from different viewpoints. This latter solution would allow storing a 3D scan (even if partial and not 360°) for further processing without the need to call the patient back to the clinic or use intrusive measurement techniques.

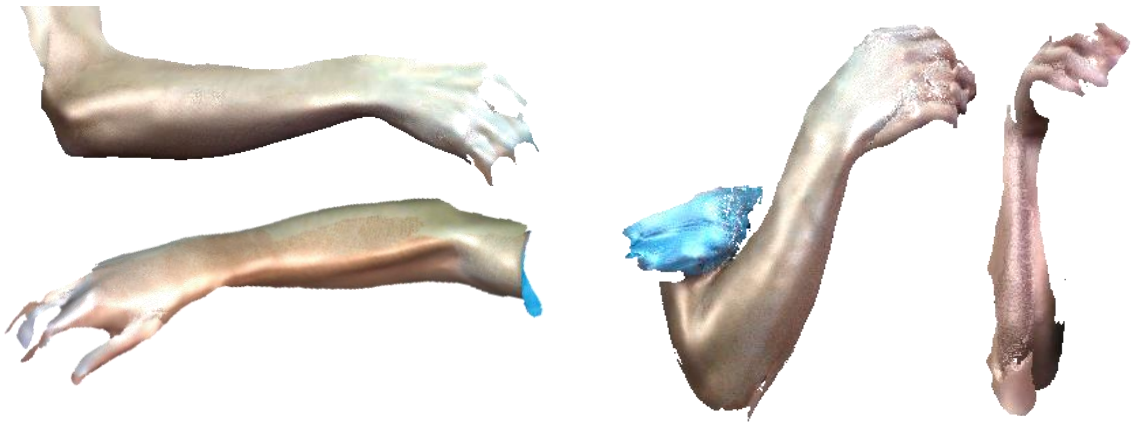
Even if this strategy could not be tested at GDIH, UOP performed the scanning process on a healthy researcher of the team, simulating the typical dystonia movements. To this extent, several tests were repeating, mimicking tremors of the hand and/or of the arm, to assess the impact of the movements on the scanning quality. In particular, two examples will be reported. The first case was simulated assuming that the patient was able to keep the arm stretched, even if he could not be still. The second case was simulated considering that the patient could not stretch the arm at all and could not be still either. In the first case, the six acquisitions around the arm could be performed as for a healthy subject, while in the second case the arm was folded too close to the patient's body, thus a 360° view was not possible, but several different orientations were acquired to describe as much geometry as possible. In both cases, the same post-processing procedure (cloud registration and denoising) applied to healthy patients was used. Figure 11(a) shows the registered point clouds for the first case, while Figure 11(b) shows the second case results.



(a) (b)

Figure 11: Scanning results for simulated dystonia patients: (a) stretched arm and (b) folded arm

As can be noted, in both cases the proper registration of different viewpoints to obtain a unique point cloud is not possible because of the uncontrolled movement, which leads to inconsistent clouds between acquisitions. Nevertheless, the single views were separately elaborated, to assess if they are still usable for measurement purposes. Some examples are reported in Figure 12:(a) and (b) showing two different viewpoints of the first and second simulated case, respectively.



(a) (b)

Figure 12: Scanning results for simulated dystonia patients: (a) stretched arm and (b) folded arm

As can be seen, the single frame appears consistent, and can be used to assess some specific anthropometric measurements or describe some portion of the geometry. Some inconsistency could appear for some perspectives, but all the frames still reported some relevant pieces of information.

4.2.3. **Stroke patients**

Testing with stroke patients should be performed at KNRC. The LL received the equipment, and the setup and training phases were successfully completed through remote assistance from UOP. Nevertheless, KNRC could not plan the testing with actual patients in time, because of covid-19 limitations. Thus, they could only perform some trials with other clinicians, providing positive feedbacks about the overall usability of the provided equipment.

4.3. Assessments of motion capture

The motion capture device was tested to evaluate its effectiveness in joint-angle measurements. Figure 13 shows the poses of the hand/wrist to be acquired during the evaluation. As can be seen, three angles of the wrist are assessed, as well as the finger closing/opening.

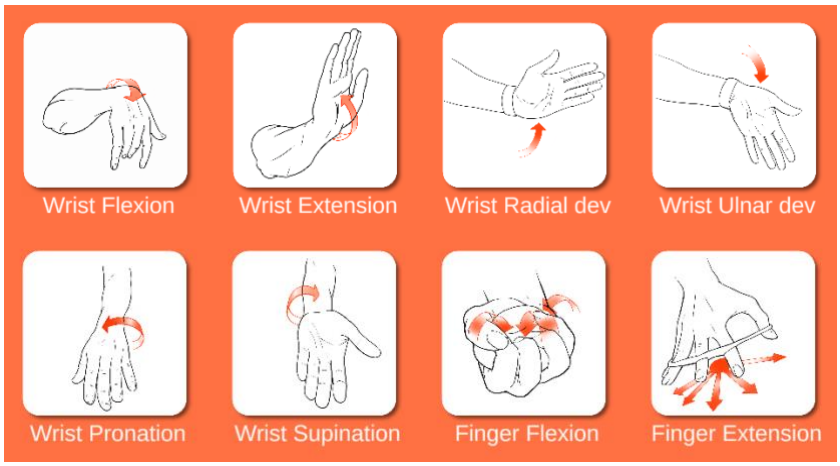


Figure 13: Poses acquired during the motion capture assessment

The assessment is performed through the Ultraleap Leap Motion, which was mounted to the 3D scanning rig. A first evaluation of the sensor performance was obtained at UOP,

by comparing the results of the sensors with conventional analogue measurements obtained through a goniometer. The results are reported in Table 3: all the wrist angles are written in the table, while only the index finger is reported for brevity, since all the other fingers gave similar results.

Table 3: Motion capture device comparison with goniometer measurements

Measurement	Leap Motion (°)	Goniometer (°)	Goniometer σ	Diff. %
Wrist Flexion	58	59	4	1.7
Wrist Extension	-57	-55	4	3.6
Wrist Radial Deviation	34	36	5	5.5
Wrist Ulnar Deviation	-39	-38	4	2.6
Index phalange 1	159	160	8	0.6
Index phalange 2	151	141	10	7
Index phalange 3	155	170	12	8

The presented data highlight some difficulties in manual measurements with a goniometer, since phalanges are often short and challenging to be manually assessed, thus the manual measurement repeatability is really low. This caused higher errors in comparison with the automatic assessment obtained through the developed rig. Nevertheless, the automated assessment shows great repeatability performances, thus providing an improvement of the clinical practice.

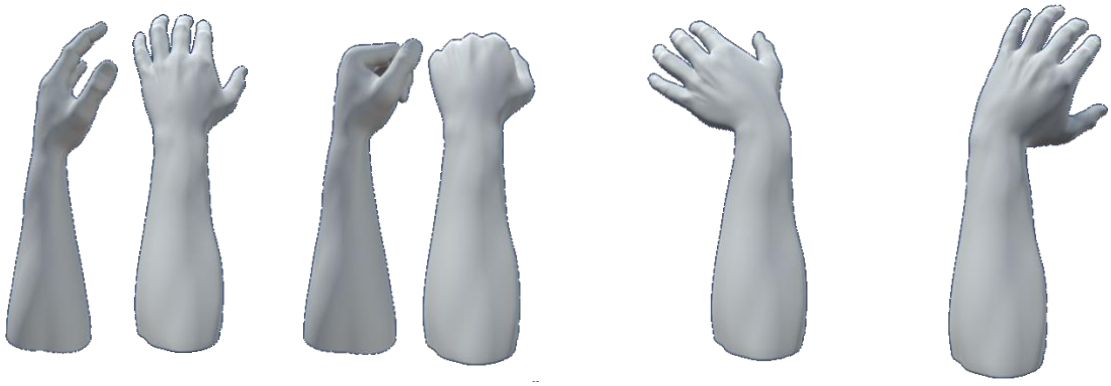
4.3.1. Sports injury patients

The same equipment was then tested at STJH with actual patients. A total of nine patients was tested, and the results obtained for patient 4, 8 and 9 are reported in Table 4, as done for the 3D scanning.

Table 4: Results of motion capture assessment at STJH

Measurement	Patient 4 (°)	Patient 8 (°)	Patient 9A (°)
Wrist Flexion	93	-25	130
Wrist Extension	-25	47	-47
Wrist Radial Deviation	47	48	43
Wrist Ulnar Deviation	-28	-31	-33
Wrist Pronation	86	-51	74
Wrist Supination	-86	-85	-81
Index phalange 1	84/14	77/14	90/30
Index phalange 2	86/16	61/12	88/12
Index phalange 3	24/19	41/12	35/17

To facilitate comprehension of the data, Figure 14 shows some images of the acquired data through a template hand, which can be used to display all the measured angles: Figure 14(a) shows the rest position (wrist angles set to 0°) with a fully open hand, Figure 14(b) shows the rest position with a fully closed hand, Figure 14(c) shows the maximum radial deviation while Figure 14(d) shows the maximum ulnar deviation.



(a) (b) (c) (d)

Figure 14: Visualization of motion capture data

4.3.2. Dystonia patients

As stated in the previous section, GDIH was not equipped with a full functional assessment rig, thus they could not test the performances of the leap motion sensor with their patient group. Nevertheless, the leap motion sensor is much faster than 3D scanners, since a single viewpoint is sufficient to obtain angle measurements. Thus, it may be possible to obtain a reliable measurement for this patient group, even if some experimental trials would be needed to assess if the protocol, which proven to be successful for STJH, would also be able to accomplish the task with mild and/or severe dystonia patients.

4.3.3. Stroke patients

Testing with stroke patients should be performed at KNRC. The LL received the equipment, ant the setup and training phases were successfully completed through remote assistance from UOP. Nevertheless, KNRC could not plan the testing with actual patients in time, because of covid-19 limitations. Thus, they could only perform some trials with other clinicians, providing positive feedbacks about the overall usability of the provided equipment.

4.4. Assessments of force assessment module

The core data gathering activity in relation to the force assessment module was facilitated by GDIH, with 5 participants providing feedback. GDIH are focused on the treatment of hyperkinetic movement disorders so the scanning procedure presented some particular challenges. Due to ethics constraints associated with GDIH and UK ethics approvals, the information obtained through force measurement cannot be presented in this document. In the absence of direct user results, a set of indicative data for the force assessments is presented below. This illustrates the format the data takes when implemented in practice. A review of the device measurement tolerances was conducted in order to meet the criteria of a 5% across the devices in terms of measurement disparities between individual acquisitions. Each device was reviewed by taking 6 measurements across 2 days to test for measurement reliability. 3 measurements were taking on the first day and then averaged. This was repeated the next day and the percentage of measurement disparity was calculated. Each device fell within the 5% tolerance and have been deemed fit for use.

Table 5: Indicative data for force assessment

PINCH GAUGE	
Day 1 tests	**Average**
13 kg	**13.9 kg**
14.8 kg	
14 kg	
Day 2 tests	
15.6 kg	**14.6 kg**
14 kg	
14.4 kg	
Disparity percentage	**4.9 %**
HAND DYNAMOMETER	
Day 1 tests	**Average**
45.7 kg	**44.5 kg**
42.1 kg	
45.7 kg	
Day 2 tests	
47.5 kg	**45.1 kg**
44.6 kg	
43.2 kg	
Disparity percentage	**1.3 %**
TORQUE/TWIST ASSESSMENT GAUGE	
Day 1 tests	**Average**
1.9 kg	**1.9 kg**
1.8 kg	
2 kg	
Day 2 tests	
1.9 kg	**1.83 kg**
1.9 kg	
1.7 kg	
Disparity percentage	**3.75 %**

4.4.1. Evaluations from clinicians

Initial evaluations from STJH are summarised in this section. It constitutes a basic review of the full assembly and tests of each testing device. We can now review some of the key insights from this evaluation which was conducted over the video. Stills have been taken from the video and key quotations have been highlighted where relevant.

Firstly, it can be demonstrated that the rig has been assembled correctly. Following the instructions and the video tutorial developed for D2.2/3, the full rig can be put together easily. This in the first instance demonstrates that the processes of assembly are comprehensible and are easy enough to follow for somebody not immediately familiar with the overall design. One observation that was made was the fact that the weight on the force module causes the structure to tip over slightly when the hoop is dismounted. This is shown in Figure 15.

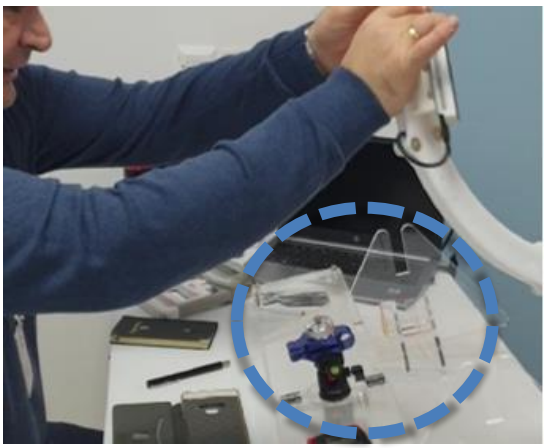


Figure 15: Force module is prone to tipping over if the hoop is removed from the stand

While this is not ideal it can easily be controlled by dismounting the force assessment module when it is needed – this is arguably a preferable mode of use. There are other options involving minor redesigns which will be discussed later. The dynamometer was noted to easily become dismounted from the shelf. The device is held by a small nut and bolt and as noted by the clinician; "this part can easily fall apart". This should not pose a problem for the functioning of the device however as it does not have to be attached to the shelf to function correctly. Indeed, a fix to the problem would be very straight forward as the device can be flipped to use the fixture mounted in the other side. The two mounting options allow for different orientations for patient comfort, for left versus right-handed users for example. This is shown in Figure 16 with the clinician pointing directly to this fact. Upon testing the device functionality, the clinician concludes: "the device is working, there is no problem with that" and demonstrates a quick acquisition.

Figure 16: Dynamometer functioned correctly but became easily dislodged from the force module

The assembly of the pinch gauge was unproblematic. Figure 17 shows the gauge correctly mounted on its stand with the clinician using it. As the device is analogue, it requires no setup or electrical power and can be used immediately.

Figure 17: Pinch gauge correctly assembled

An additional problem was identified with the torque gauge whereby the gauge was prone to moving from its designed functional position on the module. As the handle is turned, the gauge itself is pulled from its position despite being mounted with Velcro meaning that the measurement was hindered. The clinician demonstrated this issue but also showed how it could easily be solved by adding some kind of support to the device while the assessment is taking place stating: "I can control this". Figure 18 demonstrates this where the clinician is shown holding the device in position while doing the acquisition. There are a number of small design changes that could solve this problem that will be discussed later.

Figure 18: Torque gauge must be held in place to work as intended

4.4.2. Survey data

We received survey information from STJH, KNRC and GDIH with respect to the force module and this is presented below. STJH filled out the questionnaire as designed but GDIH adapted the questionnaire to provide more information to us. Starting with STJH and KNRC, we can review the answers provided when reviewing the force module:

Table 6: Evaluation of force module from STJH and KNRC

Question	**Answers provided from STJH**
1. How difficult would you rate the experience of setting up the force assessment equipment?	EASY

2. How difficult was it to direct the participant in completing the force assessment?	EASY
3. How comfortable did you feel the participant was during this stage of the assessment	COMFORTABLE
Question	**Answers provided from KNRC**
1. How difficult would you rate the experience of setting up the force assessment equipment?	EASY
2. How difficult was it to direct the participant in completing the force assessment?	EASY
3. How comfortable did you feel the participant was during this stage of the assessment	COMFORTABLE

The results demonstrate that both Living Labs were able to successfully set up and perform a force assessment procedure without any issue. While there are clearly some identifiable problems, as noted through the video review, overall, the force module is functional and usable for this user group. However, it should be noted at this point that STJH deal with sports injuries meaning that problems such as coordination and random movements are less common. KNRC deal with stroke patients who can sometimes display complex symptoms, however reported no serious difficulties conducting the assessment. The dystonic user group, which we can consider next, have a different set of needs that make the scans more volatile and more difficult to conduct. The answers provided for the questionnaires are presented as follows:

Table 7: Evaluation of force module from GDIH

Question: How difficult would you rate the experience of setting up the force assessment equipment?
"The force meters worked generally as intended. The pinch meter and grip meter were easy to use and record a reading from although both were used off the mounting block after the first trial. The turning force meter was harder to use as it had to be turned and repositioned for each hand, this proved difficult with the mounting block and so we removed half of it to make it easier to move around. This constant resetting was difficult to get right and the machine was fiddly to set up. The force meter on the turning block took too long to register the force and the participants were not able to maintain a consistent enough force to take a reliable reading from the meter. All participants reported difficulties with the force meters not moving to register the force and the instructions should really emphasize this. The base was too large and heavy to be practical and so we removed half of it at the hinge. This made it much easier to carry around, but the suctions cups no longer worked. It also meant that the device could be used on smaller hospital tables or wheelchair tables. A reduction in size and weight should be looked at in the future."
Question: How difficult was it to direct the participant in completing the force assessment?

"Many participants found it hard to use the force meters as they did not move when turned/gripped. All the participants had normal cognition and so were able to pick it up very easily, but it might be worth developing some clear, picture-based instructions or videos for people with an intellectual disability."
Question: How comfortable did you feel the participant was during this stage of the assessment?
"The turning meter had some slightly hard surfaces; some hands were left a bit red after really trying to turn it hard. Maybe a foam covering/layer would be helpful for patient comfort."

4.4.3. Evaluations with dystonic users

GDIH facilitated a recorded review of the force module as it was being used by participants with dystonia. The dystonic patients that were five in total and ranged from mild cases to more severe cases with large mobility and coordination problems. Figure 19 below shows the use of the force module. According to the feedback this participant was able to use all of the devices but required support using the dynamometer. As shown, the dynamometer has been detached from the shelf in order to ease the process of acquisition with direct support from the clinician. This supports the premise of keeping the device use parameters as flexible as possible.

Figure 19: Use of force module by dystonic user demonstrating use of pinch gauge and dynamometer

Similarly, in a more severe case, the dynamometer has been removed from the shelf in order to conduct the acquisition. The patient is however able to grasp the dynamometer and is shown providing an acquisition. Again, this shows that the flexibility of the devices is important for the dystonic user group. The same patient, also shown in Figure 20 testing the pinch gauge. As shown, the patient is able to use the gauge as intended and provide an acquisition. The device is again shown dismounted from the shelf for use further demonstrating that some user groups benefit from the flexibility of the force module's design. However, as reported later, some users involved in the evaluation were not able to grasp any of the testing devices without a lot of support and could not conceivably provide usable data acquisitions. This means that the method of acquisition must be rethought for a subset of dystonic users.

Figure 20: Dystonic user providing acquisition with dynamometer (left). Dystonic user providing acquisition with pinch gauge removed from its mount (right)

Consistent issues were encountered during the evaluation of the torque gauge. This was twofold; firstly, the configuration was reported as being limiting, only allowing for acquisitions easily from one side of the body, secondly, the measurement device itself was poorly calibrated for the task meaning that achieving usable acquisitions was consistently difficult. The main issue being that the device must record a *consistent* force for roughly 5 second before taking a reading. This is not ideal as there is a lot of variability in the wrist turning strength and consistency in this user group. This could be solved with a different kind of device with a better calibration and faster measurement time. Additionally, as shown in Figure 21, the force module was adapted by removing half of it for the torque gauge measurement. As reported, this allowed for adequate space to use the device properly, provided ease of transportation and provided a more comfortable setup for the patient.

Figure 21: Dystonic user demonstrates an acquisition with the torque gauge, the shelf has been spilt to aid the acquisition

In addition to the video stills described above, GDIH have also provided comprehensive feedback regarding the force assessment for five different patients. As there was a range of capabilities amongst the patients, some were unable to use the devices at all indicating a new approach must be explored for some patients. On the other hand, some of the patients with less severe dystonia were able to use the devices under particular conditions or with alterations to the setup. This is elucidated in the following tables (P1, P2 etc refer to the 5 different patients assessed):

Table 8: Feedback on force module from GDIH for 5 patients

Question	**Answers provided for each patient**
Dynamometer - could they try it/hold it?	P1: yes, with both hands
	P2: yes, he could hold them with both hands once therapist placed in hand
	P3: no
	P4: no
	P5: yes, with both hands
Question	**Answers provided for each patient**
Dynamometer, if they could hold it, could they then use it?	P1: yes, we could get data for both hands. The dynamometer would need to be held up in the air rather than fixed on the device.
	P2: no. Even though he can press and hold things and squeeze things, because of the positioning his hand has to be in to hold the handle of the dynamometer, then it was not possible for him to press onto the handle.
	P3: unable to try
	P4: unable to try
	P5: yes, was able to use it with ease
Question	**Answers provided for each patient**
Pinch grip, could they hold it?	P1: yes, with both hands
	P2: could hold it somehow
	P3: no
	P4: no
	P5: yes, with both hands
Question	**Answers provided for each patient**
Pinch grip, if they could hold it, could they press down to get data?	P1: yes, we could get data but we needed to get the device out of the rig for young person to use it
	P2: no, couldn't position firmly in between thumb and index finger and couldn't get data though he is able to press down with thumb against finger but not on this particular device.
	P3: unable to try
	P4: unable to try
	P5: yes, could use with ease
Question	**Answers provided for each patient**
	P1: yes, with both hands

Wrist rotation, could they hold it?	P2: could place hand over it but not use
	P3: no
	P4: no
	P5: yes
Question	**Answers provided for each patient**
Wrist rotation, if they could hold it could they use it to get the data?	P1: this was very difficult to achieve as the rotation wooden device was fixed and down on the table. It took too long for the movement to register force.
	P2: no
	P3: unable to try
	P4: unable to try
	P5: yes, had difficulty with using the turning rig for prolonged periods
Question	**Answers provided for each patient**
To what extent do you rate your comfort during the force assessment process?	P1: COMFORTABLE
	P2: NEITHER COMFORTABLE NOR UNCOMFORTABLE
	P3: n/a
	P4: n/a
	P5: COMFORTABLE
Question	**Answers provided for each patient**
How difficult would you rate the experience of following the instructions of those directing the force assessment process?	P1: easy
	P2: easy
	P3: n/a
	P4: n/a
	P5: Neither difficult nor easy

4.4.4. Evaluations with stroke users

KNRC were able to assemble the rig and provide some basic feedback on the integrated prototype as described in Table 11 but due to Covid limitations, direct measurement with patients was difficult to attain. This means that acquisition and assessment of the data has been delayed and will be reviewed at a later date to be decided.

4.5. Assessment of integrated prototype

An assessment of the overall experience using the entire integrated prototype was also provided by GDIH, providing answers for the five patients they assessed. A number of interesting points were raised regarding the workflow and difficulties experienced by the patients:

Table 9: Feedback on integrated prototype from GDIH for 5 patients

Question	**Answers provided for each patient**
Overall rig device - could it be used for assessment?	P1: yes
	P2: no
	P3: no
	P4: no
	P5: yes

Question	Answers provided for each patient
Overall rig, what were the main observations?	P1: We positioned the rig on a table in front of young person. Young person sitting on a normal chair. Needed to take the dynamometer, the 3D scanner and the pinch grip out. The wrist rotation device was very difficult as it took a long time to register the movement. We turned the device around so that the young person could use it with left hand. On doing that the clear suction cups underneath came off. You cannot turn the device on the other side (for left side).
	P2: young person was sitting on his wheelchair and we had no table in clinic. We removed the different devices so that we could try them. There was nowhere to put the full rig and it was difficult to transport around the hospital.
	P3: unable to try
	P4: unable to try
	P5: We used the smaller sized rig to measure force of turning. This worked well as the hospital table was small. P5 had very mild symptoms and so did not have difficult in using the equipment. He was also very independent and an informal history from his father indicates that he does not have many challenges with things like using his hands and fine motor manipulation. Also his father mentioned that he has previously used an adapted games controller but now uses a normal one.
Question	**Answers provided for each patient**
To what extent do you rate the comfort during the scanning process?	P1: COMFORTABLE
	P2: COMFORTABLE
	P3: n/a
	P4: n/a
	P5: n/a
Question	**Answers provided for each patient**
How difficult would you rate the experience of following the instructions of those directing the scanning process?	P1: NEITHER DIFFICULT NOR EASY
	P2: VERY EASY
	P3: n/a
	P4: n/a
	P5; n/a
Question	**Answers provided for each patient**
To what extent was the setup of the scanning devices and the testing environment intrusive for you?	SLIGHTLY INVASIVE
	NEITHER INVASIVE NOR NOT INVASIVE
	n/a
	n/a
	n/a

Question	Answers provided for each patient
To what extend was the testing room and equipment intrusive for you?	SLIGHTLY INVASIVE
	NEITHER INVASIVE NOR NOT INVASIVE
	n/a
	n/a
	n/a

Feedback was also provided by STJH indicating that the patient assessed found the process easy to follow and was comfortable throughout:

Table 10: Feedback from STJH for integrated prototype

Question	Answers provided for each patient
To what extent do you rate the comfort during the scanning process?	VERY COMFORTABLE
Question	**Answers provided for each patient**
How difficult would you rate the experience of following the instructions of those directing the scanning process?	VERY EASY
Question	**Answers provided for each patient**
To what extent was the setup of the scanning devices and the testing environment intrusive for you?	NOT INVASIVE AT ALL

Table 11: Feedback from KNRC for integrated prototype (tested with clinicians)

Question	Answers provided for each patient
To what extent do you rate the comfort during the scanning process?	VERY COMFORTABLE
Question	**Answers provided for each patient**
How difficult would you rate the experience of following the instructions of those directing the scanning process?	VERY EASY
Question	**Answers provided for each patient**

To what extent was the setup of the scanning devices and the testing environment intrusive for you?	NOT INVASIVE AT ALL

5 DISCUSSION

We can draw on a number of key observations made during the evaluations to discuss what aspects were successful and the key design changes that may need to be implemented to facilitate smooth acquisitions. All of the Living labs provided feedback to this effect and have provided additional insights into what adaptations can be made and what alterations could be made for future iterations.

The trials performed at Living Labs provided some interesting indications for further development of the assessment rig. Concerning the 3D scanning phase, clinicians suggested providing an option in the software to change the acquired frame number. In the present version of the software, six frames are acquired around the arm, to achieve the full 360° reconstruction of the arm. Nevertheless, this limited number resulted in some difficulties during the acquisition in the Living Lab's experience, since one or more additional frames would allow for a smoother acquisition and more even spatial distribution. Thus, the software will be further developed to allow the user to set a different number of acquisition frames so that each clinician can exploit the training sessions to set a specific number of frames that suit their approach.

Also, the distance between the patient's arm and the scanning device is crucial in determining the field of view of the scanner. The Living Labs reported some difficulties maintaining the proper acquisition distance, even if the scanning preview is plotted in real-time during the acquisition. To solve this issue, it was proposed to plot the real-time scanning preview with a colour code denoting whether the acquisition distance is enough. For example, too close an acquisition could be denoted by a red point cloud, while acquisition performed in the proper distance range could be previewed with a green colour. This feature will be embedded in the next version of the software, for further experimental trials

Additionally, some ergonomics issues arose during the experimental activity. Indeed, the development of the sensor at this research stage was much more oriented to the acquisition accuracy and speed, and the mechanical structure was not optimized. Sharp edges are still present on the rig, which results in some mild discomfort in the clinician's hands during the operation. This will be fixed by designing ergonomic handles, to be mounted on the scanner rig to improve the measurement experience. Thus far, the acquisition of the frames is obtained only through a button in the developed software. This results in a cumbersome acquisition phase, since a clinician on his own needs to have one hand holding the device and one hand managing the software, thus reducing acquisition comfort and accuracy. On the other hand, if an assistant is used to help the clinician managing the software, the acquisition results much more comfortable. This problem can be mitigated by developing a different acquisition approach, e.g. adding a

physical button on the device to trigger the acquisition or using voice commands to shoot the frames.

The living labs also provided some feedback concerning the motion capture assessment. This step resulted in being longer than expected, with the patient feeling uncomfortable and tired during the assessment. Thus, a slight variation to the protocol was suggested, holding the assessment rig vertically on a desk (using proper support), thus allowing the patient to rest their elbow on the desk while performing the assessment. This could allow for a higher comfort during the assessment and will be tried in future experimentation.

Considering the force module. There are a number of key observations that can be drawn from this comprehensive feedback from the three Living Labs some of which call into question the feasibility of using some of these devices with the dystonic user group.

- All LLs could successfully assemble the module using the provided instructions
- The force meters worked as intended – they all functioned correctly upon assembly
- Dynamometer was noted as being insecure in its design mounted position
- Dynamometer and pinch gauge were easy to use though difficulty was encountered getting acquisitions from the torque gauge because the position needs to be held for 4-5 seconds
- Splitting the force module in two for ease of use and was explored by GDIH with positive results
- Torque gauge was awkward to set up and settings were difficult to get right
- Some devices had to be repositioned and removed from the shelf for the dystonic users
- When shelf is mounted on the stand, it was prone to falling over slightly when it became imbalanced

Many of these points can be addressed with some simple design changes and the redesign of parts. As documented in D2.2/3, the rig is designed to be somewhat modular, meaning that parts can be adjusted and swapped in and out. For example, the shelf imbalance problem can be solved by a small redesign of the stand, lengthening the size of the support and allowing the force module more surface area in which to sit upon. While the dynamometer and pinch gauge were observed to be functional and usable albeit with a few identified issues highlighted above, the torque gauge needs to be rethought. As the problem consists of both the device and the configuration a solution lies in a rework of that side of the shelf. We need to address both the problems with the configuration being hard to use for left-handed people and with the calibration of the measurement device. The next iteration of the rig will address these issues directly. An interesting insight has been to explore the option of having the force module able to split into two parts allowing ease of transport and acquisition. This was demonstrated by GDIH and such a design option will be considered for the next iteration.

In terms of the overall experience, the Living Labs were able to provide some feedback and suggestions for adaptions they would recommend. These are summarized in the Table 12 below and include reducing the weight and bulk of the rig and allowing the hoop

to be mounted on a separate stand to improve the ease of scanning and motions capturing acquisitions:

Table 12: Suggestion from Living Labs to improve overall scanning experience

Question	**Answers provided for each patient (GDIH)**
Overall rig, if not used as intended, what were the adaptations?	P1: We had to turn it around for the left hand but did not work. We placed it on a standard table and could be used in that way, but we had to take all the individual devices out (dynamometer, pinch grip).
	P2: We took it apart to carry it in two halves so that we could carry it and also that we could hold it in front of the young person to use it.
	P3: unable to try
	P4: unable to try
	P5: used as intended, except that it was only half the rig
Question	**Answers provided by each Living Lab**
How do you suggest we could improve the testing experience?	GDIH *"The rig is bulky but the principles underlying its design are sound and we are able to test the more-able patients with it. With some adaptations particularly around reducing weight and bulk it will make the product much more feasible for use in our setting.* *It would be good to have an explanation for the logic for each force measure and how it translates to adapting the controllers. This would help us to understand why we are doing these. It might be of value to assess each finger separately if it is to assess the ability to press buttons/move joysticks."* STJH *"Leap motion should capture movement even if patient is fast in moving hand/arm"* Patient: *"Scanning is easy but could be tiring sometimes"* KNRC *"Hoop works better if it is mounted on a stand" and "torque gauge should be stabilised more so the therapist does not have to hold it during the acquisition"*

5.1. Achieving standard of comfort

Additionally, we can consider the minimum standard of comfort that was set out. PRIME-VR2 aims to have a minimum comfort standard of 8/10 for both the participants that will use the scanning rig and the clinicians/facilitators that will set up and oversee the process. While the data is perhaps too limited at the stage to establish this level of comfort and, as

has been discussed, several design changes will be explored in future iterations of the rig, we can present an initial assessment of the data gathered so far. The questions were designed to be answered in unambiguous terms with Likert scales providing positive, negative and neutral responses. Other feedback that was provided can also be interpreted as such. Taking all of the information that was gathered and splitting it into positive assessments, negative assessments and neutral assessments of the rig elements produce the following results:

Table 13: Overview of results from initial evaluations

TOTAL OBSERVATIONS AND RESPONSES WITHIN EVALUATION: ***97***
POSITIVE RESPONSES: 42
NEGATIVE RESPONSES: 18
NEUTRAL RESPONSES: 37

Assuming we have 97 reliable observations and responses to the various form of assessment, for an 80% comfort and satisfaction rating, 77.6 of the responses must be "positive". 43.2% are unambiguously positive currently. Factoring in the neutral responses, 81.4% of the responses can be viewed as positive or neutral which may be acceptable but is not ideal. This means that various aspects of the rig must be improved. The key problems with the rig, its deployment and implementation have been identified within this document and will form the core for design improvements moving forward. By implementing these changes, it is hoped the overall experience can be improved in terms of subjective feelings of comfort and ease of use. With respect to this, the next section will examine experiential factors more closely by exploring the human-centred design consideration of using the rig.

6 HCD CONSIDERATIONS

This section outlines how the scanning procedure has been formulated to consider the experience of both the end user and clinician or facilitator of the assessment process. A human-centred-design (HCD) approach [3] has been adopted, combining an experience mapping exercise with qualitative assessment and feedback which will subsequently inform changes to the process and map. The HCD approach has been applied to allow for a systematic consideration of a range of factors. As detailed in [4] HCD approaches will usually involve the following elements:

- The adoption of multidisciplinary skills and perspectives
- Explicit understanding of users, tasks and environments
- User-centred evaluation driven/refined design
- Consideration of the whole user experience
- Involvement of users throughout design and development
- Iterative process

Crucially by understanding the procedure through a process of speculative mapping and testing (much of which is still to be carried out), there is potential for further iteration and improvement from the human perspective. As [5] notes "human-centeredness takes seriously the premise that human understanding and behaviour goes hand-in-glove" meaning a level of human agency is introduced that is not present in other user-centered

approaches that favours the designer as the master-agent or arbiter of a process or product.

6.1. Experience mapping

Experience mapping is a diagrammatic description of how a person thinks and feels as they move through a system or use and interact with products. They can map person to person interactions as well as person-technology interactions and are excellent tools for understanding different contexts of use against time and can provide insights into the quality of use experiences hitherto unseen. Within the context of PRIME-VR2 experience mapping can be used to understand more fully the experience of engaging with the integrated assessment system in more depth. As stated earlier, an 8/10 level of comfort must be achieved by the scanning system and overall protocol. The 8/10 is a general metric and has not been categorically defined but relates generally to the experience of both the users and the facilitators explored in the previous sections through the observations and questionnaires. With respect to this, experience mapping will allow for a more structured and focused assessment of the process overall. It should be noted however that future iterations of the assessment process will materialise as the rig is implemented as part of the overall VR-HABIT platform and as extended physical user testing becomes more viable following the easing of the COVID-19 restrictions across Europe. The development of the integrated "all-in-one" system was explored in the previous section and the protocol for each stage of scanning described in D2.2/3. By looking holistically at these elements in the context of an experience map will address the HCD concerns of WP2 including:

- The critical stages of engagement with the system
- The subjective enjoyment of the patient and the facilitators as the process is carried out and completed
- The temporal dimension of the tasks – how long each task will take with respect to one another
- The distinction between different "stages" of the process, the distinction between scanning periods and break periods for example

The following section will review these factors in more detail and will subsequently elucidate a set of experience maps describing the three stages of the scanning process in an "idealised" format. While three different maps are presented, they should be thought of as a continuum. Experience mapping done by [6], takes a systematic approach to the mapping of a VR design review experience and many of the same tools and approaches deployed there will be explored here including representations of temporal elements of tasks and abstract illustrations of changes in emotive states.

6.1.1. Overview of map elements

In order to fully understand the maps, the distinct elements of the maps will be explained here for the benefit of the reader. Structurally, the maps have a centre or core build from large colour coded arrows. There are three arrows that represent the three actors within the system: the patient, the clinician and the researcher. Furthermore, the direction of the arrows symbolises forward movement through time. It should be noted that this iteration of the map represents a "first implementation" of the scanning system which will most likely be overseen by both a clinical professional and one the project researchers. Future

iterations can be developed that focus just on a clinician and a patient, making the maps more generalisable. The map is also speculative, COVID-19 limitations have prevented a full realisation of the procedure definition with respect to the integrated rig configuration. Figure 22 below shows the three actors and the coloured arrows that represent them within the map. These core elements have tasks or activities, or interactions highlighted upon them, showing what the individual actors are doing with respect to each other. It represents an initial interpretation of the procedure – this will be subject to further adjustment based on the results of initial user/clinician trials.

Figure 22: The three colour coded arrows represent the three actors within the map

Additional elements of the maps help to supplement the information contained in the core narrative. The maps contain "critical paths" which illustrate a necessary sequence of events – the sets of things that must happen in order to move forward in the process successfully. Additionally, a basic description of subjective emotive experience is illustrated by variations of a wavy line placed above the path of the patient. A more curved line represents a more pleasant experience, a jagged line a more unpleasant experience. Critically the qualitative experience of the patient is the most important factor to understand. Speculating about the emotional dynamics establishes the potential for stress or discomfort within the process allowing for changes to be made more systematically if required. Lastly, the stages of setup are illustrated by a block of hatch pattern. This differentiates itself from periods where the scanning is taking place and periods of break.

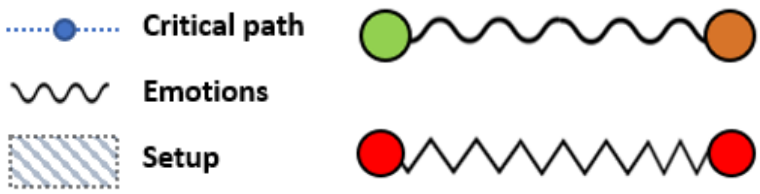


Figure 23: Supplementary information included in the maps including critical paths, emotions and setup stage indicators

6.1.2. Mapping the overall process

Presented below is the full set of experience maps developed against the three assessment procedures. For the purposes of describing and analysing the different maps that have been produced, we will consider three critical elements of the maps: tasks, temporal elements and interactions by focusing on one of the maps – the force assessment (FA) – in more detail. As the force assessment requires the use of three different technologies, it represents one of the more logistically complex assessment. With respect to this, detailing elements of the FA experience map will be beneficial and lay the groundwork for reading and analysing the other experience maps. Firstly, we can define the critical elements of the map we will consider in the discussion to follow:

1) **Tasks:** Within the context of the assessment procedure, a "task" is a duty or operation that one of the actors must perform. The tasks can range from something simple ("listen to instructions") to something complex ("perform gestures for scanner"). The tasks are placed with the core arrows of the map.
2) **Temporal elements:** These are visual descriptions of the time elapsed for a particular task. This should be seen as more of a figurative indicator and not an exact record of the elapsed time between event – conceptually the tasks are broken up but in reality, the tasks will overlap to some extent and flow into one another (something the map does not show)
3) **Interactions:** An interaction is an action or influence between actor or between actors and technologies. With respect to the tasks described for each actor within the map, there are interactions between actors and between actors and the technology that are described with supplementary instructions as offshoots of the core narrative. The interactions are not distinct elements of the map but are nonetheless critical to the functioning of the descriptions contained within it

Figure 24 shows the complete experience map, representing an informed but speculative illustration of the human-factors dynamics of the overall assessment experience. It should be treated as a continuum, beginning at the top left "START" indication and ending on the bottom right "END" indication. Each section of the map can be read from left to right as normal. For the benefit of the reader, larger scale versions of each experience map have been included in the appendices (section 9.2).

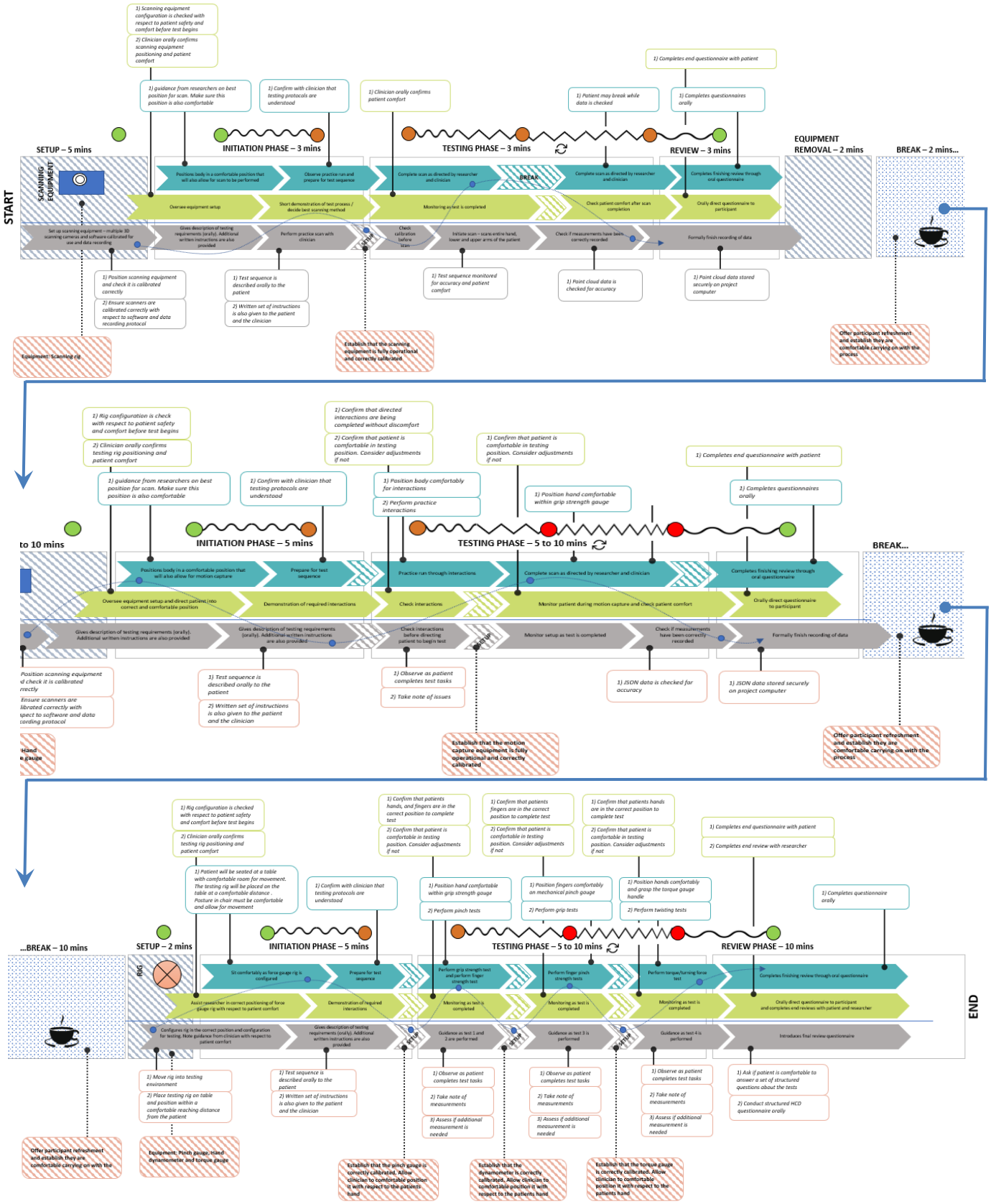


Figure 24: Experience maps for the three assessment stages

Critical tasks

The critical tasks are embodied within the core structure of the map and are marked sequentially along the "critical path". The three rows of the right-pointing arrows represent the three actors moving forward in time. The *setup* stage where the equipment is readied and check for correct calibration indicated by the stiped pattern is followed by the *initiation* phase. (As shown previously, each map includes a setup, initiation and review phase). At this early phase the tasks are oriented around preparation for the assessment. The clinician and researcher configure the devices in a correct and comfortable way for the patient and then proceed to demonstrate to the patient with both visual and oral descriptions of what is to take place - an example of the visual. Another short setup stage is completed before the test begins as a final check that the equipment is ready for the patient to interact with it – this is indicated by the striped arrows. The emotion indicators at this stage show a relatively calm state. As the test has not begun, it is assumed stress levels will remain low, as the initiation phase ends the potential for higher stress is introduced indicated by the circular amber signifier.

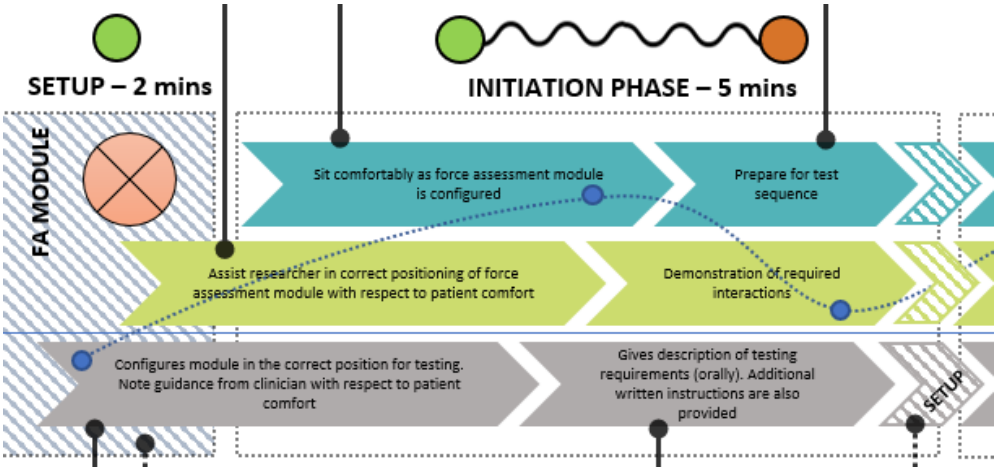


Figure 25: The core tasks of each actor within the map are differentiated by colour coding with a critical path weaving through them

Once the first FA test has started, the *testing phase* is entered which is then followed by a phase of *review* in which a survey-based qualitative assessment is undertaken. For the FA, the testing phase has a number of complexities due to the use of multiple pieces of force measurement equipment. After each test is completed by the patient, a short setup phase is entered again in order to ready the equipment. For instance, moving from the pinch test to the hand dynamometer grasp tests requires the device to be correctly turned on and setup. The specifications of the device allow for the desired setup to be stored for efficiency, but a short check will be needed to ensure the device is operating correctly before the test is conducted. With respect to this, there will be 3 short periods of setup overseen principally by the researcher – these are highlighted by the critical path. While the patient carries out all the tests with periods of rest in between, the clinician is tasked with overseeing the process and ensuring patient wellbeing and comfort. After the principal tests are completed, a period of review is entered. (A period of review will be held after each stage of the assessment procedure). The period of review involves the completion of a structured questionnaire that is orally dictated to the patient and completed manually by the researcher or other facilitator. The review has been designed

to be short and digestible and should take no longer than 5 minutes to complete for each party. After the review, the assessment process is complete.

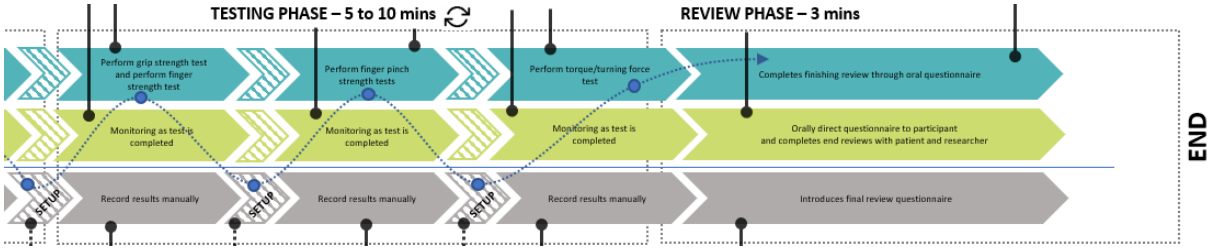


Figure 26: The critical path indicates that the setup of each device is a highly important element in the experience of this section of the overall procedure

Critical temporal elements

Time is a key component in experience maps generally and a temporal dimension has been factored into the structure of these maps also. There is a degree of flexibility and subjectivity here as the representation of the temporal elements is not strictly defined i.e. the size of a map element does not strictly map perfectly against the quantity of time. The relative size of elements should be interpreted as the relative quantity of time. For example, the testing phase for the FA is detailed to last for 5 to 10 minutes and is subdivided into six sections, 3 setup phases and 3 task phases. The relative sizes of the setup compared to the task indicates that each setup phase will be significantly shorter than each test task phase where the test is being conducted. Essentially, it is useful to interpret the temporal dimension as the relative size of the elements subdivided by the time indicated at the top of the map.

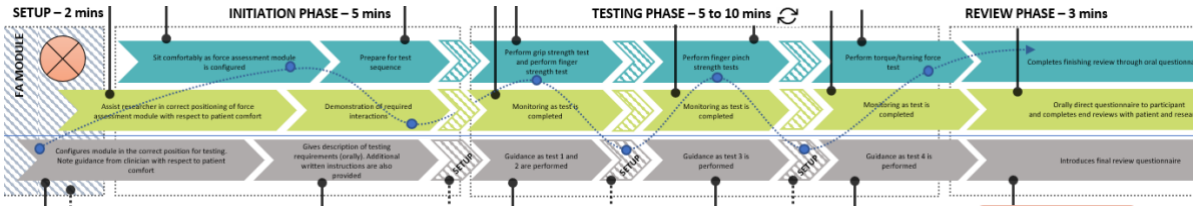


Figure 27: The different phases are detailed with rough time indications; the size of the elements should be subdivided with respect to that time indicator

Critical interactions

The interactions recorded in each experience map refer to both interaction between people and interactions between people and technology. In this respect there is some overlap between an interaction and a task described earlier. The interactions provide details and supplementary information for each actor at a given stage in the procedure – each interaction box has been colour-coded and is linked by a bold line to the core task it relates to. For the FA example, the interactions provide supplementary detail on device configuration and patient comfort protocol. Figure 28 for instance shows interaction instructions for the clinician and the patient. The clinician, in this example taken from the initial stages of the procedure is instructed to check the rig configuration with respect to patient safety and comfort and the positioning of the rig is orally confirmed with the patient to be satisfactory. The later interaction details provide more detailed instructions about testing facilitation. Throughout there is cross-referencing of actor interactions; one actor's inputs will influence the state of another. This is seen explicitly in the testing phase

where the clinician is tasked with monitoring the comfort of the patient and the patient is tasked with interacting with the devices in a way that is subjectively comfortable for them.

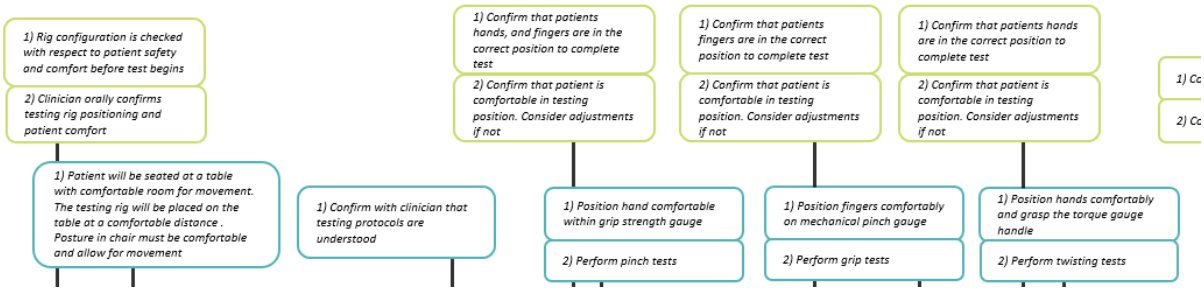


Figure 28: Interaction boxes of the clinician and patient provide supplementary information regarding testing procedure

The interactions of the researcher are also important to note. Here the researcher acts as an overseer and plays a vital role by monitoring and recording the force measurements as the patient interacts with the various devices. A secondary level of interaction information has also been added that relates to an aspect of setup and device calibration and is distinguished by its beige colouring and stripped pattern. In the FA example below, the boxes note how device calibration is important to establish, providing more detail for the short setup phases between tests.

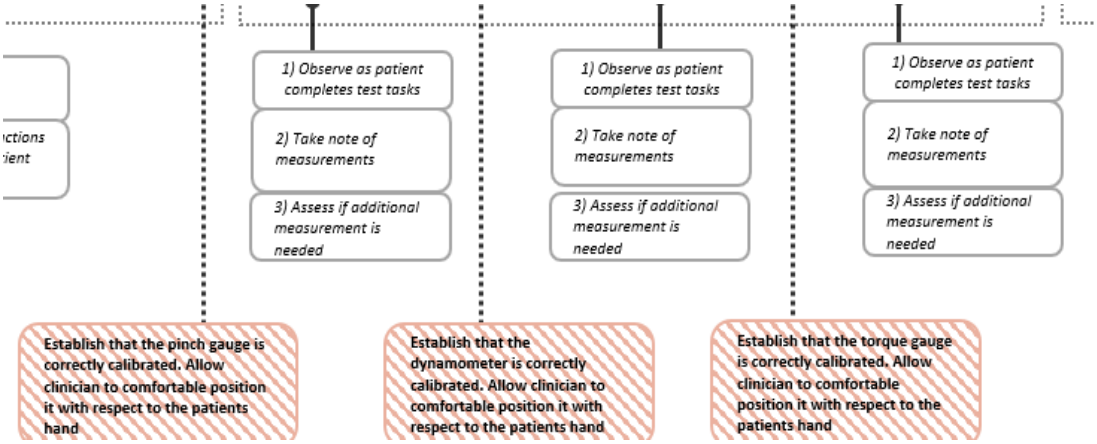


Figure 29: Interaction boxes of the researcher and supplementary boxes providing information related to device setup and calibration

Overall, the maps are designed to provide a high-level description of the experience of the assessment procedures by tying in the critical tasks, time elements and interactions between actors within the system. The maps are currently hypothetical and based on informed assumptions of how the dynamics between the patients and the facilitators will be while also considering device functionality and setup. The maps will be subject to review and refinement as the process of developing the unified assessment system develops – it would be valuable for instance to embed specific feedback from users in the form of quotes within the maps themselves. The material will prove also useful moving forward as the information can intersect with other deliverables and key milestones. Notably, having a smooth process of data acquisition will be essential by M18-24 when the critical work in understanding the controller design algorithms is undertaken – intersecting directly with WPs 4, 5 and 7 and D3.4.

7 CONCLUSION

This document elucidates upon the evaluation of a scanning rig designed to capture a biomechanical data profile from patients involved with PRIME-VR2. The evaluation was conducted across the three Living labs at different levels due to ethical approval and Covid19 restrictions. Anyway, it led to a number of conclusions regarding the current configuration of the device and understanding of the procedural dynamics.

Firstly, the broad vision for the scanning rig was presented and a description of the final testing prototype was provided. The final prototype consisted of an amalgam of the scanning and motion capture "hoop" developed by UOP and the force assessment module developed by UOS. These two elements were sent to each of the Living Labs for assessment. The assessment consisted of a series of evaluation questions and observations facilitated by the Living Labs. Additionally, this document comprehensively justifies what elements of the process we want to understand better and how the questions have been structured.

This introduction is followed by the evaluations. The evaluations are split into the three assessment types - anatomical scans, motion capturing and force assessment – with feedback being provided by each lab to varying degrees. The evaluations allowed for a more detailed understanding of the various procedural elements of the scanning process; what worked and what did not. This information which consisted of a mixture of acquisition evaluation, survey results and direct observations via video allowed a number of considerations for redesigns to be explored. Additionally, it provided insight into how the administering of the procedures can be improved. With respect to this, a series of experience maps were also created that proposed an "idealised" test sequence. This, paired with the information derived from these observations, can be used to reconfigure elements of the scanning process to create the most effective and most comfortable experience possible for those patients and clinicians involved in PRIME-VR2.

7.1. Limitations due to Covid-19

As a point of information, Covid-19 presented some serious limitations in the development of this stage of the work which will be noted here. The central issue was the ability to prototype effectively and the ability to test effectively. Manufacturing labs at UOP and UOS inaccessible meaning that the quality of the finished force module prototype potentially suffered – hopefully this will not be an issue moving forward when future iterations of the device are created. By seeking alternative manufacturing sources such as independent laser cutting companies, mitigations to future production delays can be actioned. Secondly, remote testing whereby the designers of the rig could not be present during the actual patient tests, was not ideal. Because of the strict limitations in clinical settings, the researchers from UOS and UOP were not able to facilitate the testing procedures in any way. This meant that everything had to be conducted remotely and direct observations were not possible. While some of the practical challenges were overcome utilising online video conferencing and photo documenting tools, the inability to interact directly with the clinicians or the patients during the overall scanning procedures was a hinderance to the evaluations.

8 REFERENCES

[1] see https://www.thecopm.ca/

[2] see https://cerebralpalsy.org.au/our-research/about-cerebral-palsy/assessments-and-outcome-measures/individually-prioritised-problem-assessment-ippa/

[3] Giacomin, J. (2014). What Is Human Centred Design? *The Design Journal*, 17, 606 - 623.

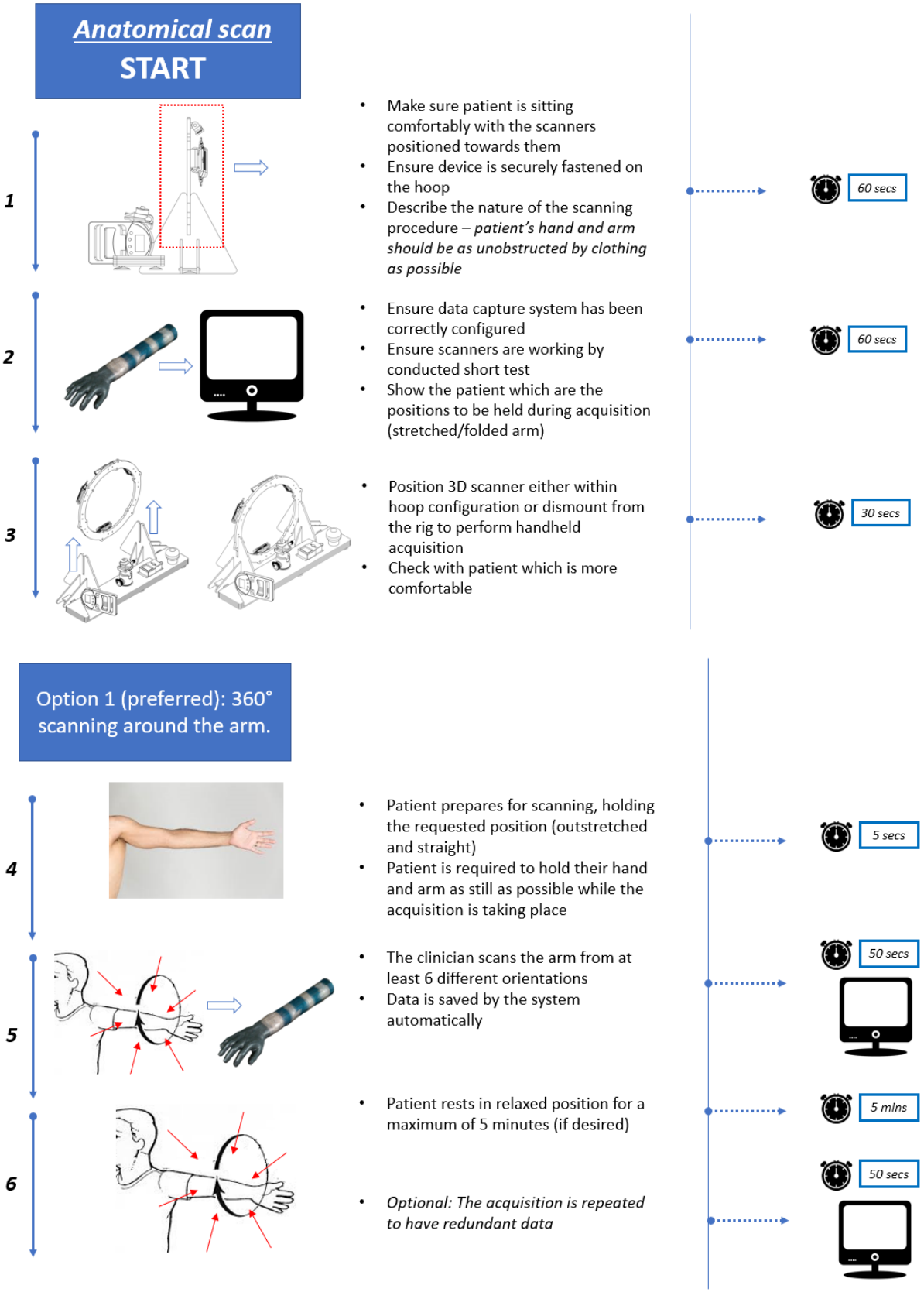
[4] Maguire, M.C. (2001). Methods to support human-centred design. *International Journal of Human-Computer Studies*, 55, 587-634.

[5] Krippendorff, K. (2004). Intrinsic motivation and human-centred design. *Theoretic Issues in Ergonomics Science*, 5(1): 43–72

[6] Wodehouse, A., Loudon, B., & Urquhart, L. Experience mapping an accessible VR environment for design interrogation. *International Journal on Artificial Intelligence for Engineering Design, Analysis and Manufacture.*

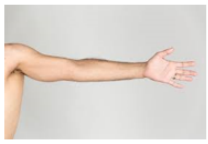
9 APPENDICES

9.1. Protocol and instructions for assessment



Option 2: arm passed inside the hoop

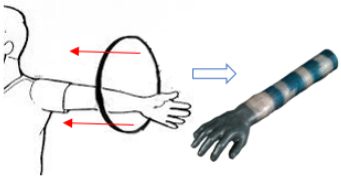
7



- Patient prepares for scanning, holding the requested position (outstretched and straight)
- Patient is required to hold their hand and arm as still as possible while the acquisition is taking place

5 secs

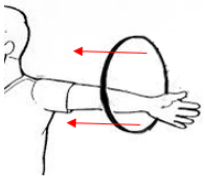
8



- The clinician passes the hoop around the patient arm
- Data is saved automatically by the system

15 secs

9



- Patient rests in relaxed position for a maximum of 5 minutes (if desired)

5 mins

- *Optional: The acquisition is repeated to have redundant data*

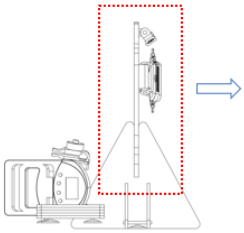
50 secs

END

Motion capture

START

1



- Make sure patient is sitting comfortably with the scanners positioned towards them
- Ensure device is securely fastened on the hoop
- Describe the nature of the scanning procedure

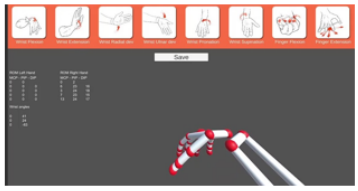
60 secs

2

- Connect the Leap Motion Controller to the PC and start the application
- Ensure system and device is configured correctly

30 secs

3



- Show the patient how the controller and the application work; guided demonstration of interactions and system

60 secs

For each gesture follow the next three steps

4a

- Patient rests in relaxed position
- The clinician shows patient the correct position of the hand and help him/her to take it

30 secs

4b

SEE APPENDIX

- Clinician demonstrates each action in turn
- The patient holds the requested position for 2/3 seconds
- Gestures should be performed in the order noted

10 secs

4c

- The clinician clicks on the icon of the specific gesture to store the data
- *Optional: Each single acquisition can be repeated if the patient moves the hand*

2 secs

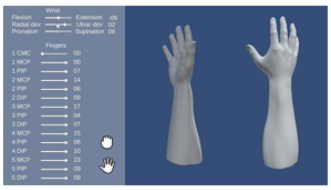
X 8 gestures

5

- To complete the mocap acquisition, the clinitian clicks on the **Save** button. The system outputs a JSON file with all the data acquired

3 secs

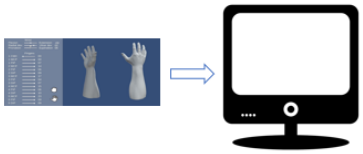
6



- Patient rests in relaxed position
- *Optional: The clinician can verify the saved data using the viewer application*

2 mins

7

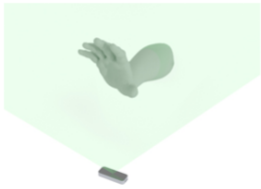
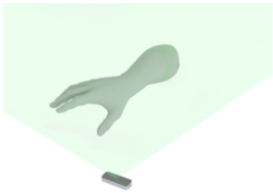


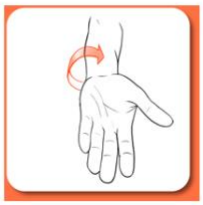
- Copy the JSON file in a suitable and secure location

5 secs

END

Appendix: Reference positions for each gesture

Wrist flexion	Wrist extension	Wrist radial deviation	Wrist ulnar deviation
			
			

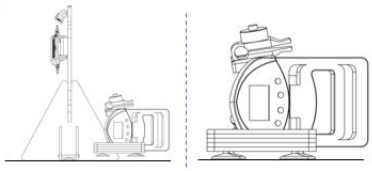
Wrist pronation	Wrist supination	Finger flexion	Finger extension
			
			

Force Assessment
START

- Make sure patient is sitting comfortably and describe the nature of the force assessment tests

120 secs

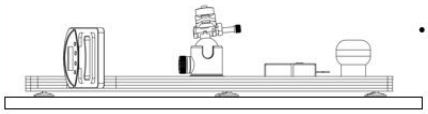
1



- Position FA module either within "hoop" configuration or dismount and attach to table using suction cups

30 secs

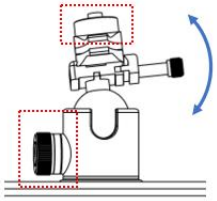
2



- Ensure module is securely assembled before testing commences
- Ensure module is securely mounted on flat surface – suction pads will provide support if detached from hoop

90 secs

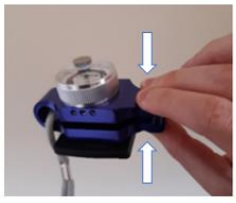
3



- Ensure pinch gauge is securely attached
- Configure device for Phase 1, Test 1 (palmer) – ensure gauge has been ZEROED, adjust gauge dial as required
- Loosen ball-and-socket using highlighted fixture, orientate pinch gauge upwards to around 45 degrees

30 secs

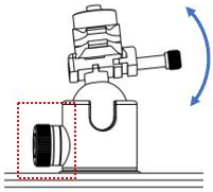
4



- Facilitator demonstrates test for patient – *pinch action performed between thumb, index and forefinger*
- Patient performs Test 1 (palmer pinch) 3 times, 15 second breaks between pinches
- Results manually recorded in data sheet

90 secs

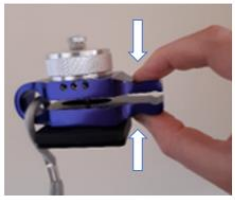
5



- Configure device for Phase 1, Test 2 (pulp pinch)
- Loosen ball-and-socket using highlighted fixture, orientate pinch gauge flat / parallel to testing surface

30 secs

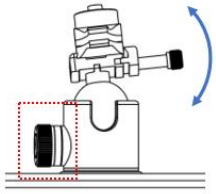
6



- Facilitator demonstrates test for patient – *pinch action performed between thumb and index finger*
- Patient performs Test 2 (pulp pinch) 3 times, 15 second breaks between each
- Results manually recorded in data sheet

90 secs

7



- Configure device for Phase 1, Test 3 (lateral pinch)
- Loosen ball-and-socket using highlighted fixture, orientate pinch gauge downwards to around 135 degrees

30 secs

8

- Facilitator demonstrates test for patient – *pinch performed between bent index finger and thumb*
- Patient performs Test 3 (lateral pinch) 3 times, 15 second breaks between each
- Results manually recorded in data sheet

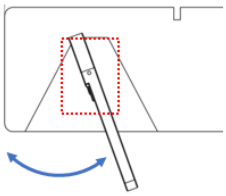
90 secs

9

- Ensure dynamometer is securely attached
- Configure device for Phase 2, Test 1 (full hand grasp) – dynamometer turned on with ON/SET button
- User information for age and gender inputted as required
- Press ON/SET to finalise information

90 secs

10



- Configure dynamometer position - dynamometer should be oriented at a comfortable grasping angle for the user to grasp while seated
- Ensure device is securely attached before testing is commenced

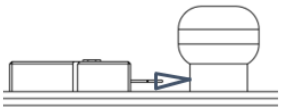
15 secs

11

- Facilitator demonstrates test for patient – *fingers are placed through gap and pressure applied in grasping motion*
- Press START button to initiate testing
- Perform Test 1 (grasp) 3 times, 15 second breaks between each, press START button in-between each test
- Results manually recorded in data sheet

120 secs

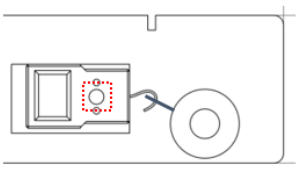
12



- Ensure torque gauge and handle are securely attached
- Ensure handle hook is attached to gauge hook
- Configure torque gauge for Phase 3, Test 1 (wrist twist)

30 secs

13



- Ensure torque gauge and handle are securely attached
- Configure torque gauge for Phase 3, Test 1 (wrist twist) – press central power button

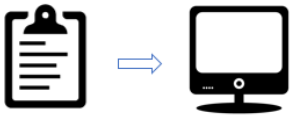
30 secs

14

- Facilitator demonstrates test for patient
- Perform Test 1 (wrist twist) 3 times, 15 second breaks between each
- Results manually recorded

120 secs

15



- Transfer data into secure Excel file

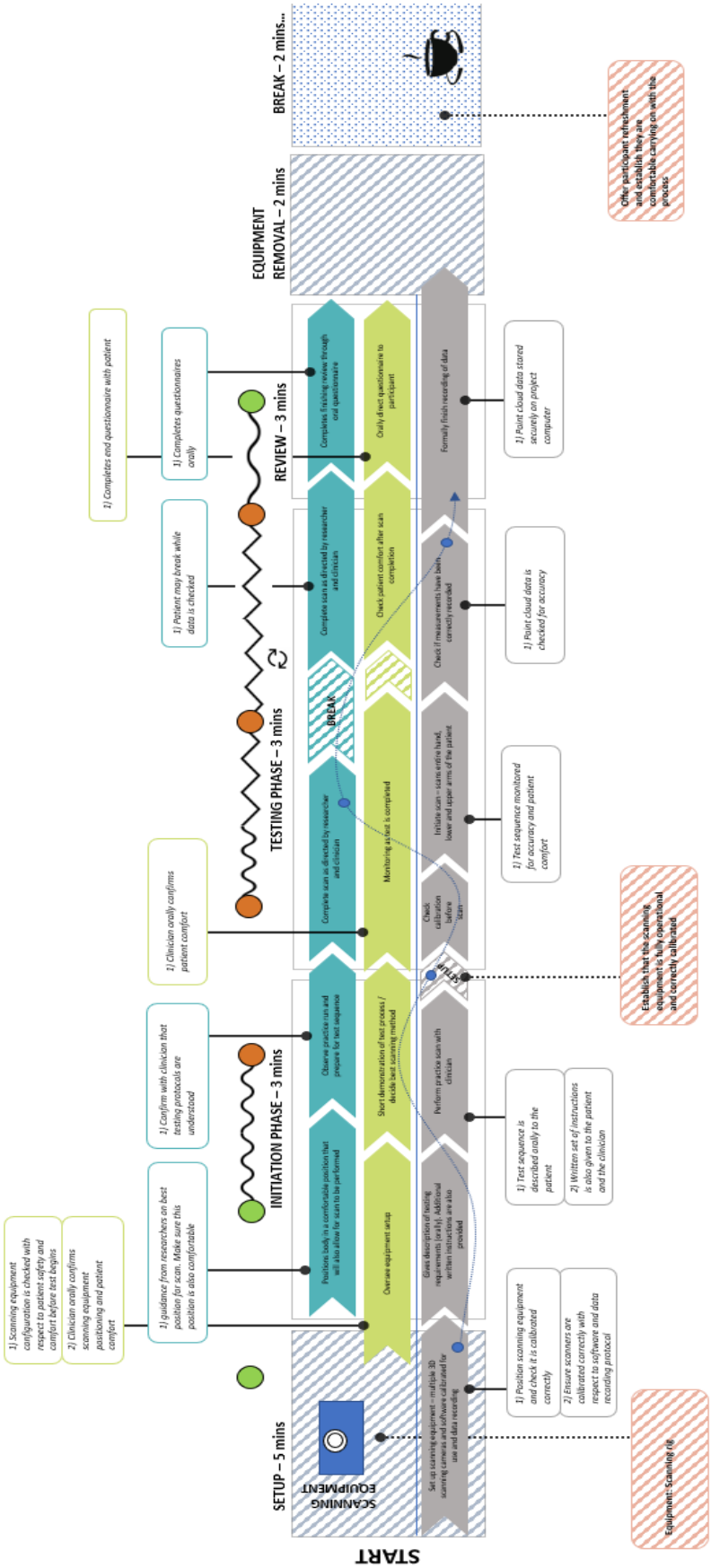
2 mins

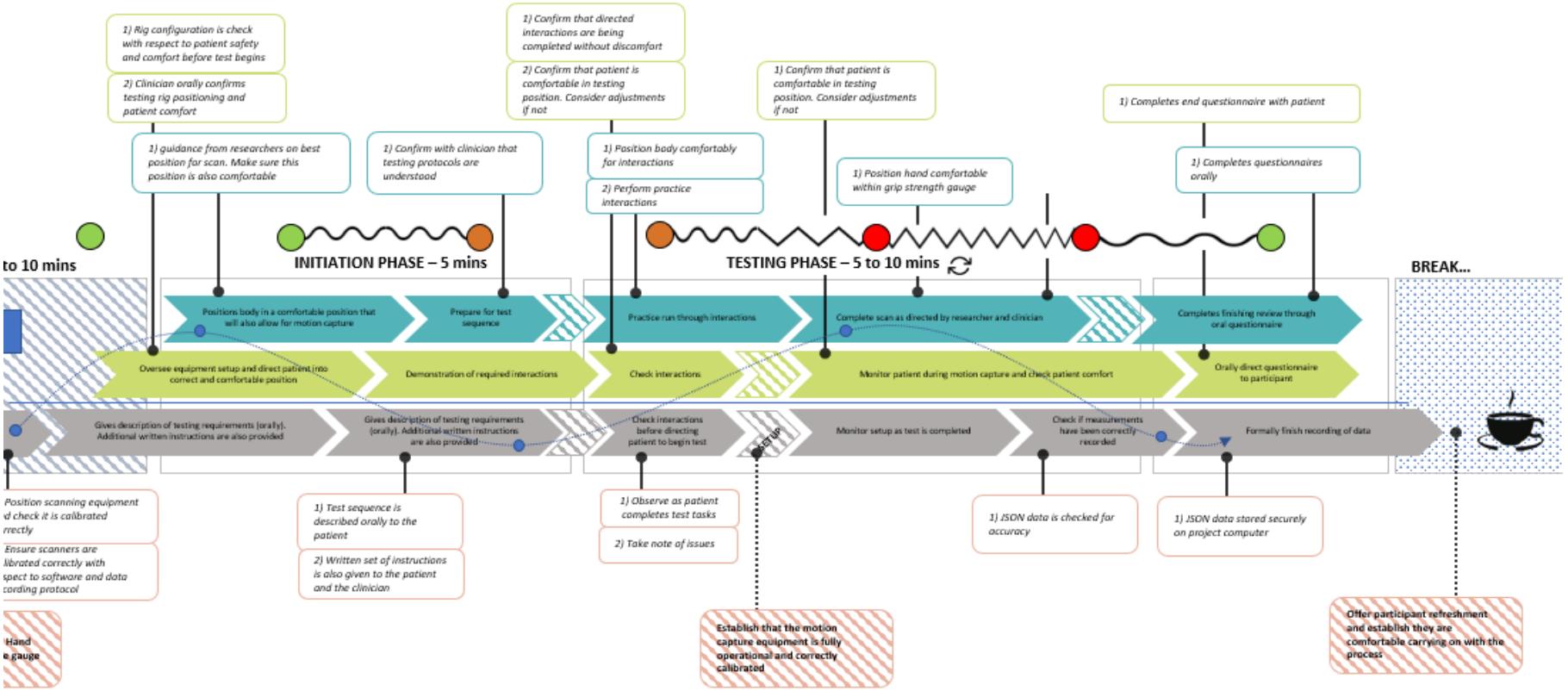
END

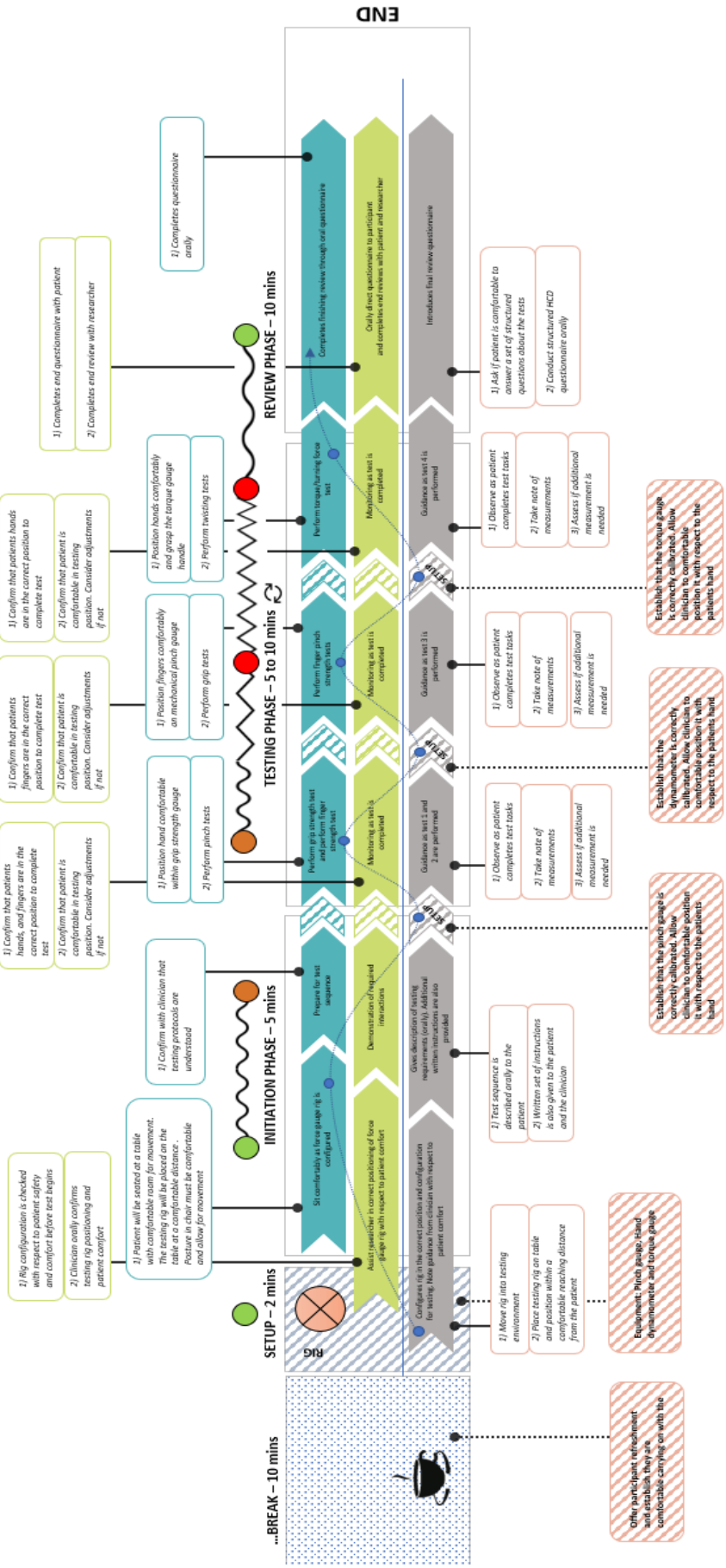
- Complete end review process for assessment stage by orally dictating questionnaire to patient
- Facilitator completes questionnaire

2 mins

9.2. Experience maps




1) Rig configuration is check with respect to patient safety and comfort before test begins
2) Clinician orally confirms testing rig positioning and patient comfort
1) guidance from researchers on best position for scan. Make sure this position is also comfortable
1) Confirm with clinician that testing protocols are understood
1) Confirm that directed interactions are being completed without discomfort
2) Confirm that patient is comfortable in testing position. Consider adjustments if not
1) Position body comfortably for interactions
2) Perform practice interactions
1) Confirm that patient is comfortable in testing position. Consider adjustments if not
1) Position hand comfortable within grip strength gauge
1) Completes end questionnaire with patient
1) Completes questionnaires orally
to 10 mins
INITIATION PHASE – 5 mins
TESTING PHASE – 5 to 10 mins
BREAK...
Positions body in a comfortable position that will also allow for motion capture
Prepare for test sequence
Practice run through interactions
Complete scan as directed by researcher and clinician
Completes finishing review through oral questionnaire
Oversee equipment setup and direct patient into correct and comfortable position
Demonstration of required interactions
Check interactions
Monitor patient during motion capture and check patient comfort
Orally direct questionnaire to participant
Gives description of testing requirements (orally). Additional written instructions are also provided
Gives description of testing requirements (orally). Additional written instructions are also provided
Check interactions before directing patient to begin test
TEST UP
Monitor setup as test is completed
Check if measurements have been correctly recorded
Formally finish recording of data
Position scanning equipment d check it is calibrated rrectly
Ensure scanners are librated correctly with spect to software and data cording protocol
Hand e gauge
1) Test sequence is described orally to the patient
2) Written set of instructions is also given to the patient and the clinician
1) Observe as patient completes test tasks
2) Take note of issues
Establish that the motion capture equipment is fully operational and correctly calibrated
1) JSON data is checked for accuracy
1) JSON data stored securely on project computer
Offer participant refreshment and establish they are comfortable carrying on with the process


END
REVIEW PHASE – 10 mins
TESTING PHASE – 5 to 10 mins
INITIATION PHASE – 5 mins
SETUP – 2 mins
...BREAK – 10 mins
RIG
1) Completes questionnaire orally
1) Completes end questionnaire with patient
2) Completes end review with researcher
Introduces final review questionnaire
Orally direct questionnaire to participant and completes and reviews with patient and researcher
Completes finishing review through oral questionnaire
Perform torque/turning force test
Perform finger pinch strength tests
Perform grip strength test and perform finger strength test
Prepare for test sequence
Demonstration of required interactions
Gives description of testing requirements (orally). Additional written instructions are also provided
Sit comfortably as force gauge rig is configured
Assist researcher in correct positioning of force gauge rig with respect to patient comfort
Configures rig in the correct position and configuration for testing. Note guidance from clinician with respect to patient comfort
1) Patient will be seated at a table with comfortable room for movement. The testing rig will be placed on the table at a comfortable distance. Posture in chair must be comfortable and allow for movement
2) Rig configuration is checked with respect to patient safety and comfort before test begins
2) Clinician orally confirms testing rig positioning and patient comfort
1) Move rig into testing environment
2) Place testing rig on table and position within a comfortable reaching distance from the patient
Equipment: Pinch gauge, Hand dynamometer and torque gauge
Offer participant refreshment and establish they are comfortable carrying on with the
1) Confirm with clinician that testing protocols are understood
1) Test sequence is described orally to the patient
2) Written set of instructions is also given to the patient and the clinician
1) Confirm that patients hands, and fingers are in the correct position to complete test
2) Confirm that patient is comfortable in testing position. Consider adjustments if not
1) Confirm that patients fingers are in the correct position to complete test
2) Confirm that patient is comfortable in testing position. Consider adjustments if not
1) Confirm that patients hands are in the correct position to complete test
2) Confirm that patient is comfortable in testing position. Consider adjustments if not
1) Position hand comfortable within grip strength gauge
2) Perform pinch tests
1) Position fingers comfortably on mechanical pinch gauge
2) Perform grip tests
1) Position hands comfortably and grasp the torque gauge handle
2) Perform twisting tests
Guidance as test 1 and 2 are performed
Guidance as test 3 is performed
Guidance as test 4 is performed
Monitoring as test is completed
Monitoring as test is completed
Monitoring as test is completed
1) Observe as patient completes test tasks
2) Take note of measurements
3) Assess if additional measurement is needed
1) Observe as patient completes test tasks
2) Take note of measurements
3) Assess if additional measurement is needed
1) Observe as patient completes test tasks
2) Take note of measurements
3) Assess if additional measurement is needed
Establish that the pinch gauge is correctly calibrated. Allow clinician to comfortable position it with respect to the patients hand
Establish that the dynamometer is correctly calibrated. Allow clinician to comfortable position it with respect to the patients hand
Establish that the torque gauge is correctly calibrated. Allow clinician to comfortable position it with respect to the patients hand
1) Ask if patient is comfortable to answer a set of structured questions about the tests
2) Conduct structured HCD questionnaire orally

9.3. Questionnaires

Scanning questionnaire for facilitator of scanning process:

Presented here are 10 questions the answers of which will be used to review and improve the scanning processes overall.

To answer the first 9 questions, highlight the most applicable box: ☑

1) Review of anatomical scanning

Q1. How difficult would you rate your experience of setting up the scanning equipment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

Additional comments: ☐

Q2. How difficult did you find your experience directing the participant in completing the scanning?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

Additional comments: ☐

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☐

Additional comments: ☐

2) Review of motion capture

Q1. How difficult would you rate the experience of setting up the motion capture equipment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

Additional comments: ☐

How difficult was it to direct the participant in completing the motion capture?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

ditional comments:

How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☐

ditional comments:

3) *Review of force assessment*

. How difficult would you rate the experience of setting up the force assessment equipment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

ditional comments:

. How difficult was it to direct the participant in completing the force assessment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

ditional comments:

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable not uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☐

Additional comments:

Final comment

Q1. How do you suggest we could improve the testing experience?

Scanning questionnaire for participant of scanning process:

Presented here are 10 questions the answers of which will be used to review and improve the scanning processes overall.

To answer the first 9 questions, highlight the most applicable box: ☑

1) Review of anatomical scanning

Q1. To what extent do you rate your comfort during the scanning process?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☐

Additional comments:

Q2. How difficult would you rate the experience of following the instructions of those directing the scanning process?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

Additional comments:

Q3. To what extent was the setup of the scanning devices and the testing environment intrusive for you?

Very invasive	Often invasive	Neither invasive nor not invasive	Slightly invasive	Not invasive at all
☐	☐	☐	☐	☐

Additional comments:

2) ***Review of motion capture***

Q1. To what extent do you rate your comfort during the motion capture process?

Uncomfortable	Slightly uncomfortable	Neither uncomfortable nor comfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☐

Additional comments:

Q2. How difficult would you rate the experience of following the instructions of those directing the motion capture process?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

Additional comments:

Q3. To what extent was the setup of the motion capture devices and the testing environment intrusive for you?

Very invasive	Often invasive	Neither invasive nor not invasive	Slightly invasive	Not invasive at all
☐	☐	☐	☐	☐

Additional comments:

3) ***Review of force assessment***

Q1. To what extent do you rate your comfort during the force assessment process?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☐

Additional comments:

Q2. How difficult would you rate the experience of following the instructions of those directing the force assessment process?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☐

Additional comments:

Q3. To what extent was the testing room and equipment intrusive for you?

Very invasive	Often invasive	Neither invasive nor not invasive	Slightly invasive	Not invasive at all
☐	☐	☐	☐	☐

Additional comments:

Final comments

Q1. How do you suggest we could improve the testing experience?

9.4. Data acquisition: Force assessment

PRIME-VR2 Force Assessment:

Test Results Recording Sheet

Name of patient:

Age:

Living Lab associated:

Disability summary:

Name of assessor:

PHASE 1 – PINCH TESTS

Test 1, Palmer (chuck pinch)

RESULT 1:

RESULT 2:

RESULT 3:

Demonstration

RESULT 1:

RESULT 2:

RESULT 3:

Test 3, Key (lateral pinch)

Demonstration

RESULT 1:

RESULT 2:

RESULT 3:

PHASE 2 – GRIP TESTS

Test 1, Full hand grip

RESULT 1:

RESULT 2:

RESULT 3:

Demonstration

PHASE 3 – WRIST ROTATION TESTS

Test 1, Wrist twisting

RESULT 1:

RESULT 2:

RESULT 3:

Demonstration

9.5. Completed evaluation sheets

From GDIH

PRIME-VR2 Scanning Procedure Questionnaire – *Facilitator*

Grant Agreement nr	**856998**
Project title	Personalised recovery through a multi-user environment: Virtual Reality for Rehabilitation
Project Acronym	PRIME-VR2
Start day of project (dur.)	October 1st 2019 (3 years)
Document Reference	PRIME-VR2_D_WPx_partner_Dx.x-SHORT TITLE-v.w
Type of Report	[PU/CO]
Document due date	DD/MM/YYYY
Actual date of delivery	DD/MM/YYYY
Leader	Partner
Responsible	Name (email)
Additional main contributors (Name, Partner)	
Document status	[Draft/Final] (reviewed by XXXX)

1) *Review of anatomical scanning*

Q1. How difficult would you rate your experience of setting up the scanning equipment?

Setting up the equipment was varied, I have broken down the differ components below:

- The Ring
  - This was easy to set up and use, transporting it around the hospital was slightly harder due to its size and shape meaning it could not fit in a backpack. The ability to fold was extremely useful. The ring also needs to be cleaned after every use (even though patients do not touch it) and this should be considered as part of future design iterations.
- The ring holder
  - This was an effort to set up and offered little to no benefit for us. We found that it would add additional bulk to the device when set up and to carry around as well as unnecessary steps to the set up process. We only used it for the first testing session then did not use if after.

Q2. How difficult did you find your experience directing the participant in completing the scanning?

- The instructions were clear and easy to follow, however we only tested patients with mild dystonia. The general consensus is that it would be a lot more difficult with patients with more severe involuntary movements.

Q3. How comfortable did you feel the participant was during this stage of the assessment?

- The participants were comfortable during the process and I don't think that comfort is a major risk/concern for this process.

2) *Review of motion capture*

Q1. How difficult would you rate the experience of setting up the motion capture equipment?

Same as above

Q2. How difficult was it to direct the participant in completing the motion capture?

Same as above

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Same as above

3) Review of force assessment

Q1. How difficult would you rate the experience of setting up the force assessment equipment?

- The Force Meters and mount
  - The force meters worked generally as intended. The pinch meter and grip meter was easy to use and record a reading from although both were used off the mounting block after the first trial. The turning force meter was harder to use as it had to be turned and repositioned for each hand, this proved difficult with the mounting block and so we removed half of it to make it easier to move around. This constant resetting was difficult to get right and the machine was fiddly to set up.
  - The force meter on the turning block took too long to register the force and the participants were not able to maintain a consistent enough force to take a reliable reading from the meter.
  - All participants reported difficulties with the force meters not moving to register the force and the instructions should really emphasize this.
  - The base was too large and heavy to be practical and so we removed half of it at the hinge. This made it much easier to carry around but the suctions cups no longer worked. It also meant that the device could be used on smaller hospital tables or wheelchair tables. A reduction in size and weight should be looked at in the future.

Q2. How difficult was it to direct the participant in completing the force assessment?

- Many participants found it hard to use the force meters as they did not move when turned/gripped. All the participants had normal cognition and so were able to pick it up very easily but it might be worth developing some clear, picture based instructions or videos for people with an intellectual disability.

Q3. How comfortable did you feel the participant was during this stage of the assessment?

- The turning meter had some slightly hard surfaces, some hands were left a bit red after really trying to turn it hard. Maybe a foam covering/layer would be helpful for patient comfort.

Final comment

Q1. How do you suggest we could improve the testing experience?

- The rig is bulky but the principles underlying its design are sound and we are able to test the more-able patients with it. With some adaptations particularly around reducing weight and bulk it will make the product much more feasible for use in our setting.
- It would be good to have an explanation for the logic for each force measure and how it translates to adapting the controllers. This would help us to understand why we are doing these. It might be of value to assess each finger separately if it is to assess the ability to press buttons/move joysticks.
- The feedback questions that were given to the participants were not detailed or relevant enough to build a clear picture of the efficacy of the process. I have attached a link to a generic ease of use questionnaire that could provide a framework for further questions.

  https://garyperlman.com/quest/quest.cgi?form=USE

From STJH

PRIME-VR2 Scanning Procedure Questionnaire – *Facilitator*

Grant Agreement nr	**856998**
Project title	Personalised recovery through a multi-user environment: Virtual Reality for Rehabilitation
Project Acronym	PRIME-VR2
Start day of project (dur.)	October 1st 2019 (3 years)
Document Reference	PRIME-VR2_D_WPx_partner_Dx.x-SHORT TITLE-v.w
Type of Report	[PU/CO]
Document due date	DD/MM/YYYY
Actual date of delivery	DD/MM/YYYY
Leader	Partner
Responsible	Name (email)
Additional main contributors (Name, Partner)	
Document status	[Draft/Final] (reviewed by XXXX)

Presented here are 10 questions the answers of which will be used to review and improve the scanning processes overall.

To answer the first 9 questions, highlight the most applicable box: ☑

1) *Review of anatomical scanning*

Q1. How difficult would you rate your experience of setting up the scanning equipment?

☐	☐	☑	☐	☐
Difficult	**Quite difficult**	**Neither difficult nor easy**	**Easy**	**Very easy**

Additional comments:

Q2. How difficult did you find your experience directing the participant in completing the scanning?

☐	☐	☐	☑	☐
Difficult	**Quite difficult**	**Neither difficult nor easy**	**Easy**	**Very easy**

Additional comments:

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
☐	☐	☑	☐	☐

Additional comments:

2) *Review of motion capture*

Q1. How difficult would you rate the experience of setting up the motion capture equipment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☑	☐

Additional comments:

Q2. How difficult was it to direct the participant in completing the motion capture?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☑	☐

Additional comments:

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
☐	☐	☑	☐	☐

Additional comments:

3) *Review of force assessment*

Q1. How difficult would you rate the experience of setting up the force assessment equipment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☑	☐

Additional comments:

Q2. How difficult was it to direct the participant in completing the force assessment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☑	☐

Additional comments:

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable not uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☑	☐

Additional comments:

Final comment

Q1. How do you suggest we could improve the testing experience?

LEAP MOTION SHOULD CAPTURE MOVEMENT EVEN IF PATIENT IS FAST IN MOVING HAND / ARM

PRIME-VR2 Scanning Procedure Questionnaire – *Participant*

Grant Agreement nr	856998
Project title	Personalised recovery through a multi-user environment: Virtual Reality for Rehabilitation
Project Acronym	PRIME-VR2
Start day of project (dur.)	October 1st 2019 (3 years)
Document Reference	PRIME-VR2_D_WPx_partner_Dx.x-SHORT TITLE-v.w
Type of Report	[PU/CO]
Document due date	DD/MM/YYYY
Actual date of delivery	DD/MM/YYYY
Leader	Partner
Responsible	Name (email)
Additional main contributors (Name, Partner)	
Document status	[Draft/Final] (reviewed by XXXX)

Presented here are 10 questions the answers of which will be used to review and improve the scanning processes overall.

To answer the first 9 questions, highlight the most applicable box: ☑

1) *Review of anatomical scanning*

Q1. To what extent do you rate your comfort during the scanning process?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☑

Additional comments:

Q2. How difficult would you rate the experience of following the instructions of those directing the scanning process?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☑

Additional comments:

Q3. To what extent was the setup of the scanning devices and the testing environment intrusive for you?

Very invasive	Often invasive	Neither invasive nor not invasive	Slightly invasive	Not invasive at all
☐	☐	☐	☐	☑

Additional comments:

2) *Review of motion capture*

Q1. To what extent do you rate your comfort during the motion capture process?

Uncomfortable	Slightly uncomfortable	Neither uncomfortable nor comfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☑

Additional comments:

Q2. How difficult would you rate the experience of following the instructions of those directing the motion capture process?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☑

Additional comments:

Q3. To what extent was the setup of the motion capture devices and the testing environment intrusive for you?

Very invasive	Often invasive	Neither invasive nor not invasive	Slightly invasive	Not invasive at all
☐	☐	☐	☐	☑

Additional comments:

3) *Review of force assessment*

Q1. To what extent do you rate your comfort during the force assessment process?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☐	☑

Additional comments:

Q2. How difficult would you rate the experience of following the instructions of those directing the force assessment process?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	☐	☑

Additional comments:

Q3. To what extent was the testing room and equipment intrusive for you?

Very invasive	Often invasive	Neither invasive nor not invasive	Slightly invasive	Not invasive at all
☐	☐	☐	☐	☑

Additional comments:

Final comments

Q1. How do you suggest we could improve the testing experience?

Scanning is easy but can be tiring sometimes..

From KNRC

PRIME-VR2 Scanning Procedure Questionnaire – *Facilitator*

Grant Agreement nr	**856998**
Project title	Personalised recovery through a multi-user environment: Virtual Reality for Rehabilitation
Project Acronym	PRIME-VR2
Start day of project (dur.)	October 1st 2019 (3 years)
Document Reference	PRIME-VR2_D_WPx_partner_Dx.x-SHORT TITLE-v.w
Type of Report	[PU/CO]
Document due date	DD/MM/YYYY
Actual date of delivery	DD/MM/YYYY
Leader	Partner
Responsible	Name (email)
Additional main contributors (Name, Partner)	
Document status	[Draft/Final] (reviewed by XXXX)

Presented here are 10 questions the answers of which will be used to review and improve the scanning processes overall.

To answer the first 9 questions, highlight the most applicable box: ☑

1) *Review of anatomical scanning*

Q1. How difficult would you rate your experience of setting up the scanning equipment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☒	☐	☐

Additional comments: Difficult in the beginning, easier with experience

Q2. How difficult did you find your experience directing the participant in completing the scanning?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☒	☐	☐

Additional comments: More difficult assessing more advanced patients

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
			X	

Additional comments: Patient amazed by technology. Patient response positive

2) *Review of motion capture*

Q1. How difficult would you rate the experience of setting up the motion capture equipment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
X				

Additional comments: Problems because of tremors

Q2. How difficult was it to direct the participant in completing the motion capture?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
			X	

Additional comments: After short practice it is easy. Support added

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable nor uncomfortable	Comfortable	Very comfortable
				X

Additional comments: Feel secure in a seated position, no pain, very comfortable

3) *Review of force assessment*

Q1. How difficult would you rate the experience of setting up the force assessment equipment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	X	☐

Additional comments:

Q2. How difficult was it to direct the participant in completing the force assessment?

Difficult	Quite difficult	Neither difficult nor easy	Easy	Very easy
☐	☐	☐	X	☐

Additional comments: Using additional strap was sometime required

Q3. How comfortable did you feel the participant was during this stage of the assessment?

Uncomfortable	Slightly uncomfortable	Neither comfortable not uncomfortable	Comfortable	Very comfortable
☐	☐	☐	☐	X

Additional comments: Feel secure in a seated position, no pain, very comfortable

Final comment

Q1. How do you suggest we could improve the testing experience?

RING – Better to be stabilized in a stand, tremor movements cause mistakes

FA – Torque gauge needs stabilization. Hold secure without therapist holding

Patients tested all have problem across one side of the body