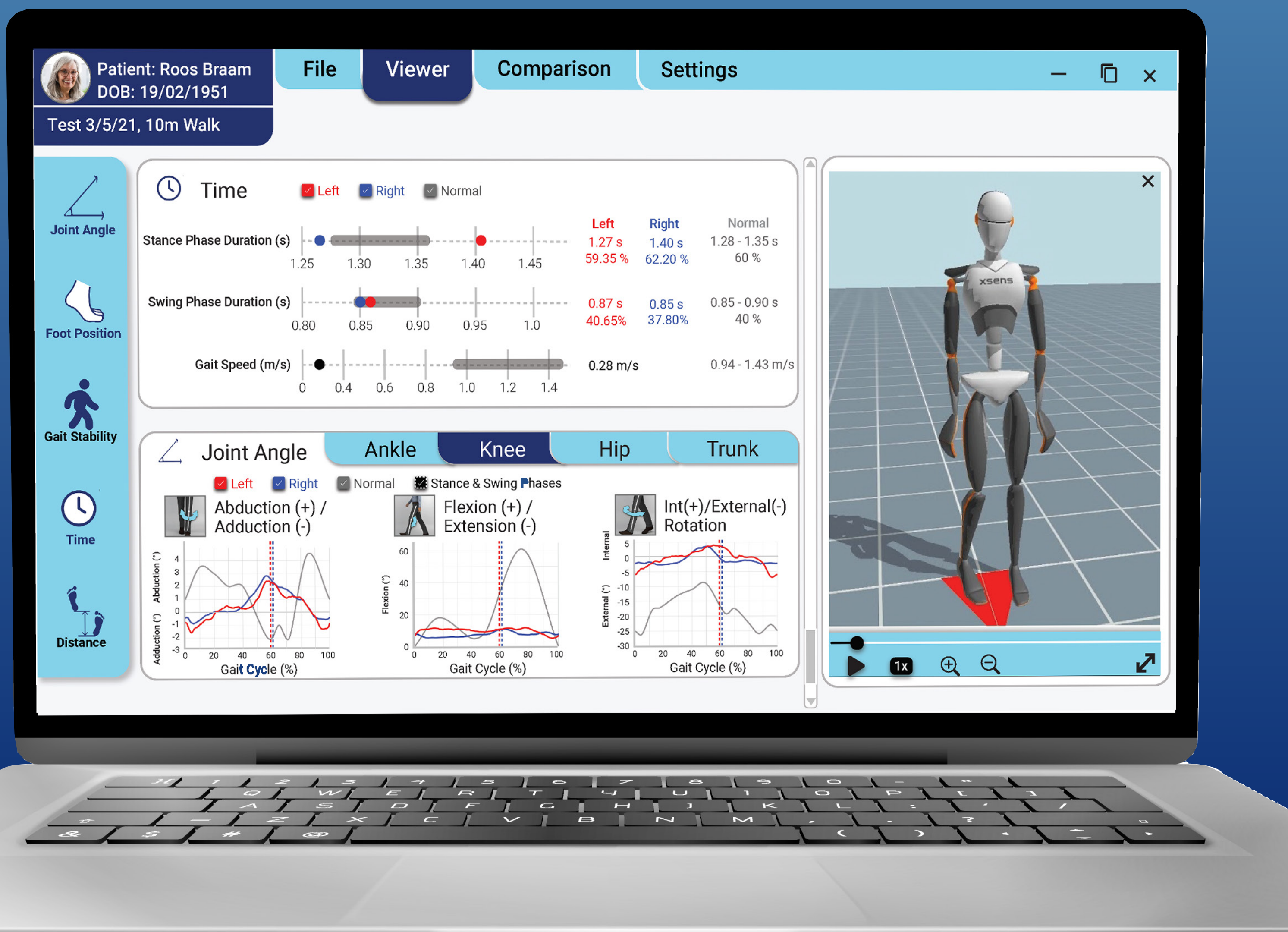
Design of Interface for Gait Assessment in Spinal Cord Injury

Master Thesis

Rebekah Kempske



Design of Interface for Gait Assessment in Spinal Cord Injury

Rebekah Kempske

Industrial Design Engineering
MSc Integrated Product Design
Delft University of Technology
July, 2021

Student Rebekah Kempske
Delft University of Technology
Industrial Design Engineering
MSc Integrated Product Design

Supervisory Team Dr. ir. Armagan Albayrak | Chair
Prof. dr. ir. Richard Goossens | Chair
MSc. BSc. Hilbrand Bodewes | Mentor

Company Erasmus MC
Dr. Herwin Horemans | Mentor
Dr. Daniel Lemus Perez | Mentor

Executive Summary

Spinal cord injuries (SCI) occur when damage to any part of the spinal cord is sustained. Depending on what vertebrae segment the injury occurs, the patient will develop paraplegia or tetraplegia and have a complete or incomplete spinal cord injury. After sustaining a spinal cord injury, the patient must undergo rehabilitation.

For incomplete SCI patients, part of their rehabilitation is improving their mobility skills through gait training. To assess gait, the methods of the clinical eye and laboratory gait assessment are used. The starting goal of the project was to combine the quickness and easiness of conducting a gait assessment with the clinical eye with the objective data from a laboratory gait assessment into one system. This system consists of Xsens Awinda wireless motion trackers to collect the kinematic data and a user interface to view it.

User research was conducted in the form of questionnaires and focus groups. The research aimed to learn more about how physiotherapists and physicians within Rijndam Revalidatie currently assess gait, what features and parameters they would like in the user interface, and how they would prefer the selected parameters to be visualized (in numbers, graphs, or animations). Three physiotherapists and physicians were also interviewed to better understand the process incomplete SCI patients go through in gait rehabilitation and who is involved in each step.

From the results, a design direction and vision was created,

> *“To develop an* ***easy to use*** *user interface that aids physicians and physiotherapists in* ***selecting interventions*** *for patients with incomplete spinal cord injuries in an* ***objective*** *and* ***time efficient manner*** *through* ***intuitive*** *data visualizations.”*

Using design methods and tools, ideas for the data visualizations and the interface layout were formed, selected, and then made into concepts. The layout and visualizations concepts were evaluated through concept test sessions with physiotherapists and physicians. In the sessions, the interface layout was assessed in terms of usability and functionality. The data visualizations were evaluated based on if the participants, who had minimal pre-existing knowledge on gait analysis, could understand them. From the evaluation results, the final design of Gait Vision was created.

Gait Vision is an easy-to-use interface that allows physiotherapists and physicians to assess gait objectively and time-efficiently. It provides more accurate and objective information than can be obtained with the clinical eye, in a way that is more intuitive and comprehensible for clinicians with minimal gait assessment experience than laboratory gait assessment.

An interactive prototype of the final design was developed using Adobe XD. The interface prototype and the visualization concepts were evaluated through conducting individual user tests with seven physicians and physiotherapists. The interface and visualizations were tested with regard to usability, functionality, intuitiveness, and aesthetics. Overall positive feedback was received regarding the interface and visualizations. Testing was also conducted to compare gait assessment with the clinical eye versus with the interface. The interface was found to more objective than the clinical eye.

An implementation plan was developed to ensure Gait Vision survives in the long term. Future recommendations were also made to aid in the continuation of the development of Gait Vision.

Design Process

The structure of the report is based on the design process that was undergone in the project. This process was based on the Double Diamond Method (Figure 1).

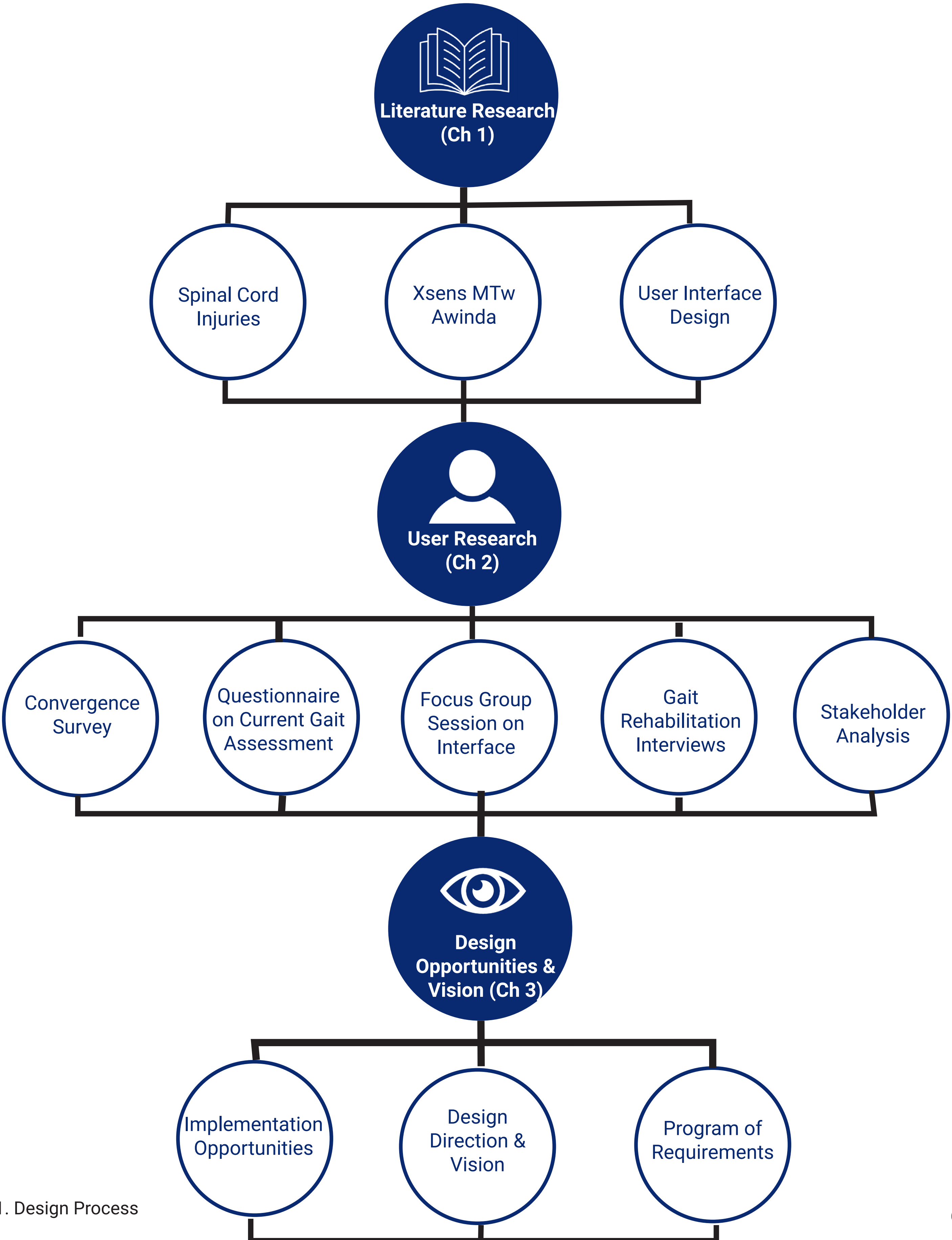


Figure 1. Design Process

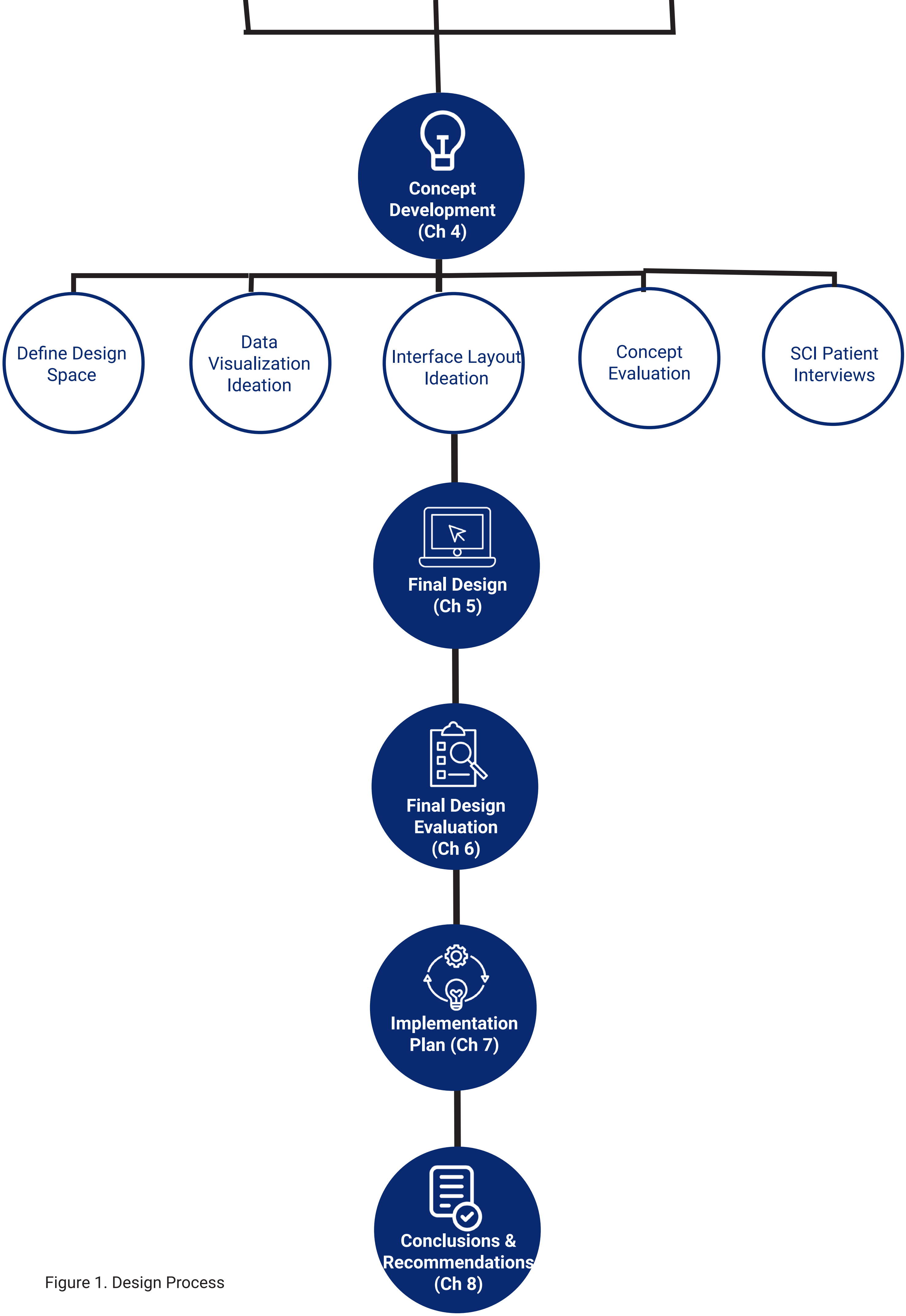


Figure 1. Design Process

Table of Contents

Chapter 1
Literature Research

1.1 Background on Spinal Cord Injuries

Spinal cord injuries (SCI) occur when damage to the spinal cord is sustained. Depending on what vertebrae segment the injury is sustained, the patient will develop paraplegia or tetraplegia and have a complete and incomplete spinal cord injury. After sustaining a spinal cord injury, the patient must undergo rehabilitation. For incomplete SCI patients, a part of their rehabilitation is improving their mobility skills through gait training. To assess gait, the methods of the clinical eye and laboratory gait assessment are used.

SPINAL CORD INJURIES IN THE NETHERLANDS

The United States Center for Disease Control and Prevention defines a spinal cord injury (SCI) as "an acute traumatic lesion of the neural elements in the spinal canal, resulting in temporary or permanent sensory deficit, motor deficit, or bowel/bladder dysfunction" ("Spinal Cord Injury," 1990).

Spinal cord injuries can stem from traumatic or non-traumatic accidents. In the Netherlands in 2010, there were 14.0 traumatic spinal cord injuries per million people, with a 16% mortality rate (Nijendijk et al., 2014). The most common causes of traumatic SCI are falling and road traffic accidents (Figure 2). In these types of accidents, when the patient receives a sudden impact to their spine, one or more of their vertebra can become fractured, dislocated, crushed, or compressed, resulting in a spinal cord injury ("Spinal Cord Injury - Symptom," n.d.).

The top causes of nontraumatic SCI in the Netherlands are vascular diseases and spinal degeneration (Figure 3). Other causes include inflammation, malignant tumor(s), and benign tumor(s) (Osterthun et al., 2009). It is unknown the exact number of nontraumatic cases in the Netherlands.

In the Netherlands, 74% of traumatic SCI patients are male, and 53% are over 60 years old (Nijendijk et al., 2014).

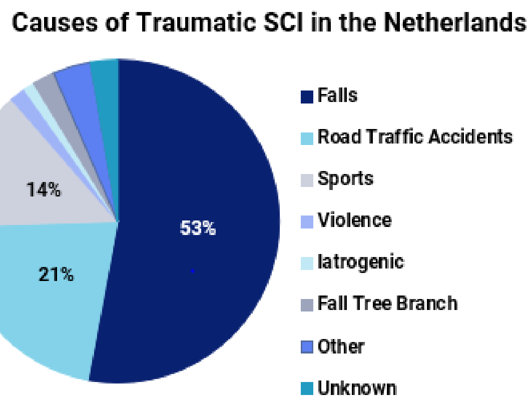


Figure 2. Causes of Traumatic SCI in the Netherlands

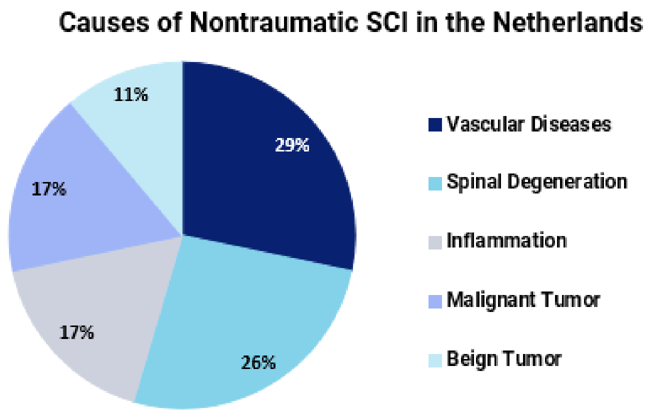


Figure 3. Causes of Nontraumatic SCI in the Netherlands

TYPES OF SPINAL CORD INJURIES

The level and type of impairment of a spinal cord injury depends on what area of the spinal cord is injured and to what severity. The two primary classifications are Paraplegia and Tetraplegia ("Symptoms of Spinal Cord Injury," n.d.).

Paraplegia occurs when the T1 vertebrae segment or below is injured (Figure 4). There is loss of sensation and movement in the lower half of the body ("Symptoms of Spinal Cord Injury," n.d.). This includes all or part of the trunk, legs, and pelvic organs ("Spinal Cord Injury - Symptom," n.d.).

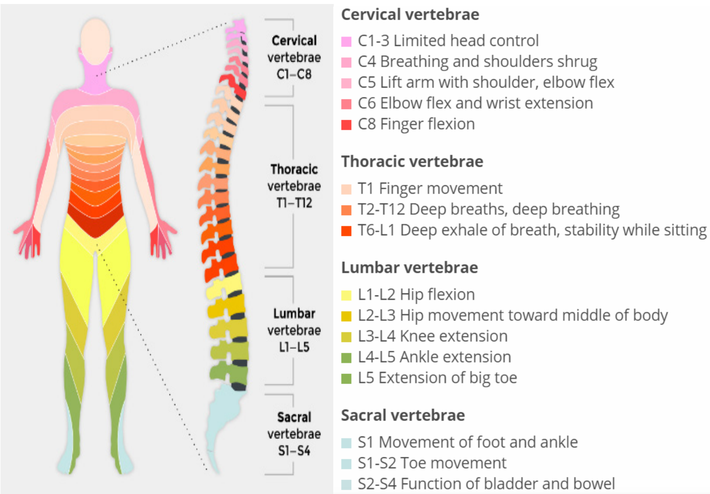


Figure 4. Level of Impairment ("Spinal Cord Injury and how", n.d.)

When an injury is sustained at the T1 vertebrae segment or above, the patient has tetraplegia, also known as quadriplegia. They lose sensation and movement below the neck. This includes both the left and right arms and legs as well as the chest muscles. If the injury occurs at the C4 segment or above, the patient will need a ventilator ("Symptoms of Spinal Cord Injury," n.d.).

Within paraplegia and tetraplegia, they are levels of complete and incomplete spinal cord injuries. Complete spinal cord injuries occur when upon impact, the spinal cord is severed or fully compressed. The brain is then no longer able to send signals below the injured vertebrae segment, resulting in complete loss of feeling and movement control below the injury (Figure 5) ("Spinal Cord Injury - Symptoms," n.d.; "Complete vs. Incomplete," n.d.).

In an incomplete spinal cord injury, the spinal cord is injured or compressed, but the brain can send some signals below the injured vertebrae segment ("Complete vs. Incomplete," 2020). The patient still has some sensation and movement control, but the level and in which limbs depend on the injury site. For example, they can have more movement control and sensation in one side of the body or one limb more than the other (Figure 6) ("Types of Spinal Cord Injury," n.d.).

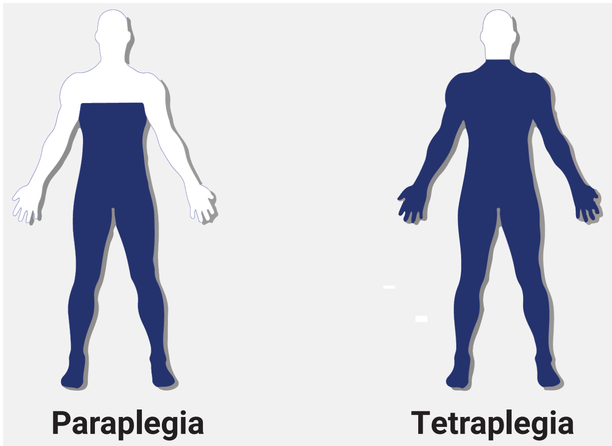


Figure 5. Complete SCI ("Complete vs Incomplete", n.d.)

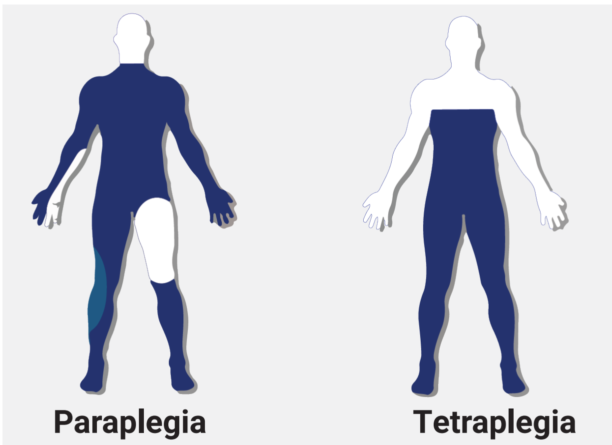


Figure 6. Incomplete SCI ("Complete vs Incomplete", n.d.)

TREATMENT JOURNEY OF SCI PATIENT IN THE NETHERLANDS

An overview of the rehabilitation journey a spinal cord injury patient undergoes and the stakeholders involved in each phase is depicted in Figure 7 (Nijendijk et al., 2014; Osterthun, 2021; Postma, 2021; Post et al. 2017).

Hospital

When a traumatic accident occurs, the patient is transported by ambulance to a nearby hospital. After an initial assessment, it is shown that the patient may have damage to their spinal cord, so they are then taken to a Level I trauma center. There are eleven Level I trauma centers in the Netherlands. At the trauma center, depending on the level of injury, the patient may undergo surgery to stabilize their spine (Post et al., 2017). Surgery may also be required to take care of any other injuries sustained in the accident and address any other damages to the spinal cord. This can include broken bones, blood clots, and damaged tissue ("Spinal Cord Injury: Types," n.d.).

The patient will stay in the hospital's acute care ward for about 17 days (Nijendijk et al., 2014).

Rehabilitation Center

The SCI patient will then be transferred to a rehabilitation center that specializes in rehabilitation for spinal cord injuries. There are eight such centers in the Netherlands. On average, SCI patients stay in the rehabilitation center for 4 to 6 months. For patients with tetraplegia, their stay tends to be longer, and they are in inpatient rehabilitation for 6 to 9 months (Post et al., 2017). In rehabilitation, the patient receives multidisciplinary treatment and meets with numerous specialists (Figure 8).

Outpatient Rehabilitation

After the patient is discharged from the rehabilitation center, they will go to outpatient rehabilitation and therapy for a few more months (Post et al., 2017). Depending on the patient's progress and what they still need to improve on, they will either continue outpatient therapy at the same rehabilitation center or go to another center closer to their home (van der Veeken, 2021).

Follow Up Consultation

One to two times a year, the patient will return to the rehabilitation center to meet with their physician for a follow-up consultation (Post et al., 2017).

Figure 8. Rehabilitation Treatments

Spinal Cord Injury Patient Experience Journey

Nursing Home: 13.5% Traumatic SCI
Home: 7% Traumatic SCI

	Injury	Transport to Nearby Hospital	Transport to Level I Trauma Center	Surgery	Hospital Stay	Rehabilitation Center	Outpatient Rehabilitation	Follow Up Consultations
Duration	Within 15 minutes after calling 112		17 days			4 to 6 months for Paraplegia 6 to 9 months to Tetraplegia	Few Months	1 Time per Year
Type of SCI: Traumatic SCI	✓	✓	✓	✓	✓	✓	✓	✓
Type of SCI: Non-Traumatic SCI				✓	✓	✓	✓	✓
Patient	The most common causes of traumatic SCI are falls (53%), road traffic accidents (22%), and sports (14%).	Transported to nearby hospital.	Due to spinal cord injuries, the patient is transported to a trauma center for further treatment.	For traumatic injuries, depending on the level of injury, the patient undergoes surgery to stabilize their spine and address any other injuries. For non-traumatic injuries the patient may need surgery to remove tumors or treat vascular disease, spinal degeneration, or inflammation.	Stay in the acute care ward to recover from surgery and/or receive treatment.	Transported to one of eight rehabilitation centers that specializes in rehabilitation for spinal cord injuries. Receive medical, functional, and psychological rehabilitation.	Patients who are capable of living at home once discharged from the hospital go straight to outpatient rehabilitation. Rehabilitation center patients are discharged to home or to a care facility. They go the rehab to improve on skills learned while in the rehabilitation center. Depending on their progress and what they need to work on, the patient may continue rehab at the same center or go to another center closer to home.	Go to physician to evaluate their progress and to address any additional issues they have.
Emergency Services		Arrive by ambulance or helicopter to give the patient first aid and transport them to the hospital.	Transports patient from the hospital to one of eleven Level I trauma centers.			Transports patient from hospital to rehabilitation center.		
Emergency Room Physician		Evaluate the patient and see that they have symptoms of spinal cord damage. Order for patient to be sent to trauma center.						
Surgeon (Orthopedic, Trauma, or Neuro)				For traumatic SCI, conduct surgery to stabilize the patient's spine, take care of any other injuries sustained in the accident, and address any other damages to the spinal cord, including broken bones, blood clots, and damaged tissue. For non-traumatic SCI, conduct surgery to remove tumors or treat vascular disease, spinal degeneration, or inflammation. Surgery can be done during rehabilitation if disease progresses.				
Rehabilitation Staff (Physio-therapist, Occupational Therapist, Social Worker, Psychiatrist)						Provide medical, functional, and psychological rehabilitation to improve patient's functioning.	Work with patient to further improve on functioning skills	
Rehabilitation & Spinal Cord Physician						Responsible for patient's rehabilitation and developing patient's rehabilitation plan. Prescribes interventions to improve patient's functioning	Continue to see patient and prescribe additional interventions as needed.	Sees patient to evaluate their progress and if any additional interventions or treatment is needed.
Rehabilitation Nurses						Takes care of patient. In patient physiotherapy, aid in walking and practicing transferring in and out of bed.		

GAIT REHABILITATION FOR INCOMPLETE SCI

In rehabilitation, the primary focus of physiotherapy is to strengthen the SCI patient's mobility skills. For patients with incomplete SCI, a crucial part of this is gait training ("Spinal Cord Injury Rehab," n.d.).

Introduction to Gait

Gait is a person's pattern of walking ("Gait Disorders," n.d.). A single gait cycle starts when a person's heel first makes contact with the ground and ends when the heel of the same foot makes contact with the ground again (E, 2017).

The main phases of a gait cycle are the swing and stance phases (Figure 9). The stance phase is when the foot is in contact with the ground. It comprises about 60% of one gait cycle. The swing phase is the time in the gait cycle when a person's foot is not in contact with the ground. This lasts for about 40% of one gait cycle (Birch et al., 2015). Within these phases, there are the sub-phases of initial contact, loading response, mid-stance, terminal stance, pre-swing, toe-off, mid-swing, and terminal swing (Pirker & Katzenschlager, 2017).

Gait Training Equipment

At the beginning of rehabilitation, incomplete SCI patients are unable to walk on their own. Physiotherapists therefore use equipment to aid in gait training. This ranges from electronic equipment like body weight-supported treadmills and robotic body-weight support systems to non-electric systems like leg braces, orthosis, and walking aids (Figure 10) (Lam et al., 2007).

Figure 10. Gait Training Equipment

Types of Gait Assessments

The patient's gait is assessed throughout gait training. This is done to evaluate the patient's progress, select interventions, or determine what exercises to conduct in physiotherapy. Currently, clinicians' primary methods to asses gait are with the clinical eye and laboratory gait analysis.

Clinical Eye

When assessing with the clinical eye, a clinician observes the patient walking and evaluates the gait in real-time (Figure 11). In the observation, the clinician tries to detect deficits, impairments, or abnormalities in the patient's gait ("Gait Analysis in Cerebral Palsy," n.d.). In addition to evaluating the gait in real-time, clinicians can also record the patient walking and then play back the video in slow motion. Since the clinical eye can be performed quickly and be done within a physiotherapy session,

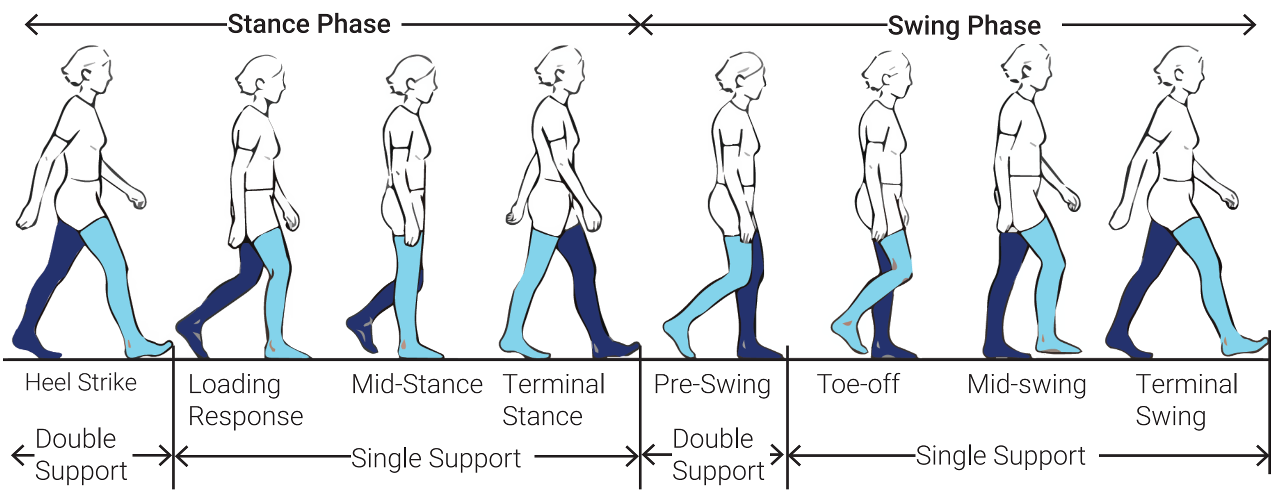


Figure 9. Gait Phases (Pirker & Katzenschiager, 2017; "EM040 - Human Gait Phase", 2021)

it is the preferred assessment method for physiotherapists (Jacinot & Silva, 2018).

Figure 11. Clinical Eye

Drawbacks of Clinical Eye

While the clinical eye is a valuable tool in gait assessment, this method also has shortcomings. Since the clinical eye relies only on the clinician's interpretation and no additional equipment, it is subjective ("Gait Analysis in Cerebral Palsy," n.d.). Due to the limits in visual perception, memory, and concentration, clinicians cannot observe and gather information on all relevant features at one time (Jacinot & Silva, 2018).

There is also not a defined test procedure patients undergo or a specific list of what parameters clinicians are to assess. In doing so, each clinician has their own way of going about the clinical eye assessment. This personal bias, as well as the level of the clinician's experience, also impact the results of the assessment (Coutts, 1999). Consequently, compared to laboratory gait analysis, the clinical eye has lower validity, reliability, sensitivity, and specificity ("Gait Analysis in Cerebral Palsy," n.d.). Thus, the clinical eye is useful in obtaining a general impression of a patient's performance, but not for collecting quantitative measurements or conducting an in-depth analysis (Coutts, 1999).

Laboratory Gait Analysis

A laboratory gait analysis is conducted when objective measurements are needed to define clinical problems or select treatments. A gait analysis can consist of a 2D or 3D analysis, depending on the software and equipment used. In the analysis, information is collected on a patient's joint kinematics, kinetics, and EMG data (Simon, 2004).

In the case of the Convergence Project, the laboratory gait analyses were previously conducted at Erasmus University Medical Center. However, in December 2020, the lab was moved to Rijndam Revalidatie in the Westersingel Center.

A 2D gait analysis is conducted by placing 2D markers on the patient and recording the patient walking in the front, back, and side views with three cameras. The patient walks on a force plate embedded into the floor as well (Figure 12). Twelve wireless EMG sensors, Freeemg, are also placed on the patient (Figure 13). These EMG sensors are composed of 6 data channels.

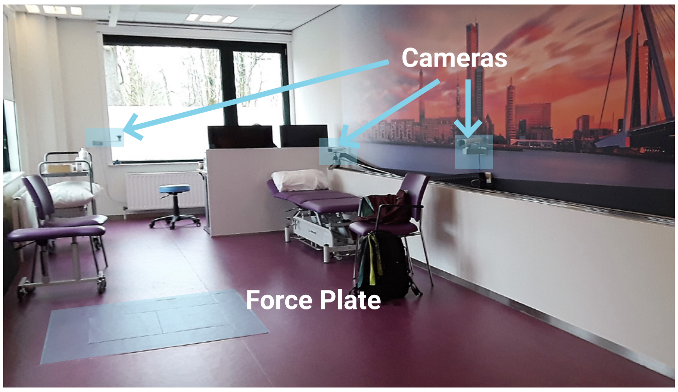


Figure 12. Laboratory Gait Analysis Setup at Rijndam Revalidatie Westersingel

Figure 13. Freeemg Sensors

Using BTS SMART-Clinic, the gait lab operator collects the data during testing. After the test is finished, the operator analyzes the data to determine the ground reaction forces and the knee, hip, and ankle angles in the sagittal plane. In the analysis, the operator also evaluates the patient's EMG data. They collect this information into a clinical test report which is then sent to the rehabilitation physician.

The test lasts about one hour, and analyzing the results takes approximately 1.5 hours. Due to the time, it takes to prepare for each patient and conduct and analyze the test, a maximum of three tests can be conducted in a day. Due to the tests being conducted back to back, the gait lab operator is unable to analyze the results right after the test. Consequently, It can take up to two weeks for the physician to receive the test report. After receiving the test report, the clinician then decides the patient’s treatment plan to go forward with (Horemans, 2021).

Drawbacks of Laboratory Gait Analysis

While a laboratory gait analysis allows clinicians to obtain objective information, there are several hindrances in its use. The technical skills required to operate the gait lab equipment and software restrict those who can perform the tests to only those trained in laboratory gait analysis. In addition, to most physicians and physiotherapists not being able to conduct the testing, the time it takes to schedule the tests and receive the test report also proves an impedance.

The technical knowledge needed to interpret the data further restricts who can operate and use the system. Clinicians have to rely on and wait for the gait lab operator to interpret the results (Vallery & Ribbers, 2019). When clinicians receive the clinical test report, they still struggle to understand the results. The current format of the report’s text, graphs, and figures is too complex for the average clinician to understand easily. Furthermore, they do not have the time or previous knowledge to fully grasp what is being reported (Simon, 2004). The reports also contain extra information that is not relevant for clinicians (Vallery & Ribbers, 2019).

For these reasons, laboratory gait analyses are currently not commonly used for SCI rehabilitation at Erasmus MC. A gait lab operator at Erasmus MC estimated that less than 10% of all SCI patients are referred for a laboratory gait analysis (Horemans, 2021).

1.2 Xsens MTw Awinda

Xsens MTw Awinda is an inertial tracker system that will be used in collaboration with the interface. It consists of wireless motion trackers and a software system called MVN Analyze. Using MTw Awinda, data can be collected to calculate time, distance, kinematics, gait stability, and gait variation parameters. MVN Analyze also contains additional features to aid in interpreting results, including calculating the difference between the left and right sides, comparing the measurements against normal values, and comparing results between tests.

SELECTION OF GAIT ANALYSIS SYSTEM

Before the designer joined the project, members of the Convergence Team selected the gait analysis system that the interface will be used with. To select a gait analysis sensor system, the team evaluated possible systems against the criteria of the system being valid, implementable, providing direct information, and assessing parameters (Appendix B). From this evaluation, the Xsens MTw Awinda was selected (Figure 14) (Horemans & Lemus Perez, 2021). Testing the system's validity was done by a member of the Convergence Team, as it is out of this project's scope.

Figure 14. Xsens MTw Awinda

ABOUT XSENS MTW AWINDA

Hardware

The Xsens MTw Awinda is an inertial motion tracker system. Through 3D gyroscopes, 3D accelerometers, and 3D magnetometers, MTw Awinda captures complete body motion and provides real-time 3D kinematic data (Paulich et al., 2018).

MTw Awinda consists of wireless motion trackers that are placed on a participant's body with velcro straps or inserted into the Xsens shirt pockets (Figure 15) ("MTw Awinda," n.d.). Through connecting the Awinda station or USB dongle to a computer, the data from the motion trackers can be transmitted to the computer (Figure 16) (Paulich et al., 2018).

Figure 15. Xsens MTw Awinda Motion Trackers

Figure 16.. Awinda Station & USB Dongle

Since the motion trackers are wireless and the system does not require cameras to capture the participant's movement, Awinda can be used outside of a lab and is not restricted to one location.

Additional specifications of the Awinda system can be seen in Appendix C.

Software

MVN Analyze is the software used to operate MTw Awinda. By combining the StrapDown Integration (SDI) data obtained from the motion trackers with advanced biomechanical models, MVN can track the position and orientation of the patient's body segments. In doing so, MVN Analyze can collect and show data for 23 segments and 22 joints (Appendix D).

The user can view this data through an avatar mimicking the patient's motion, as well as graphs and metrics (Figure 17). (Schepers et al., 2018) Members of the Convergence Team have developed a MATLAB program to visualize the data (Figure 18).

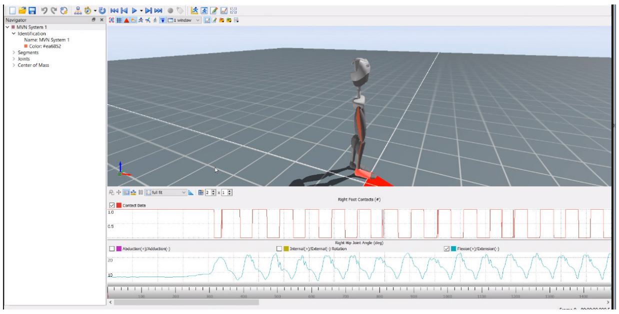


Figure 17. MVN Analyze Avatar & Data Display

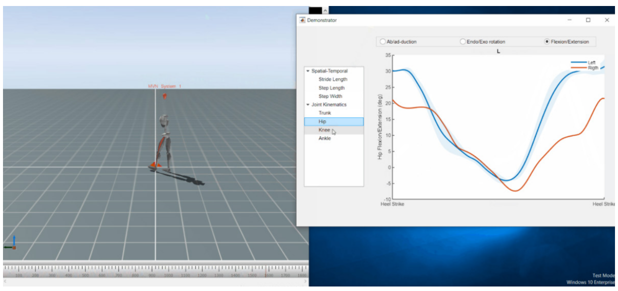


Figure 18. Data Visualization Developed by Convergence Team

The data can be viewed in real-time as well after the trial has concluded. After the trial has concluded, in addition to real-time reprocessing, the data is also processed in reprocess HD mode. Through having additional time to process the data, a more optimal and consistent assessment of the patient's position and orientation is obtained (Schepers et al., 2018). The data can also be exported to Excel, Matlab, and C-Motion ("Learn what MVN," n.d.).

Similar challenges as with laboratory gait analysis are encountered with MVN Analyze. The way the data is visualized is difficult for clinicians to understand, and the report contains irrelevant information.

Operation

The process to set up MTw Awinda was developed into an experience journey map, Figure 19 ("Xsens Tutorials," 2021).

Before MTw Awinda is used for the first time with a patient, their body measurements need to be taken. For basic motion capture, only the body height and shoe length need to be measured. Depending on how precise it is desired for the collected data to be, additional measurements such as shoulder width and elbow span are also recorded. The velcro straps and motion trackers are then placed on the patient for the desired segments one would like to receive data for ("Xsens Tutorials," n.d.).

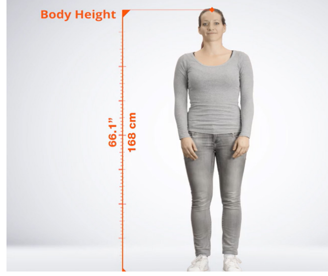
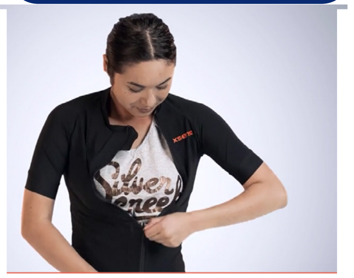
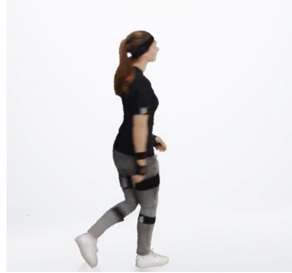
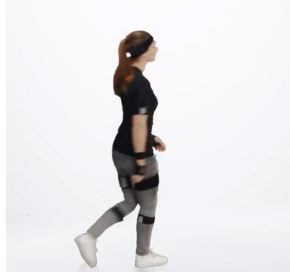
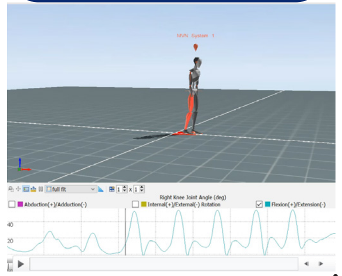
After the Awinda station is connected to a computer, the system is then calibrated. Calibration is done at the start of every session to estimate the patient's dimensions and the orientation of the motion trackers in relation to the respective segments (Schepers et al., 2018). It consists of the patient holding an N-Pose or T-pose for 4 seconds and then walking forward and backward. The participant walks for another 10 seconds to initialize the system, and then the recording can be started ("Xsens Tutorials," n.d.). After this, the testing can commence and the data can be recorded.

Challenges

There are a few steps in the set up process that prove challenging for patients with an incomplete spinal cord injury. For accurate calibration, the patient needs to be able to stand up completely straight in the N-pose. SCI patients cannot be in such a position without assistance or until the later stages of rehabilitation, if at all. In order to have patients be in the correct pose, additional actions need to be taken. This includes, but is not limited to, using walking aids or estimating the patient's knee flexion and using it to correct the data after collection.

The walking needed for calibration also poses difficulties. The patient may not be able to walk the distance needed for accurate calibration without taking breaks. Additionally, after the patient completes the walking required to calibrate the system and initialize the recording engine, they may not have the strength to complete the entire planned test.

Xsens MTw Awinda Set Up Experience Journey

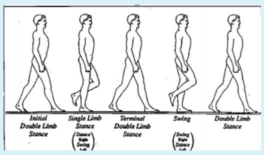
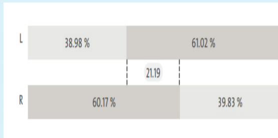
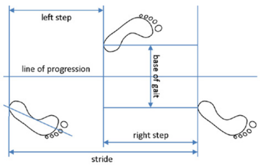
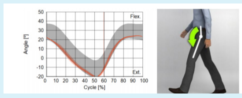
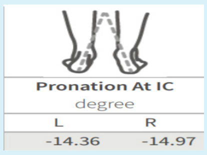
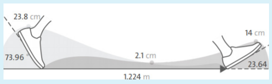
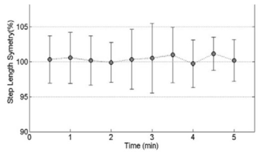
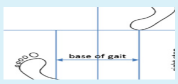
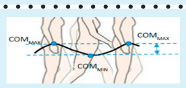
					Calibrate System			
	Take Body Measurements	Put on Straps and Shirt	Place Wireless Motion Trackers	Connect Awinda Station to Computer	Patient Stands in Upright, Neutral Position (N Pose)	Patient Walks Forward and Backwards	Patient Walks to Initialize Recording Engine	Record Patient & View Data
								
Time	3 minutes	5 minutes	5 minutes	1 minute	4 seconds	10 seconds	10 seconds	Depends on Test
Patient	Stand up straight and move as directed by Gait Lab Operator.	Put on the Xsens shirt over clothing.			Stands in N-Pose	Walks forwards and backwards	Walks forwards and backwards	Patient walks and does tasks asked by gait lab operator
Gait Lab Operator (Physiotherapist, Physician, Physiotherapy Technician)	Before first motion capture measure and record patient's body height and shoe length. For precise data also measure patient's body height, shoulder height, shoulder width, elbow span, wrist span, arm span, hip height, hip width, knee height, and ankle height.	Select setup based on what segments it is wanted to obtain data for and place straps on patient accordingly: · Minimum setup for lower extremities (upper leg, lower leg) · Minimum setup + trunk · Full setup without hands (upper arm, lower arm, hip, upper leg, lower leg) · Full setup including hands	Power on motion trackers and place them underneath straps and in the headband, shirt pockets, and patient's shoes.	Connect USB cable to Awinda Station and computer	Starts calibration on MVN Analyze	Checks system to see if distance was sufficient		Starts recording View data in real time and at the end of the trial
Challenges	Patient may not be able to straighten segments completely or stand straight up, which will effect the accuracy of the measurements. Patient's height may change when trying different orthesis.				May not be possible for the patient to be in such a position without additional assistance or until the later stages of rehabilitation, if at all. For patients who cannot stand up straight, the knee flexion can be estimated and used to correct the data. Accurately estimating knee flexion is difficult to do.	Difficult to or not possible to use if patient cannot walk without assistance. The distance cannot be too short or else there will be poor calibration results. Patient may not have strength to walk long enough to receive quality calibration results.	After doing so much walking for the calibration, the patient may not have the strength to continue.	Visualized data is difficult to understand and interpret.

GAIT PARAMETERS & FEATURES

Gait Parameters

In addition to displaying the kinematics of the patient's segments and joints, the data collected by MVN Analyze can also be used to calculate other parameters that aid in gait assessment. These include time, distance, kinematics, gait stability, and gait variation parameters (Table 1).

Table 1. Gait Parameters Measured by Xsens Awinda

Category	Parameter	Definition	Graphical Representation
Time	Single Support Time	In the stance phase, the time during which only one foot is in contact with the ground (Ayyappa, 1997)	
	Double Support Time	In the stance phase, the time during which both feet are in contact with the ground (Birch, et al., 2015)	
	Walking Speed	The distance the participant travels over a period of time. Is measured in meters per second (m/s) (Birch, et al., 2015)	
	Swing Time	For one gait cycle, "the time during which one foot is in contact with the ground." (Silva & Stergio, 2020)	
	Stance Time	For one gait cycle," the time during which the same foot is in the air." (Silva & Stergio, 2020)	
	Duration of Sub-phases	For one gait cycle, the time spent in each subphase (initial contact, loading response, mid-stance, terminal stance, pre-swing, toe-off, mid-swing, and terminal swing).	
Distance	Step Length	Measured along the line of progression, the distance between the point where the heel makes contact with the ground of one foot to the next heel contact of the other (Birch, et al., 2015).	
	Stride Length	Measured along the line of progression, the distance between the point where the heel makes contact with the ground to the next heel contact of the same foot (Birch, et al., 2015).	
Kinematics	Joint Angles	For 22 joints (Appendix D) measured for one gait cycle in terms of flexion(+)/extension(-), abduction(+)/adduction(-), and internal(+)/external(-) rotation (Horemans, 2021)	
	Prepositioning of Foot in Swing	The neutral position of the ankle in the swing phase (Horemans, 2021)	
	Foot Placement in Stance	The rotation of the foot measured in degrees (Horemans, 2021)	
	Clearance in Swing	For one gait cycle, the height of the toe in the swing phase ("Foot Clearance", n.d.)	
Gait Variation	Gait Symmetry	The difference between the left and right side for a measured parameter (such as joint angles, step length, & swing duration) (Horemans, 2021)	
	Step to Step Variation	The step to step fluctuation in the same leg/foot (Horemans, 2021)	
Gait Stability	Base of Support	Measured at 90° to the line of progression, the distance between the back of the left and right heels (Birch, et al., 2015).	
	Position Center of Mass (CoM)	The point at which the sum of forces equal zero and only linear acceleration occurs (Tesio & Rota, 2019)	

Interpretation Features

In addition to measuring and displaying the gait parameters, MVN Analyze contains additional features to aid in interpreting the results. For the time, distance, and kinematic parameters, the difference between the left and right sides can be measured (Figure 20). This is calculated by subtracting the right measurement of the parameter from the left.

Step Length (cm)		Step Width (cm)		Stride Length (cm)	
Left	53.89 ± 3.48	Left	21.36 ± 5.21	Left	87.08 ± 4.84
Right	33.65 ± 2.84	Right	20.51 ± 5.46	Right	88.63 ± 4.86
Difference	20.24 (37.56 %)	Difference	0.85 (3.97 %)	Difference	-1.55 (-1.78 %)

Figure 20. Visualization for Difference Between Left & Right Side

Measurements can also be compared against normal values for the time, distance, kinematics, gait stability, and gait variation parameters (Figures 21, 22, and 23). Normal values are the reference values for each parameter of a healthy individual ("normal values," n.d.). The same set of normal values is used for each patient, regardless of their age or type of SCI. The normal values are not used to reference what a patient should work towards to meet, but rather a way to identify which areas or parameters need the most attention.

Temporal Parameters	RIGHT LIMB	LEFT LIMB	NORMAL VALUES
Stride Time (s):	1.07 ± .01	1.07 ± .01	*1.1 ± .09*
Stance Time (s):	0.64 ± 0	0.65 ± .01	*0.65 ± .07*
Swing Time (s):	0.43 ± .01	0.42 ± .01	*0.44 ± .05*
Stance Phase (%):	59.84 ± .53	61.07 ± .53	*58.98 ± 1.97*
Swing Phase (%):	40.16 ± .53	38.93 ± .53	*40.03 ± 3.56*
Single Support Phase (%)	39.11 ± .73	39.98 ± .8	*38.87 ± 2.57*
Double Support Phase (%):	10.2 ± .47	10.3 ± .73	*10.27 ± 3.09*

Figure 21. Table Visualization for Normal Values

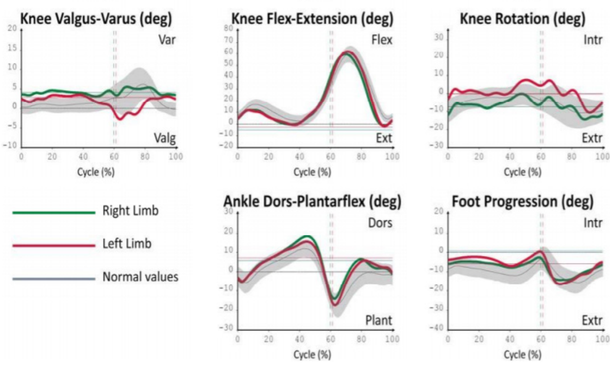


Figure 22. Graph Visualizations for Normal Values

A final feature is comparing results between physiotherapy sessions or between patients (Figure 22). MVN Analyze currently does not do this, but it has the capability to do so. The results are compared to determine the difference between sessions or between patients.

Lower Limb

<table>
<tr><th>BILATERAL</th><th>NORMATIVE</th><th>2014-05-01 12:16</th><th>CHANGE FROM 2014-04-29 10:26</th></tr>
<tr><td>Foot Clearance(cm)</td><td>2.72 – 3.92</td><td>3.90 | 3.57</td><td>↑ 2.1% | 14.7% ↑</td></tr>
<tr><td>Lateral Step Variability(cm)</td><td>1.94 – 2.94</td><td>3.38 | 3.64</td><td>↓ 18.9% | 24.7% ↓</td></tr>
<tr><td>Circumduction(cm)</td><td>2.09 – 6.53</td><td>4.17 | 3.37</td><td>↓ 23.7% | 16.7% ↓</td></tr>
<tr><td>Foot Strike Angle(°)</td><td>17.6 – 28.7</td><td>32.9 | 32.5</td><td>↑ 20.8% | 11.8% ↓</td></tr>
<tr><td>Toe Off Angle(°)</td><td>28.0 – 39.5</td><td>38.0 | 37.9</td><td>↓ 0.1% | 3.5% ↓</td></tr>
<tr><td>Stance(%GCT)</td><td>58.1 – 63.3</td><td>60.2 | 60.3</td><td>↑ 2.4% | 0.7% ↑</td></tr>
<tr><td>Step Duration(s)</td><td>0.486 – 0.730</td><td>0.559 | 0.585</td><td>↑ 5.0% | 11.5% ↑</td></tr>
<tr><td>Stride Length(m)</td><td>1.20 – 1.41</td><td>1.53 | 1.50</td><td>↓ 7.8% | 9.7% ↓</td></tr>
<tr><td>Swing(%GCT)</td><td>36.7 – 41.9</td><td>39.8 | 39.7</td><td>↓ 3.4% | 1.0% ↓</td></tr>
<tr><td>Toe Out Angle(°)</td><td>3.35 – 17.6</td><td>3.18 | 13.0</td><td>↓ 87.2% | 51.8% ↑</td></tr>
</table>

Figure 23. Comparing Between Sessions

1.3 Research for Design of User Interface

In the development of the user interface design, several factors need to be taken into account. To allow for comfortable viewing and operation, the ergonomic factors of text, sound, screen brightness, and mouse use should be incorporated. To provide a pleasant user experience, user interface design principles regarding usability, interface layout, and color must also be considered.

ERGONOMICS

Text

An important aspect of the interface design is text formatting. To allow for comfortable viewing and operation, the capital font size should be a minimal of 1/200th of the reading distance (Figure 24). The space between the line should be at least 1/30th the length of the line (Figure 25). If the lines are spaced too closely together, the user will have difficulty distinguishing the end of one line and the beginning of the next. In the same manner, justification should only be used as necessary, as excessive letter spacing between text makes it difficult to read (Dul & Weerdmeester, 2008).

	70 cm Viewing Distance	40 cm Viewing Distance
Low Luminance	5.1 - 7.6 mm	2.9 - 4.3 mm
High Luminance	3.0 - 5.1 mm	1.7 - 2.9 mm

Figure 24. Text Sizing (Morrison & Zander, 2008)

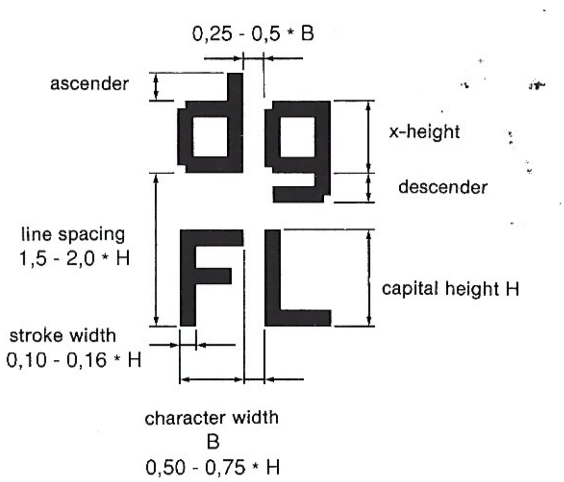


Figure 25. Character Specifications (Dul & Weerdmeester, 2008)

When having large sections of text, lower-case is preferred. Having entirely capital letters is much less legible. Additionally, to improve readability, sanserif fonts are used over serif and contrast between the text and background is needed (Figure 26) (Dul & Weerdmeester, 2008).

Figure 26. Example of Contrast

Sound

Sound is useful as a warning signal to the user, but avoid using the same sound frequently as not to irritate the user. Implement high-pitched sounds if the user is in an environment with low-itched sounds. To not harm the user's hearing, keep the noise level below 80 decibels (Dul & Weerdmeester, 2008).

Additional Formatting

To provide a pleasant user experience, the screen's brightness should not be three times larger or smaller than the brightness of the user's close surroundings.

When designing the interface menu, complex hierarchy should be avoided and the user should not have to sort through irrelevant information to find what they need. Selections are made more rapidly when a menu has seven topics or less to choose from.

Finally, alternate between the user using a mouse and the keyboard or a touch screen. Frequent mouse use can cause strain on muscles and tendons in the hands and wrists (Dul & Weerdmeester, 2008).

USER INTERFACE DESIGN

Usability

In "Don't Make Me Think," Steve Krug defines usability as "a person of average (or even below average) ability and experience can figure out how to use the thing to accomplish something without it being more trouble than it is worth." This is a key aspect of user interface design.

A part of usability is that the operation of each screen should be self-evident. If the average user was to look at it, they should know what it is and how to use it. To aid in understanding and usability of the interface, conventions should be used. For example, typically the primary navigation is located across the top of the screen or down the left side. If conventions are not used, then it should be replaced with a clear concept that the user can understand with minimal to no explanation or with the new change that has enough added value the user will not mind a slight learning curve (Krug, 2014).

To aid in the intuitive operation of an interface, affordances should be implemented. Affordances are "visual clues in an object's design that suggest how we can use it." For example, having buttons be in a three-dimensional style indicates they should be clicked (Figure 27) (Krug, 2014).

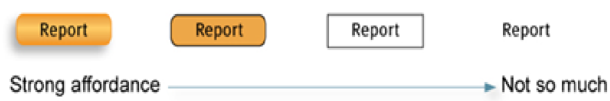


Figure 27. Affordance of Buttons

Furthermore, the interface design should be more geared towards intermediates, as most users will in time fall into this category. In making the operation self-evident, users who are beginners should be able to reach intermediacy rapidly. Intermediates who want to become expert should be able to do so; however, it is most important to keep intermediate users satisfied (Cooper et al., 2014)

Layout

When designing the layout, there needs to be a balance between having so much negative space that there is no flow between elements and not enough such that it feels crowded. Attention also needs to be taken to the hierarchy ("What is User," n.d.). Effective Visual Hierarchy can be done through alignment, text size, color, spacing, and/or positioning (Krug, 2014) (Figure 28).

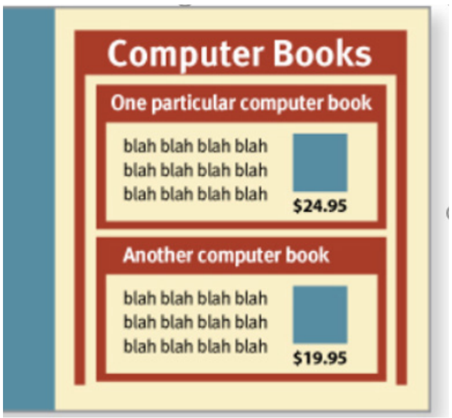


Figure 28. Example of Visual Hierarchy

To allow for ease of use, the style should be consistent throughout the interface (Dai, 2018). The layout should follow a logical flow (Figure 29) (Cooper et al., 2014). There should also be an indication to users where they are with respect to the whole interface. This can be done by highlight their current location in the navigation bar, list, or menu (Krug, 2014) (Figure 30).

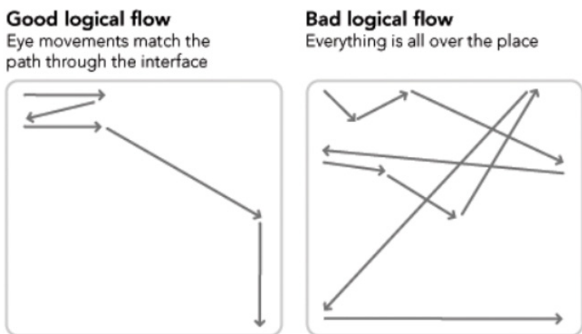


Figure 29. Layout Flow

Figure 30. Ways to Indicate Location in Interface

To further aid in usability, the user should only focus on one primary function per page ("What is User," n.d.). With this also comes formatting the interface to support scanning. This can be done through use headers, keeping paragraphs short, using bulleted items when possible, and highlighting key terms (Cooper et al., 2014).

Color

Bright colors should be used as an accent to draw the user's attention, but not in large areas. When using text on images, add a color overlap to aid in readability (Figure 31) (Barry, 2021).

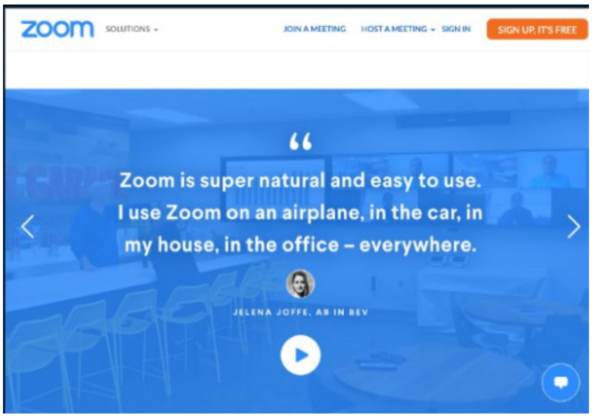


Figure 31. Color Overlap

To allow for the interface to be accessible by all, check the contrast between the text and the background as well as the font sizing (Figures 32 and 33) (Barry, 2021). Having a high contrast ratio makes the interface easier to use for the visually impaired and color-blind ("Contrast Checker," n.d.). Additionally, without contrast between colors and display, the user can feel overwhelmed (Dai, 2018).

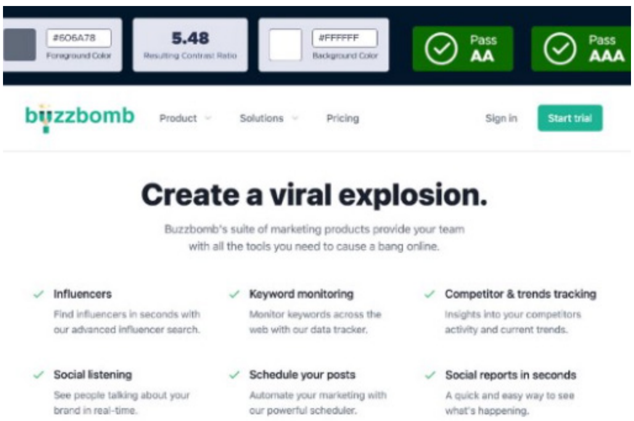


Figure 32. Website with High Contrast

Figure 33. Examples of Low (Top) & High (Bottom) Contrast

Additional principles for user interface design can be found in Appendix E..

Chapter 2
User Research

2.1 Convergence Project Survey

In November 2020, the Convergence Project Team conducted a survey to gain a better understanding of clinicians' current experience with gait assessment, what they look for in gait training, and what features they would like to be included in technological aids used for gait training. After the designer analysed the results, it was concluded that additional user research would need to be conducted. There were still numerous unanswered questions regarding clinicians' current gait assessment process and their wants and needs for the future user interface.

In November 2020, members of the Convergence Project Team sent a Google Forms survey to physicians and physiotherapists within the Nederlands Vlaams Dwarslaesie Genootschap (NVDG) and Shirley Ryan Ability Lab (SRAL). The purpose of the survey was to better understand the clinicians' current experience with gait assessment and gait training. The survey was also meant to help gauge what the clinicians think is important when assessing gait and using technological aids in gait training.

METHOD

Participants

The survey was sent to physiotherapists and physicians within the Nederlands Vlaams Dwarslaesie Genootschap (NVDG) and Shirley Ryan Ability Lab (SRAL) who had experience with treating people with incomplete spinal cord injuries. There was a total of 36 participants, 12 physicians and 24 physiotherapists

Procedure

Participants were sent a survey via email using Google Forms. The survey contained a mix of multiple choice and free response questions that covered the topics of gait assessment, gait training, and technological aids used for gait training.

Data Analysis

The data was collected, processed, and analyzed by the Convergence Team. It was later interpreted by the designer.

RESULTS & INTERPRETATION

Only the questions regarding gait assessment were evaluated by the designer, as gait training and technological aids for gait training are outside the project's scope.

To evaluate what gait parameters clinicians need in gait assessment, participants were asked to rate twenty-five gait parameters in terms of great need, some need, or no need. It was not possible to determine what parameters should be included in the user interface as participants had a need for all parameters, except for single/double support time (Figure 34).

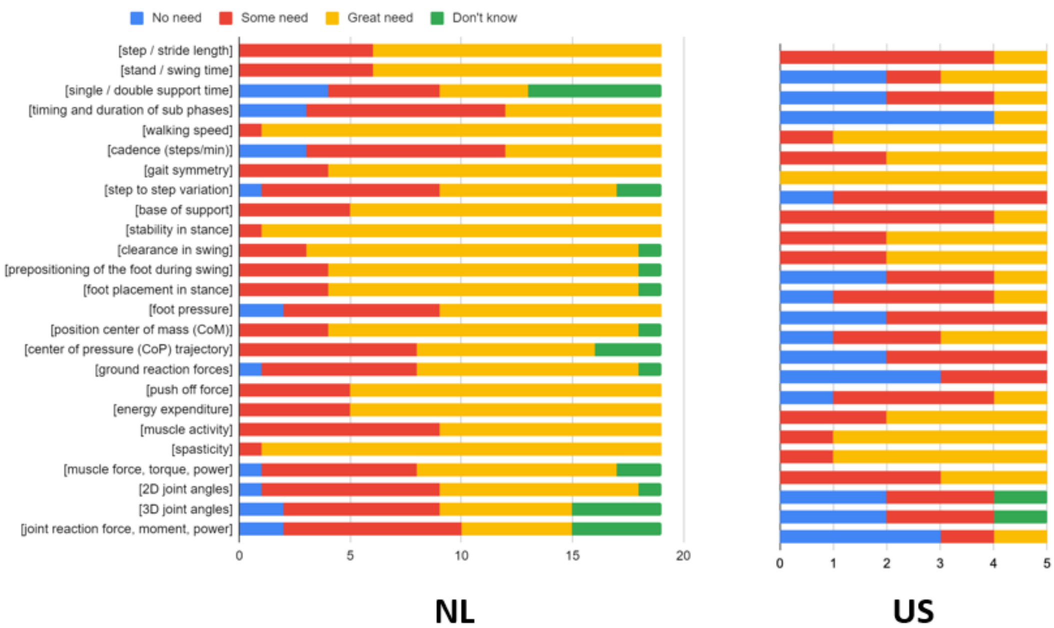


Figure 34. Gait Parameters Evaluated by Need

In assessing walking ability, participants found the elements featured in Figure 35 to be the most desirable. The most desired elements were to able to measure the data quickly and easily and to be able to display results clearly and interactively for the therapist or physician and for the patient.

The top features participants wanted to be included in the user interface were that it should be safe for both the patient and clinician and be user-friendly for the clinician (Figure 36).

Potential pitfalls of the current gait assessment that should be avoided include not being able to interpret the outcomes easily, the report containing too much data that is not fully utilized, and the assessment method not being quicker or better than the clinical eye. In addition, it was brought up that the user interface also needs to adapt to the insufficient knowledge of clinicians on gait analysis and to clinicians' lack of time.

In the survey, it was expressed by participants numerous times that the user interface should not only be able to be used by clinicians but by patients as well.

UNANSWERED QUESTIONS

While the survey provided valuable information regarding clinicians' wants and needs in gait assessment, there were still questions that needed to be answered regarding how clinicians currently assess gait and what they would like to be included in the user interface. (Figures 37). In order to answer these questions, additional user research was required. Additional user research was also needed to gain additional clarity on the questions asked in the survey. With many participants being confused by the wording of the questions and terminology included, the validity of the results was put into question.

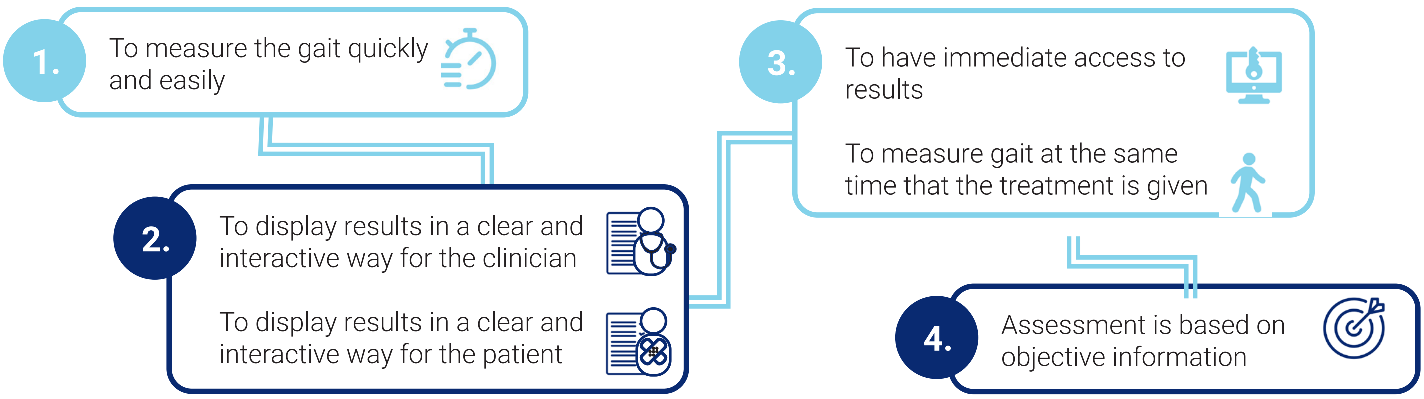


Figure 35. Desired features in assessing walking ability

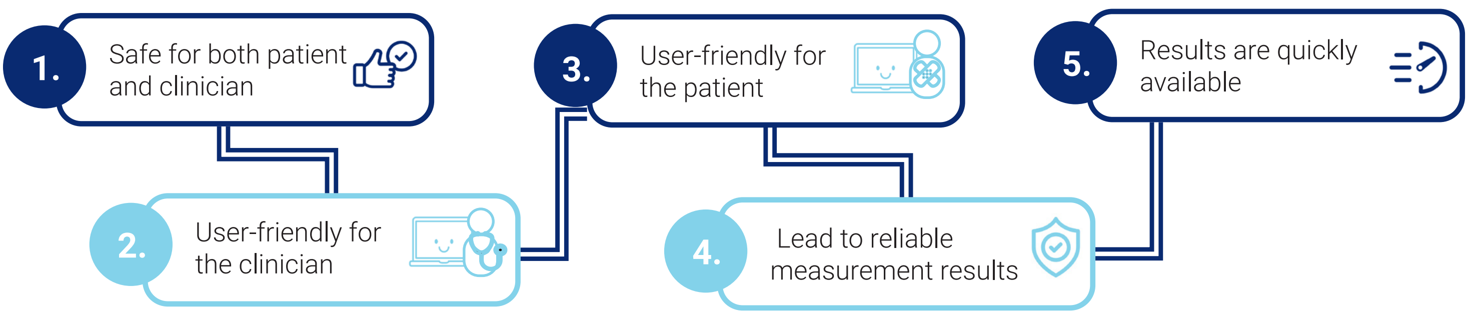


Figure 36. Features wanted to be included in user interface

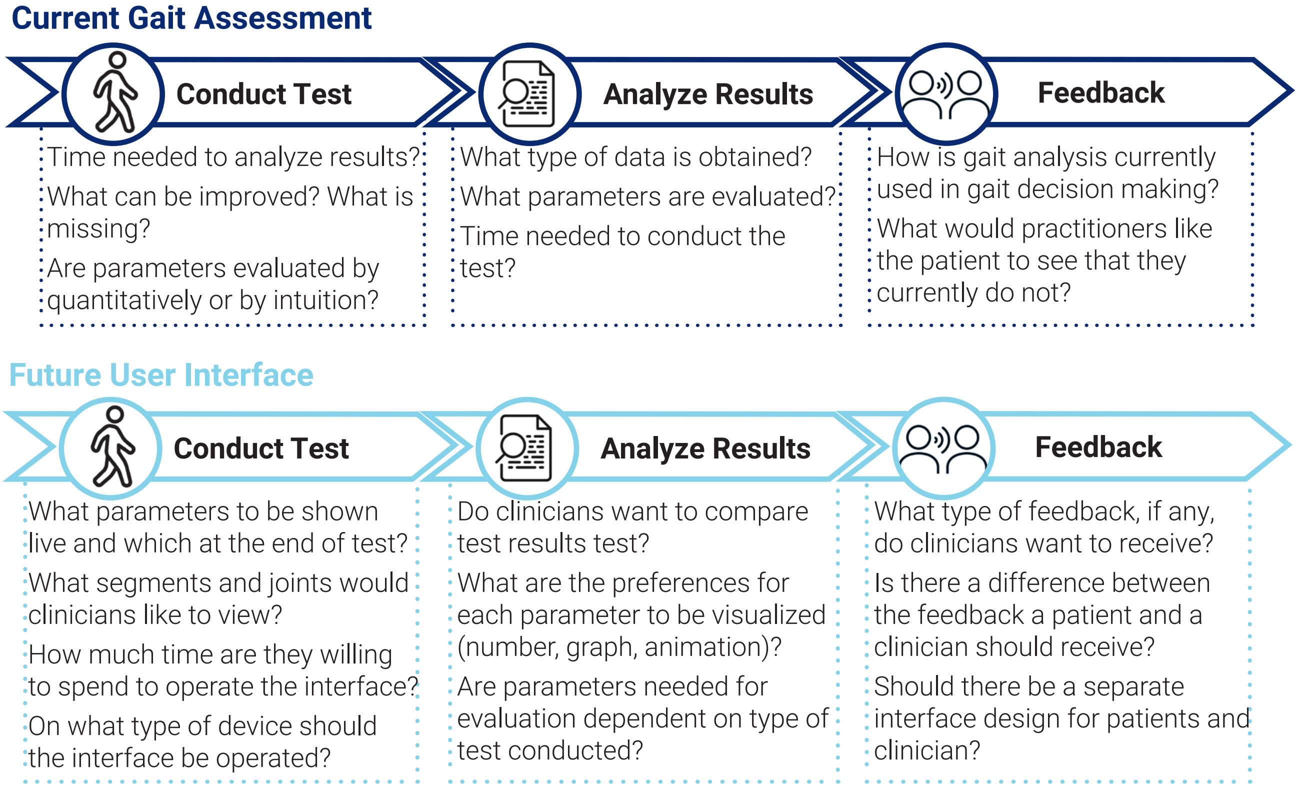


Figure 37. Unanswered Questions from Convergence Project Survey

2.2 Research Questions

Research questions were developed to examine how physiotherapists and physicians currently assess gait, what features and parameters should be present in the user interface, how the parameters should be visualized, and what journey incomplete spinal cord injury patients undergo in rehabilitation.

Research Question 1 - Current Gait Assessment Method

How and why is gait assessment currently conducted? What can be improved and what built upon?

1.1. How do physicians and physiotherapists currently assess gait, and what populations do they work with to assess gait?

1.2. What is the purpose of assessing gait?

1.3. In a gait assessment, what parameters are evaluated?

1.4. How can current gait assessment methods be improved?

1.5. What do physicians and physiotherapists like and dislike about how parameters are visualized in current gait analyses?

Research Question 2 - Development of User Interface

In the design of an intuitive gait analysis user interface for physicians and physiotherapists with limited experience with gait analysis, what parameters and features should be present? How should the parameters be visualized such that they can be easily understood and interpreted by clinicians?

2.1. What parameters do physicians and physiotherapists want in the user interface, and how do they want them visualized?

2.2. Do practitioners want information reported for the upper body in addition to the lower body? If so, for what segments?

2.3. What interpretation features do physicians and physiotherapists want to be included in the user interface, and how do they want them visualized?

2.4. On what type of device would physicians and physiotherapists prefer to operate the user interface?

2.5. What added benefit does the user interface need to have in order for physicians and physiotherapists to adapt it and use it over their current gait assessment method?

Research Question 3 - Gait Rehabilitation Work Flow

What currently occurs in gait rehabilitation for patients with incomplete spinal cord injuries?

3.1. In gait rehabilitation for patients with incomplete spinal cord injuries, what activities are done and who is involved?

3.2. What are the challenges and frustrations that those involved experience throughout this process?

3.3. What are the emotions of the patient, physician, and physiotherapist throughout this process?

2.3 Methods

Eighteen physiotherapists and physicians participated in the user research. This consisted of completing a questionnaire on their current experience with gait assessment and participating in a focus group session on what they would like to be in the user interface. Four clinicians were also interviewed to learn more about the process a patient with incomplete SCI goes through in gait rehabilitation.

An application was submitted to the TU Delft Human Research Ethics Committee for the questionnaire and focus groups. The application was approved, allowing the information collected to be featured in published works (Appendix F).

QUESTIONNAIRE ON CURRENT EXPERIENCE WITH GAIT ASSESSMENT

It was not possible to discuss both clinicians' current experience with gait assessment and what they would like implemented into the user interface in just a one-hour interview. Since discussing their current experience did not require any additional explanation or clarification from the designer, it was decided to obtain this information via a questionnaire with free-response questions.

The purpose of the questionnaire was to understand how physicians and physiotherapists assess gait and what they are trying to accomplish by doing so. The questionnaire was also developed to find unmet desires of their current method. The user interface will bring added value to the system through meeting these unmet desires.

Research Questions

1. How and why is gait assessment currently conducted? What can be improved and what built upon?

    1.1. How do physicians and physiotherapists currently assess gait, and what populations do they work with to assess gait?

    1.2. What is the purpose of assessing gait?

    1.3. In a gait assessment, what parameters are evaluated?

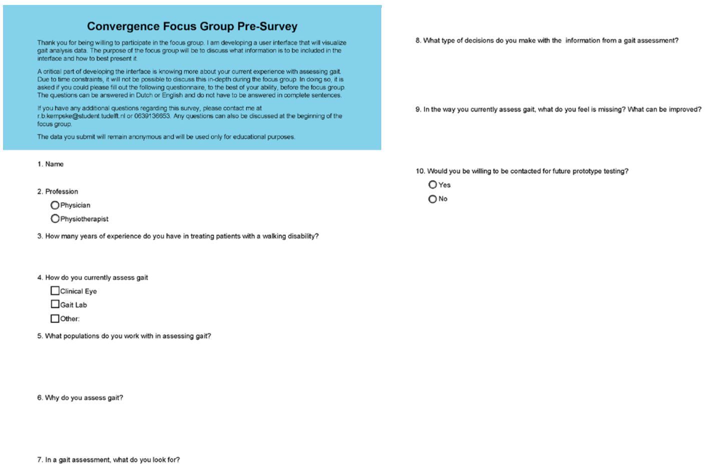
    1.4. How can current gait assessment methods be improved?

Participants

Physiotherapists and physicians who treat patients with spinal cord injuries and work for Rijndam Revalidatie Westersingel or Erasmus University Medical MC were recruited to participate. There was a total of 18 participants, 12 physiotherapists and 6 physicians

Procedures

A member of the Convergence Project first contacted the participants to confirm their interest in participating in the project. They were then contacted by email by the designer. In the email, the purpose of the project and questionnaire were explained. The questionnaire contained questions regarding their current experience with gait assessment and took about 10 minutes to complete (Figure 38) (Appendix G). Participants were asked to fill out the survey and send it back to the designer before attending the focus group. For data security purposes, the survey was a fillable Adobe Acrobat pdf.



Convergence Focus Group Pre-Survey

Thank you for being willing to participate in the focus group. I am developing a user interface that will visualize gait analysis data. The purpose of the focus group will be to discuss what information is to be included in the interface and how to best present it.

A critical part of developing the interface is knowing more about your current experience with assessing gait. Due to time constraints, it will not be possible to discuss this in-depth during the focus group. In doing so, it is asked if you could please fill out the following questionnaire, to the best of your ability, before the focus group. The questions can be answered in Dutch or English and do not have to be answered in complete sentences.

If you have any additional questions regarding this survey, please contact me at r.b.kempske@student.tudelft.nl or 0639136653. Any questions can also be discussed at the beginning of the focus group.

The data you submit will remain anonymous and will be used only for educational purposes.

1. Name

2. Profession
   - Physician
   - Physiotherapist

3. How many years of experience do you have in treating patients with a walking disability?

4. How do you currently assess gait
   - Clinical Eye
   - Gait Lab
   - Other:

5. What populations do you work with in assessing gait?

6. Why do you assess gait?

7. In a gait assessment, what do you look for?

8. What type of decisions do you make with the information from a gait assessment?

9. In the way you currently assess gait, what do you feel is missing? What can be improved?

10. Would you be willing to be contacted for future prototype testing?
    - Yes
    - No

Figure 38. Questionnaire on current experience with gait assessment

The email also contained a Participant Information Letter. This letter informed participants about how their data will be stored and additional information regarding the purpose of the questionnaire and focus group (Appendix H). Participants were also asked to fill out a Consent Form and email it back to the designer along with their survey (Appendix I).

Data Analysis

Quantitative answers were collected and analyzed using Excel. Qualitative answers for each question were collected and categorized using the Affinity Diagram method (Figure 39). In this method ideas are clustered into similar groups and themes. These groups are then broken down to smaller groups to evaluate the relationship between the ideas.

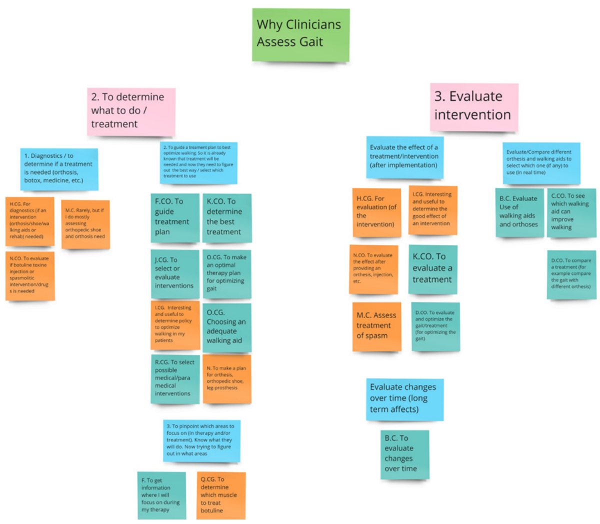


Figure 39. Affinity Diagram Example

FOCUS GROUP SESSIONS

With the Convergence Project survey, there was confusion with how some of the questions were worded and with the terminology used, as most participants had no to limited experience with technical gait analysis. To avoid this confusion, it was decided to talk with the participants. A focus group format was selected, as it allowed participants to talk through questions with each other.

Research Questions

1. How and why is gait assessment currently conducted? What can be improved and what built upon?

    1.5. What do physicians and physiotherapists like and dislike about how parameters are visualized in current gait analyses?

2.In the design of an intuitive gait analysis user interface for physicians and physiotherapists with limited experience with gait analysis, what parameters and features should be present? How should the parameters be visualized such that they can be easily understood and interpreted by clinicians?

    2.1. What parameters do physicians and physiotherapists want in the user interface, and how do they want them visualized?

    2.2. Do practitioners want information reported for the upper body in addition to the lower body? If so, for what segments?

    2.3. What interpretation features do physicians and physiotherapists want to be included in the user interface, and how do they want them visualized?

    2.4. On what type of device would physicians and physiotherapists prefer to operate the user interface?

    2.5. What added benefit does the user interface need to have in order for physicians and physiotherapists to adapt it and use it over their current gait assessment method?

Participants

All participants who took part in the survey also participated in the focus groups. In doing so, there were 12 physiotherapists and 6 physicians.

Procedure

Information regarding the focus group was sent to participants in the same email as the survey. If participants wanted to know more about the Xsens MTw Awinda system before the focus group, they could watch a brief video, which was within the email.

The focus groups ranged in size to fit participants' schedules. Groups were formed based on work location (Erasmus MC or Westersingel) and occupation (physician or physiotherapist). Almost all focus groups of two or more participants were conducted in person, with individual interviews conducted over Zoom (Figure 40). The interviews and focus groups were conducted over two weeks.

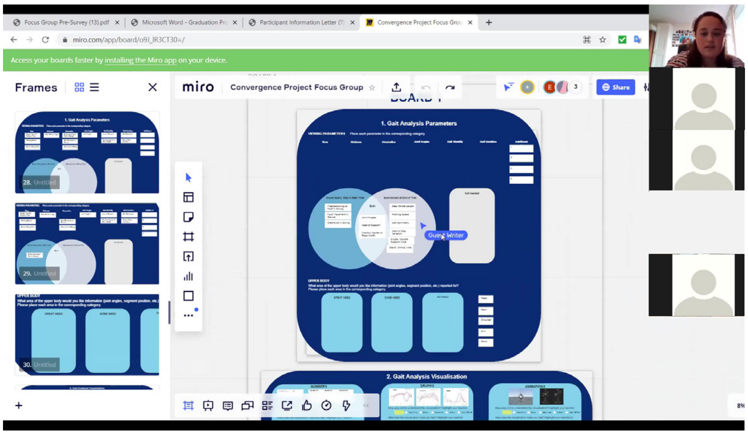


Figure 40. Zoom Session

All sessions lasted one hour. At the beginning of each session, a short presentation explained the project's purpose and session. The presentation also explained what Xsens MTw Awinda was and how it would be incorporated into the project.

The participants then completed a series of interactive activities on a Miro Board (Figure 41). Each participant was assigned their own board. To retain anonymity, the boards were labelled with letters rather than the participants' names.

The board was broken down into three sections: selecting gait analysis parameters, selecting how they would like these parameters visualized, and additional features they would like included in the user interface. Each activity was first explained, and then after the participants completed it, there was a discussion on why the participants formed those answers.

The activity board format was selected as it facilitated group discussion but still allowed for answers to be collected from every participant. Making the focus group interactive rather than just questions also made the session more engaging and enjoyable. Miro was chosen rather than the alternative of a paper activity because with the sessions being conducted over Zoom and in person, it allowed all participants to conduct the same activity and have the same experience. Additionally, with participants working from home and in different office locations, it would be difficult and time-consuming to distribute a paper activity and then collect it. Miro also allowed the designer to look at the participants' answers in real time and ask questions about their answers.

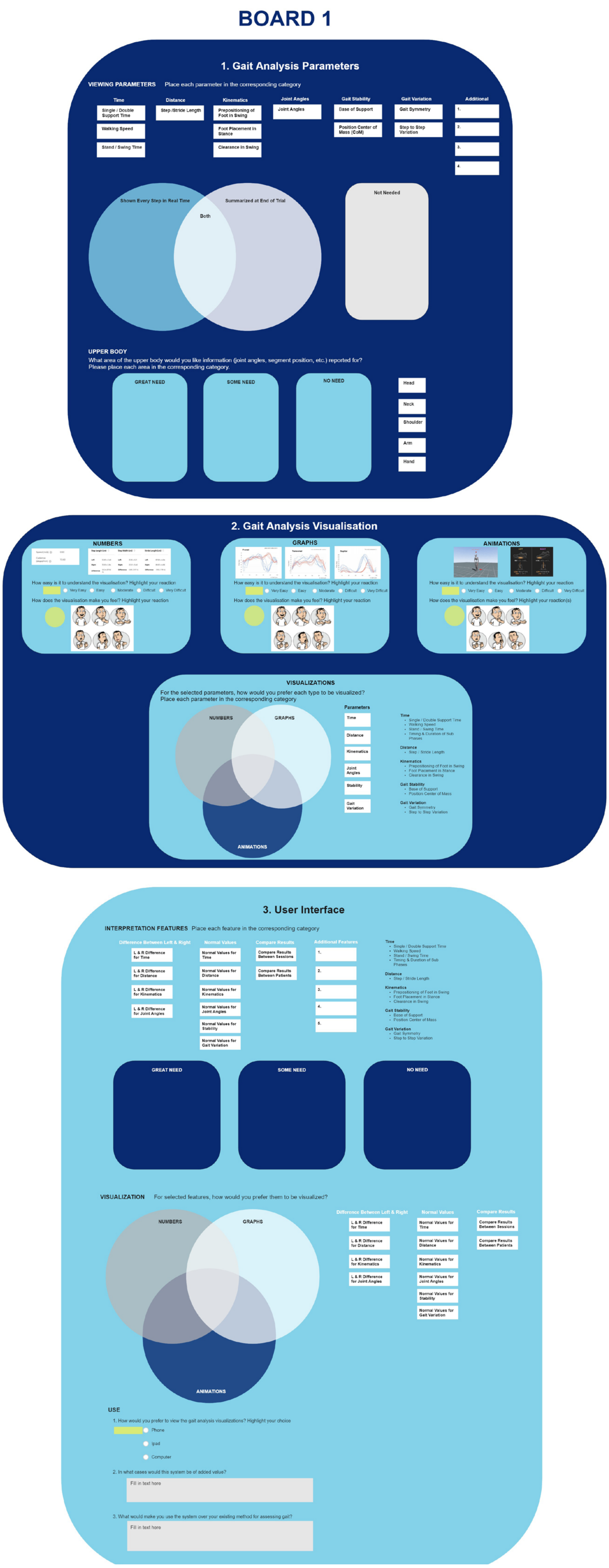


Figure 41. Activity Board

Data Analysis

During each session, notes were taken. The audio of each session was recorded and transcribed. All board answers were recorded in Excel. Quantitative questions were evaluated using Excel. Answers for qualitative questions were organized and clustered using the Affinity Diagram Method.

GAIT REHABILITATION WORK FLOW

The questionnaire and focus group sessions focused on gait assessment. However, there was still information missing regarding the overall process a patient with incomplete spinal cord injuries goes through in gait rehabilitation.

Research Questions

3. What currently occurs in gait rehabilitation for patients with incomplete spinal cord injuries?

    3.1. In gait rehabilitation for patients with incomplete spinal cord injuries, what activities are done and who is involved?

    3.2. What are the challenges and frustrations that those involved experience throughout this process?

    3.3. What are the emotions of the patient, physician, and physiotherapist throughout this process?

Participants

Two physiotherapists and one physician who specialized in spinal cord injuries were interviewed. The coordinator of Klinisch Bewegingslab was also interviewed as he currently conducts all of the laboratory gait analyses. They all previously participated in the questionnaire and focus group sessions.

Procedures

Individual interviews were conducted over Zoom and lasted for 30 to 45 minutes. The questions asked differed per participant but were all regarding their roles in the gait rehabilitation of incomplete spinal cord injuries and whom they interacted with throughout this process. The specific questions asked can be seen in Appendix J.

The focus of the interview was on incomplete spinal cord injuries rather than complete SCI as the user interface will be used for incomplete SCI patients.

Data Analysis

Notes were taken during the interviews.

2.4 Results & Interpretations

From the questionnaire, it was found how the participants currently assess gait, what type of patients they work with in assessing gait, and what parameters they evaluate. In the focus groups, the participants expressed what parameters and features they would like in the future user interface and how they want them to be visualized. With the information from the gait rehabilitation interviews, an experience journey was created for gait rehabilitation of an incomplete spinal cord injury patient. Using all of this information, a stakeholder analysis was conducted.

QUESTIONNAIRE ON CURRENT EXPERIENCE WITH GAIT ASSESSMENT

The raw data and Affinity Diagrams can be seen in Appendices K and L.

RQ 1.1 How do physicians and physiotherapists currently assess gait and what populations do they work with to assess gait?

All 18 participants used clinical eye to assess gait. Eight participants also used laboratory gait analysis. It was more common for physicians than physiotherapists to use this method (Figure 42). Eight participants (44%) also used an additional method to assess clinical eye. This included recording the patient walking with a camera and watching the video back in slow motion, using the C-Mill and Zero-G, physical examination, and walking tests. Video recording was the most popular.

The most common type of patient the participants work with in assessing gait is neurological disorders (Figure 43). This includes multiple sclerosis (MS), cerebral palsy (CP), stroke, and traumatic brain injuries. Ten participants work with patients with spinal cord injuries. Physicians and clinicians who use laboratory gait analysis tend to work more with neurological disorders than any other type of patient.

Since most clinicians interviewed deal with patients other than SCI and the gait assessment process is similar for all disorders, the user interface could not only be limited to SCI patients, but also be used for amputees and patients with neurological disorders.

RQ 1.2 What is the purpose of assessing gait?

The most common reason why clinicians assess gait is to aid in selecting treatment for the patient. In doing so, they use gait assessments to determine if treatment is needed, guide the treatment plan to optimize walking, and pinpoint what area to focus on in treatment and physiotherapy. Additional purposes are to help patients improve their waking, determine the underlying problems in the patient's gait, and evaluate interventions

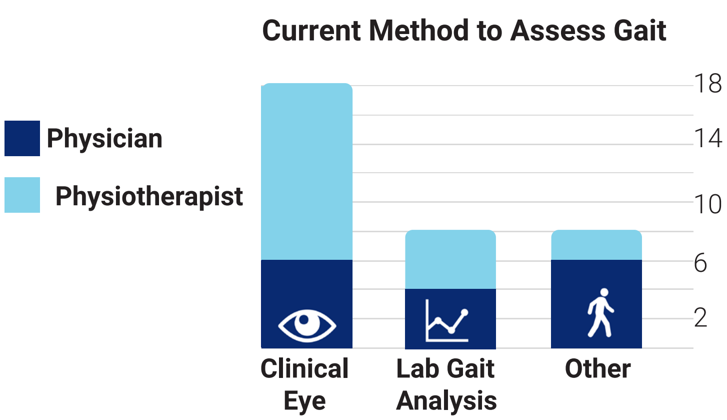


Figure 42. Results for Current Methods to Assess Gait

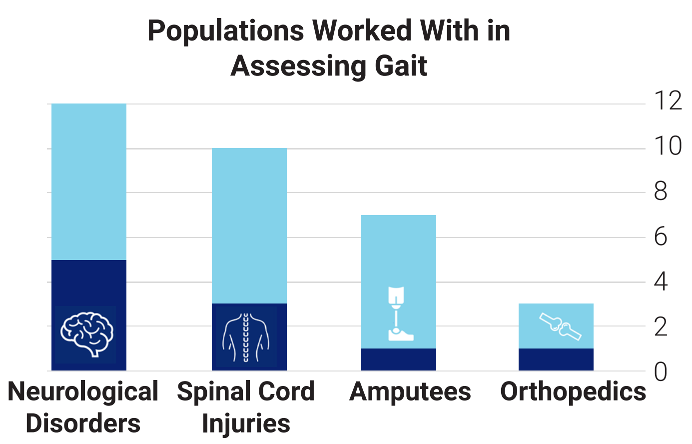


Figure 43. Results for Populations Participants Work With

(Figure 44). Physicians primarily use gait assessment to select treatment and evaluate interventions.

Similarly, when asked "*What type of decisions do you make with the information from a gait assessment*," a majority of participants answered that they use the information to further hone in on treatment and select specific types of treatments (Figure 45). Physiotherapists use gait assessment when developing their physiotherapy sessions to determine what areas of the body to focus on and what exercises to do. Physiotherapists and physicians also commonly use gait assessment to determine if a patient needs an orthosis to improve walking ability and if so, what type. .

RQ 1.3 In gait assessment, what parameters are evaluated?

When assessing gait, participants evaluate kinematic, time, distance, gait variation, and gait stability parameters (Figure 46). Kinematics is evaluated most often, with joint angles being the most popular parameter. As physicians do not assess gait as frequently as physiotherapists, they struggled to answer this question. Answers were either left blank or including very broad parameter categories.

RQ 1.4 How can current gait assessment methods be improved?

The clinical eye can be improved by allowing clinicians to obtain detailed kinematic measurements and measure the patient's energy consumption. Additional improvements include being able to compare interventions and providing visual feedback to patients.

Laboratory gait analysis can be improved by making it easier to use and access. The data should also be presented in a more intuitive manner, and it should not take as long to receive the test report. An added benefit of the gait analysis would be to have the option to conduct tests in different settings.

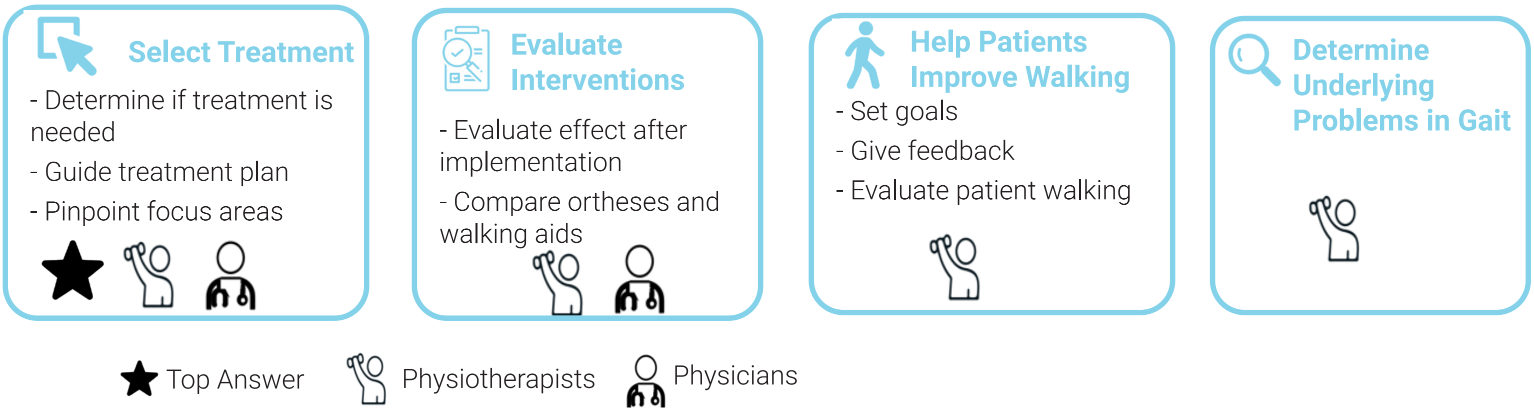


Figure 44. Purpose of Assessing Gait

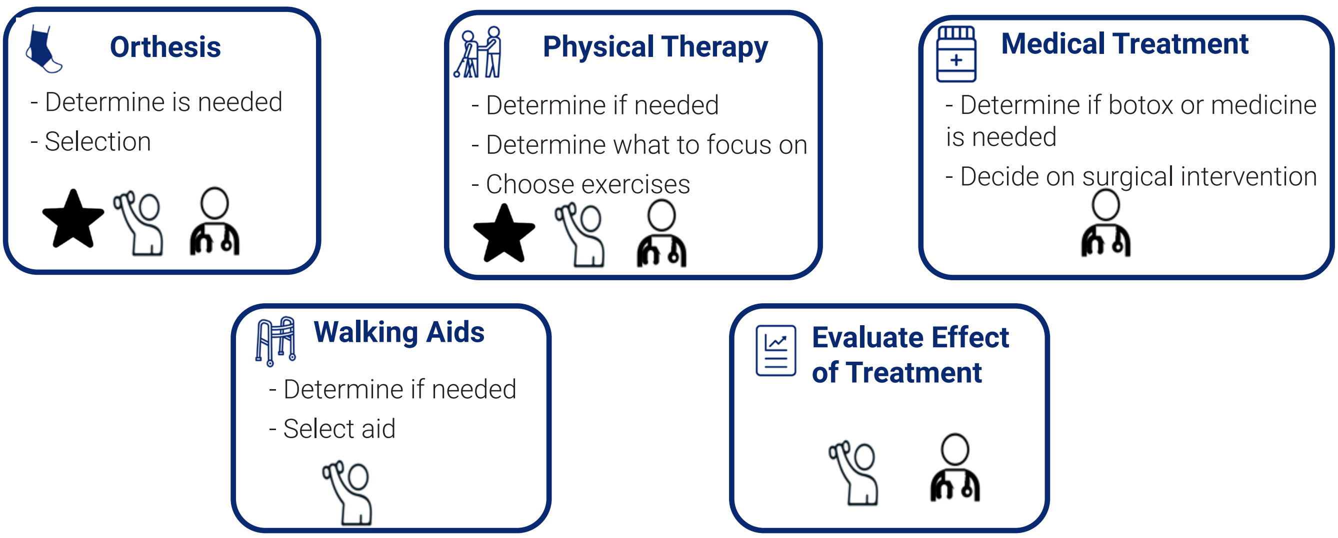


Figure 45. Decisions Made with Gait Assessment Information

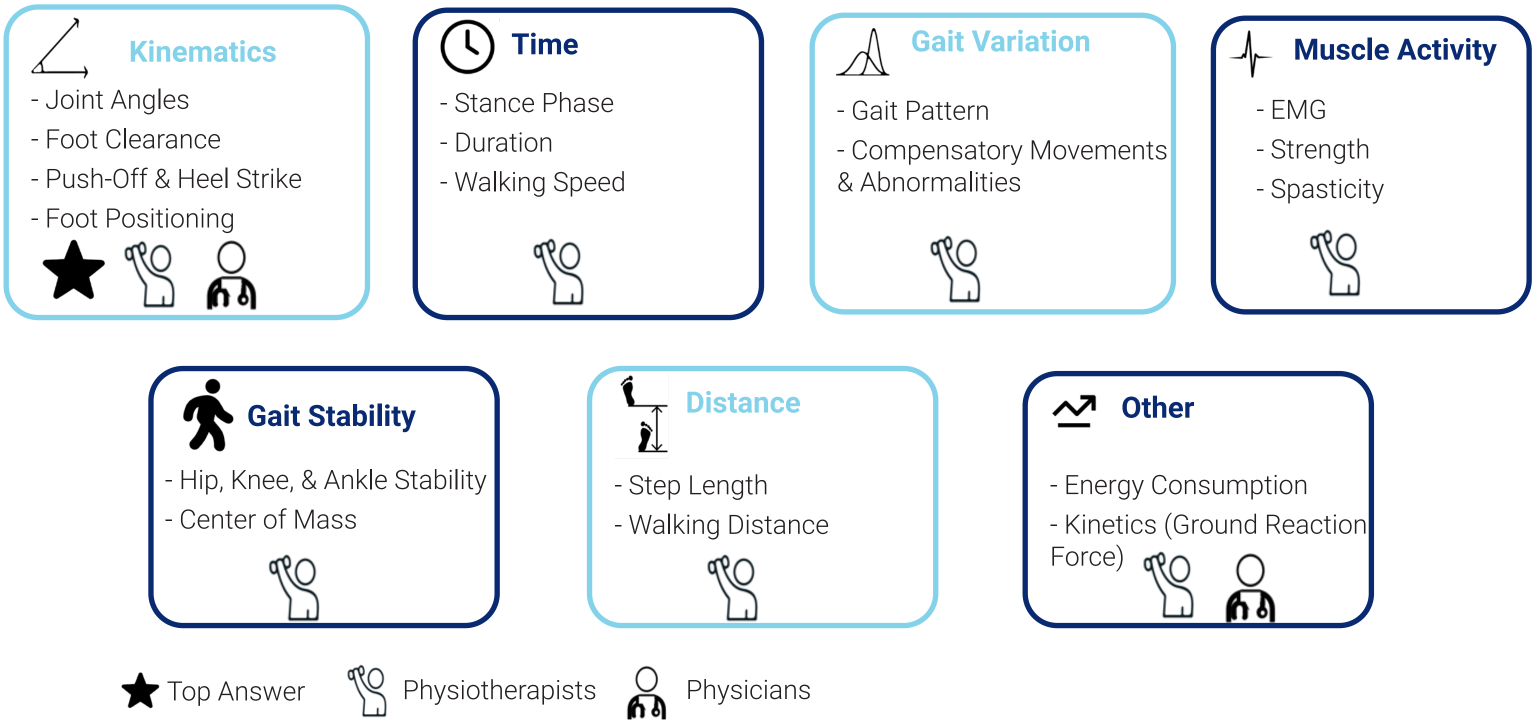


Figure 46. Parameters Evaluated in Current Gait Assessment

FOCUS GROUP SESSIONS

The data and Affinity Diagrams can be found in Appendix M and N respectively .

RQ 1.5. What do physicians and physiotherapists like and dislike about the way parameters are visualized in current gait analyses?

When given examples of how numbers, graphs, and animations are currently visualized, participants found graphs the most difficult to understand (Figure 46). Participants knew in general what the purpose of the graphs are, but at first glance were not sure of their meaning. It, therefore, took them extra time and energy to interpret the results. To improve the ease of interpretation, it was suggested to include a legend, add a normal line, include less information, or label which parts of the graph are in the stance and swing phases.

While most participants were put off and scared by the graphs, some were interested and wanted to know more. Some participants favored graphs as they can take one look at a graph and get an overview of what occurred.

> *"For me, one look at a graph gives me quicker information than all the numbers."*

Animations were found to be the easiest to understand and participants felt happy when looking at them. Animations allow participants to get an overall impression right away. In addition, animations are easier for patients to understand.

> *"For animations, for patients it is definitely the most easy way. Graphs and numbers take more expertise."*

An improvement that could be made to the existing avatar would be to make the avatar's color and surroundings more contrasting. Currently, the avatar, ground, and surroundings are grey, making it difficult to view the avatar's motions.

In terms of understanding and satisfaction, numbers fall in the middle. Participants rated

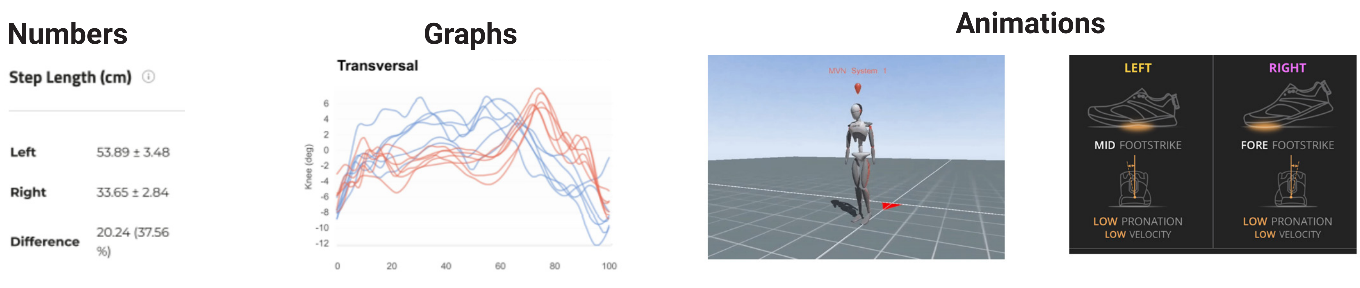


Figure 46. Examples of number, graph, and animation visualizations shown to participants

the number visualizations as moderate to easy to understand. While they do not fully understand them, they are still interested to learn more. With numbers, it is difficult to see how the parameters progressed, but it is easier to see the difference between left and right.

In rating how participants felt when looking at the visualizations, the emotions were more consistent for physiotherapists, but for physicians, there was a mix of positive and negative emotions.

RQ 2.1 What parameters do physicians and physiotherapists want in the user interface and how do they want them visualized?

Parameter Selection

Participants were asked to categorize the twelve parameters defined in Section 1.2 by if they wanted to view them in real time, at the end of trial, both in real time and at the end of trial, or not at all. For seven out of twelve parameters, the majority of participants wanted to view them both in real time and at the end of the trial (Figure 47). Participants wanted to view the time and gait variation parameters only at the end of the trial. Trunk rotation was not on the list but was suggested by participants.

The majority of participants did not select any parameters of not needing to be viewed. However, the parameters of stand/swing time and single/double support time were selected by most as not being needed. In the group discussion, it was mentioned numerous times that since stand/swing and single/double support time are similar, only one or the other needs to be included in the interface. Additionally, in comparing physicians' and physiotherapists' answers, there was no clear correlation between profession and parameter selection.

Visualization

The visualizations for each parameter category were analyzed such that the simplest combination of visualizations was selected that would satisfy at least half of the participants.

As seen in Table 2, except for time and distance, participants wanted all other parameters to be visualized as animations and numbers or graphs. Animations allow the physiotherapists and physicians to have a quick summary of the gait assessment, with numbers and graphs being used for a more in-depth analysis. It was not desired only to have animations, as participants wanted to see the reasoning behind the animation. Numbers and graphs were also selected to allow for a more objective analysis. In selecting visualizations, there was not much difference between physiotherapists and physicians.

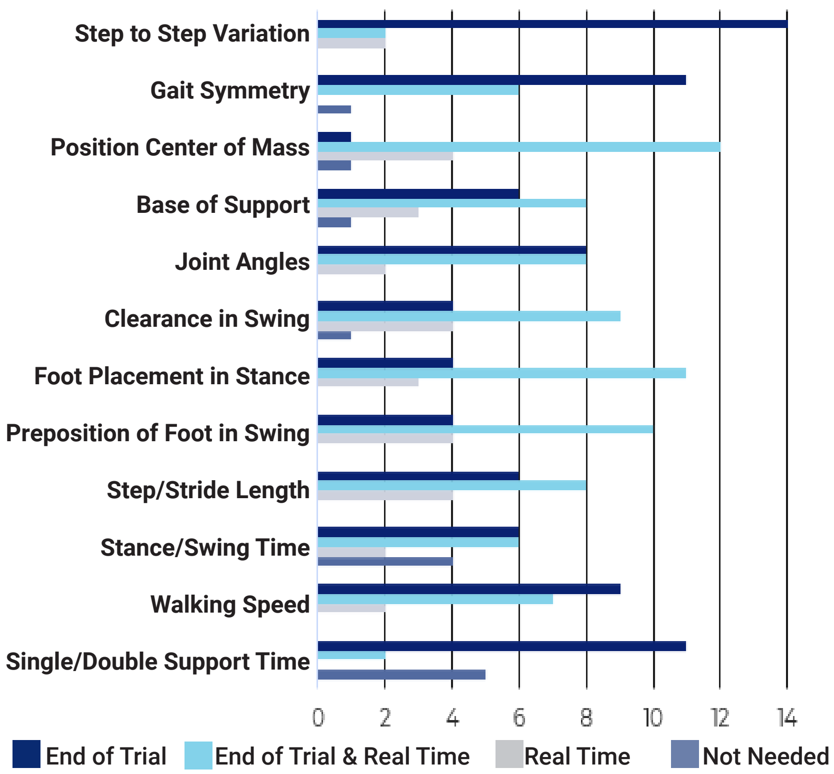


Figure 47. Results for how participants want to view parameters

Table 2. Parameter Visualizations & Viewing

Parameter	Visualization	Viewing
Time: Single/Double Support Time, Walking Speed, Stance/Swing Time	Numbers	End of Trial
Distance: Step/ Stride Length	Numbers & Graphs	Real Time & End of Trial
Kinematics: Prepositioning of Foot in Swing, Foot Placement in Stance, Clearance in Swing	Graphs & Animations	Real Time & End of Trial
Joint Angles	Numbers, Graphs, & Animations	Real Time & End of Trial
Gait Stability: Base of Support, Position Center of Mass	Graphs & Animations	Real Time & End of Trial
Gait Variation: Gait Symmetry, Step to Step Variation	Numbers & Animations	End of Trial

RQ 2.2. Do practitioners want information reported for the upper body in addition to the lower body? If so, for what segments?

The twelve parameters previously mentioned primarily deal with the lower half of the body. In doing so, it was of interest if the physiotherapists and physicians would also like information, such as joint angles and segment positioning, reported for any areas of the upper body (hand, arm, shoulder, neck, and head). There was the most need to view the arms and shoulders, with some need for the head.

It was desired to see the movement of the arms and shoulders. Participants wanted to know the head movement to see where the patient is looking. They were satisfied with just seeing the avatar for these areas and do not need to view any detailed parameter information..

RQ 2.3. What interpretation features do physicians and physiotherapists want included in the user interface and how do they want them visualized?

Selection

Participants were asked to rank interpretation features capable of being performed by Xsens MTw Awinda (Section 1.2) according to great need, some need, or no need. There was a need for all features except comparing results between patients (Figure 48). The features with the most need were comparing results between sessions, kinematics (difference between left and right, normal values), and joint angles (difference between left and right, normal values). Physiotherapists had placed more features in great need than physicians.

Visualizations

As with the parameters, the interpretation feature visualizations were selected as the simplest combination that would satisfy the most participants. There was more favor towards numbers and graphs visualizations than when selecting the parameter visualizations (Table 3). Physicians selected numbers or graphs for most features, while physiotherapists selected more combinations of visualizations. They more often selected the combination of numbers, graphs, and animations than physicians as well.

RQ 2.4. On what type of device would physicians and physiotherapists prefer to operate the user interface?

Fifteen participants wanted to operate and view the user interface on a computer. All physiotherapists and physicians have access to a laptop. They currently use a laptop during physiotherapy sessions and consultations. In addition, they want to be able to view the visualizations on as big of a screen as possible.

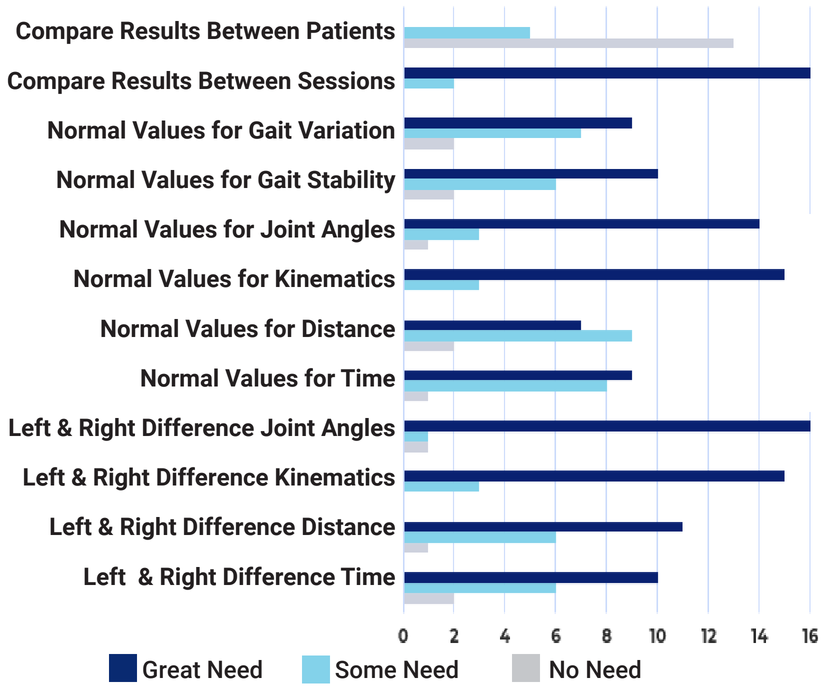


Figure 48. Interpretation features rated by level of need

Table 3. Interpretation Features Visualizations

Interpretation Feature		Visualization
Compare Results Between Sessions		Numbers, Graphs, & Animations
Normal Values	Time	Numbers
	Distance	
	Gait Stability	
	Gait Variation	
	Kinematics	Numbers & Graphs
	Joint Angles	
Left & Right Difference	Distance	Numbers
	Time	Numbers & Graphs
	Kinematics	Graphs & Animations
	Joint Angles	Numbers, Graphs, & Animations

RQ 2.5. What added benefit does the user interface need to have in order for physicians and physiotherapists to adapt it and use it over their current gait assessment method?

Cases The System Would Be Of Added Value

As with why participants currently assess gait, the majority of participants also said that the system (Xsens MTw Awinda hardware and user interface) would be of added value in selecting interventions (Figure 49). In particular, selecting orthosis, walking aids, physiotherapy treatment, and medical interventions. Another popular answer was using the system when it is not possible to detect abnormalities with the clinical eye. Also mentioned previously in participants' current experience with gait assessment (Section 1.1), participants would find the system of added value when evaluating the effects of interventions.

Using System over Existing Gait Assessment

Participants had several requirements that the system had to meet in order for them to use it over their current gait assessment method. What it comes down to is that the system has to be better than their current method and make up for what it lacks. For the clinical eye, this by providing more accurate, objective, and detailed information. For laboratory gait analysis, the system has to be accessible, easy to use, time efficient, and the results are not difficult to interpret.

Additional Insights

Participants struggled with selecting visualizations more so than with selecting the parameters. This was especially true for physicians.

> *"It is difficult to translate it (selecting visualizations) into what you would like to see and what is possible. It is a bit of intuition."*

As the participants have had no or limited experience with the parameters before to focus group session, they made decisions based on what they could picture in their head.

> *"I just cannot imagine how you do it with animation. There might be an animation, but I'm not sure how."*

However, with this inexperience comes the willingness to adapt. Even though the interface may not include everything they selected, participants will still try it out because they do not have any reference to base it on.

> *"The facts about the gait will not change. The facts about the interface may because I have no experience with it."*

In addition, with participants wanting to have the option to view all features and parameters, in designing the user interface, not only will the visualizations be of importance, but also how the parameters and features are organized.

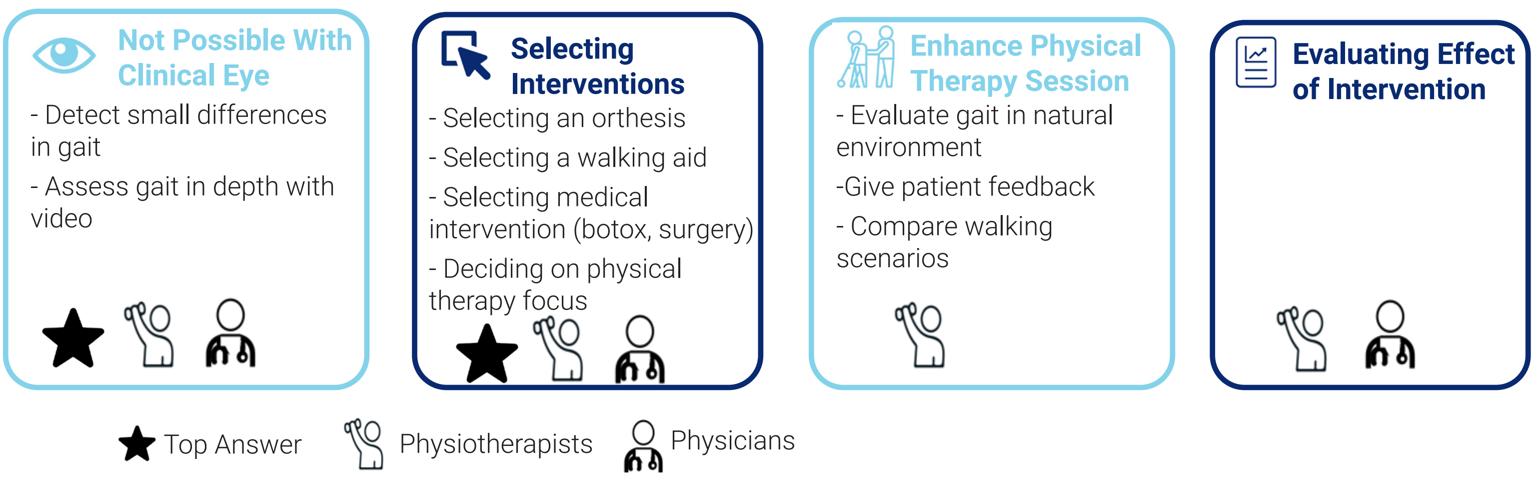


Figure 49. Cases when the system would be of added value

WORK FLOW FOR INCOMPLETE SCI GAIT REHABILITATION

From the information collected through the interviews, an experience journey was created for incomplete spinal cord injury patients in gait rehabilitation (Figure 50 & 51). A detailed description of the role the stakeholders play in each phase can be viewed in Appendix O.

RQ 3.1. In gait rehabilitation for patients with incomplete spinal cord injuries, what activities are done and who is involved?

As described in Section 1.1, after patients are discharged from the hospital, they either go straight home or are transferred to a rehabilitation center specializing in spinal cord injuries. In order to go straight home, patients need to be independent and be able to care of themselves. Consequently, most patients go to a rehabilitation center for inpatient therapy. On average, paraplegic patients stay at a rehabilitation center for 4 to 6 months and tetraplegic patients for 6 to 9 months (Post et al., 2017).

Observation Period

After undergoing an observation period for the first two weeks of their stay, the rehabilitation team meets to develop the patient's goals and determine a functional diagnosis for the patient, such as using a wheelchair after rehabilitation. The rehabilitation team consists of a physician, physiotherapist, occupational therapist, psychiatrist, social worker, and rehabilitation nurses.

Physiotherapy

Within gait rehabilitation, patients partake in several types of physiotherapy per week. This includes individual physiotherapy sessions with a physiotherapist, sports therapy, exercise sessions, walking group, and fitness group. The clinical eye is used within the physiotherapy sessions and in walking group. The level and type of activities conducted in the sessions vary per patient. There is no set progression that all incomplete SCI patients undergo.

Meetings

Every four weeks, the rehabilitation team meets to discuss the patient's progress and if any changes need to be made to the patient's treatment or goals. Every two months, the patient and their family attend the meeting. There are also daily meetings between physicians and physiotherapists to discuss any pressing patient issues. In between physiotherapy sessions, physiotherapists, sport therapists, and physiotherapist technicians also talk with each other about the patient's performance and discuss what exercises they should conduct in the coming sessions.

Select Interventions

Throughout gait rehabilitation, interventions are used to improve and optimize gait. These include walking aids, orthosis, medicine, botox, and surgery. Physicians and physiotherapists can use the information they obtain in physiotherapy sessions to help guide intervention selection. The timing of when interventions are implemented is dependent on the patient.

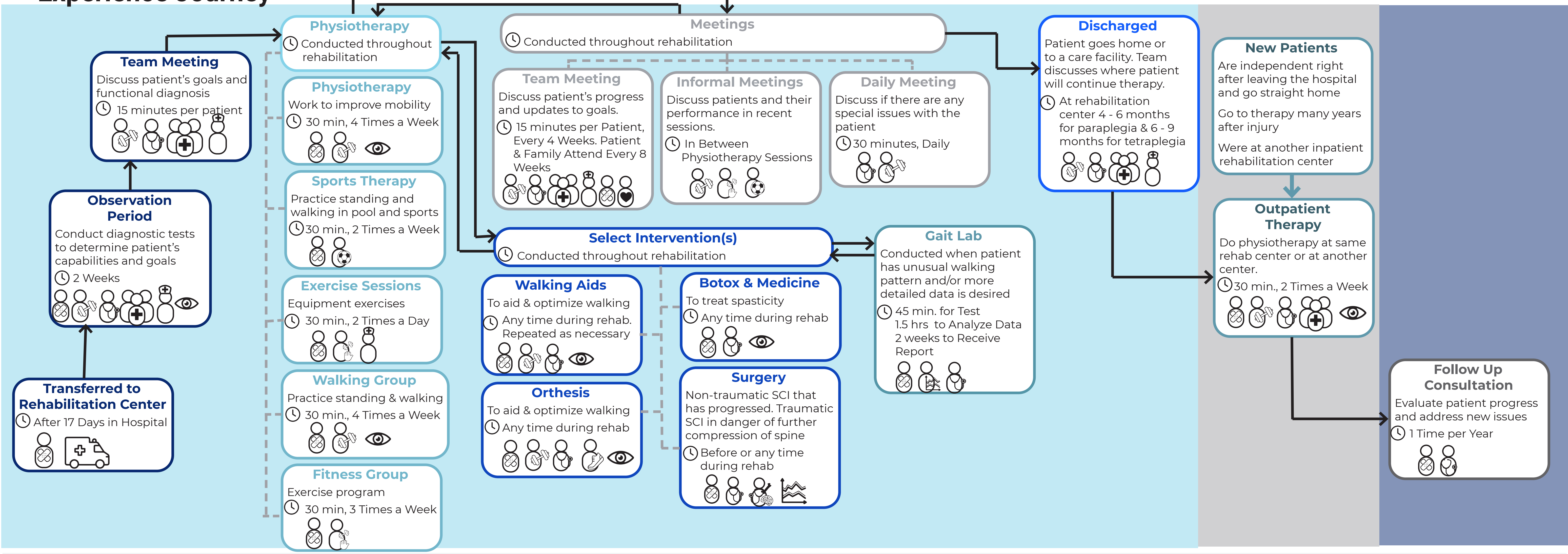
Gait Lab

When patients have unusual walking patterns and/or more detailed data on the patient's gait is desired, especially for deciding on surgical treatment, the physician sends the patient for a laboratory gait analysis. As described in Section 1.1 , the patient undergoes a 45-minute walking test with sensors and cameras. The gait lab operator then analyses the results, develops them into a report, and sends the report to the physician. Due to limited access and time-consuming process, laboratory gait analyses are currently not done often.

Discharged

Before a patient is discharged, there is a team meeting to decide if the patient will continue outpatient therapy at the same rehabilitation center or go to a center closer to home. If a patient still needs help walking, then they will continue at the same center. If the patient is already walking and just needs to improve, then they can attend physiotherapy closer to home.

Incomplete Spinal Cord Injury Gait Rehabilitation Experience Journey



Challenges & Frustrations

Physiotherapy

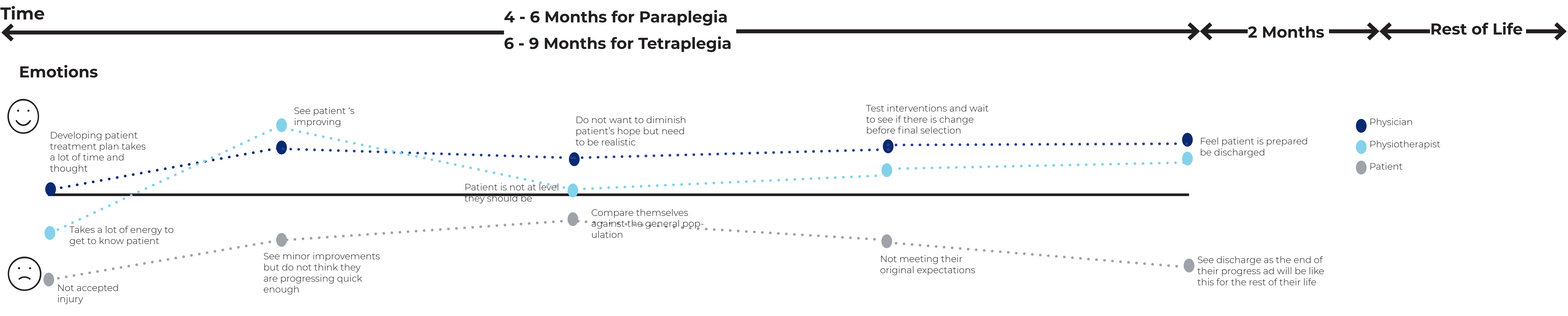
- Clinical Eye:
  - Not very objective
  - Cannot obtain detailed kinematic measurements
  - Difficult to see small changes
  - Cannot measure energy consumption
- Not able to provide visual feedback to patient

Select Interventions

- Physician makes final decision, rather than entire team.
- Have to wait to ensure patient does not have any changes in spasticity before prescribing orthesis
- Due to delay in prescribing orthesis and time to manufacture them, they are usually not done before the patient is discharged.
- Difficult to see small changes with clinical eye when comparing between walking aids and orthesis and determining effects of interventions.

Gait Lab

- Not used often because is time consuming and access is not possible or difficult
- Difficult to view and interpret data
- Interface is difficult to operate
- Testing cannot be conducted outside of lab
- 2 weeks between test conducted test and physician receives report



LEGEND

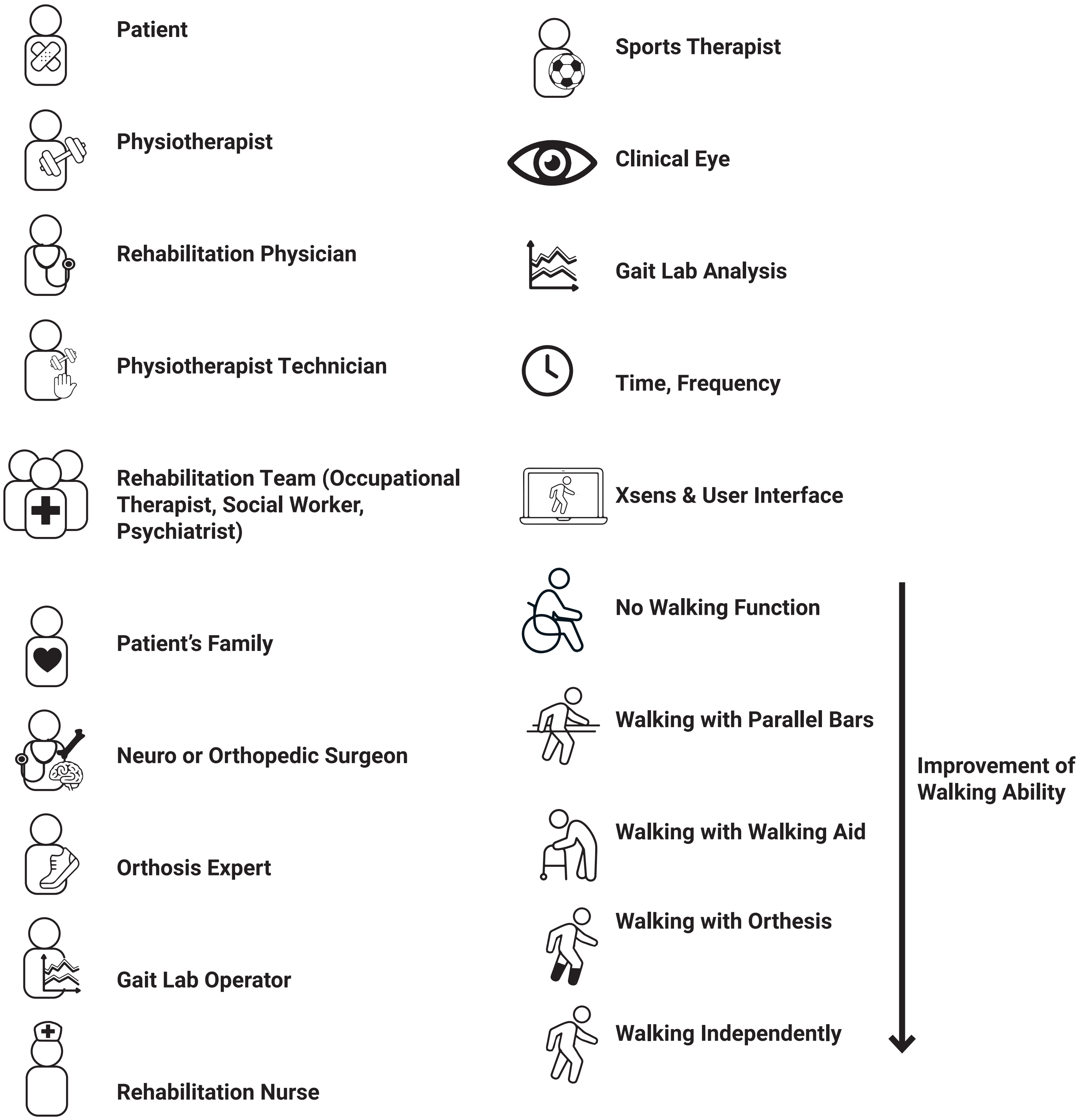


Figure 51. Legend for *Incomplete Spinal Cord Injury Rehabilitation Experience Journey* & *Opportunities for User Interface Experience Journey*

Outpatient Therapy

The patient continues physiotherapy for a few more months and has sessions two days a week. Patients who are discharged straight from home after leaving the hospital attend outpatient therapy. People who attended other inpatient rehabilitation centers can also attend outpatient therapy at the rehabilitation center. Additionally, people who had a spinal cord injury many years ago but recently new issues have arisen can take part in outpatient therapy.

Follow Up Consultation

Every year the patient will go to the physician for a follow up consultation. In the consultation, the physician will evaluate the patient to see their progress over the past year and address any new issues.

RQ 3.2. What are the challenges and frustrations that those involved experience throughout this process?

In evaluating the questionnaire, focus group results, and gait rehabilitation interviews, numerous challenges that the physiotherapists and physicians encounter throughout the gait rehabilitation process were found.

In physiotherapy, the clinical eye is not very objective. It is difficult to see small changes and obtain detailed kinematic measurements.

In selecting interventions, while in the current process both the physiotherapist and physician discuss what interventions should be implemented, the physician has the final say. Selecting orthosis also poses several challenges. Before prescribing an orthosis, physiotherapists and physicians have to wait to ensure patients do not have any changes in spasticity. This delay causes the orthosis not to be done before the patient is discharged.

As previously mentioned, with the laboratory gait analysis, physicians have to wait up to two weeks after the test is conducted to receive a test report. When they do receive the test report, they have difficulty interpreting the results.

3.3. What are the emotions of the patient, physician, and physiotherapist throughout this process?

The emotions of a patient do not depend on if it is a complete or incomplete injury. For emotions, there are three main types of patients (Figure 52):

Positive Throughout Rehabilitation: Upon entering rehabilitation, the patient has accepted their injury and is happy to be alive. As they progress in rehabilitation, they are satisfied with their improvements and are motivated to continue. At the end of their stay, they are happy with and proud of their achievements in physiotherapy.

Negative to Positive: When entering rehabilitation, they have not yet accepted their injury. In the beginning, they see minor improvements but do not think they are progressing quickly enough. Towards the middle of their rehabilitation, they start to see more drastic improvements and are motivated to exercise. At the end of rehabilitation, they are satisfied with their progress but are hesitant to go home because that means they will be entirely on their own.

Negative Throughout Rehabilitation: When entering rehabilitation, they have not yet accepted their injury. In the beginning, they see minor improvements but do not think they are progressing quickly enough. Throughout rehab, they continue to compare themselves against the general population and are frustrated why they are not more like

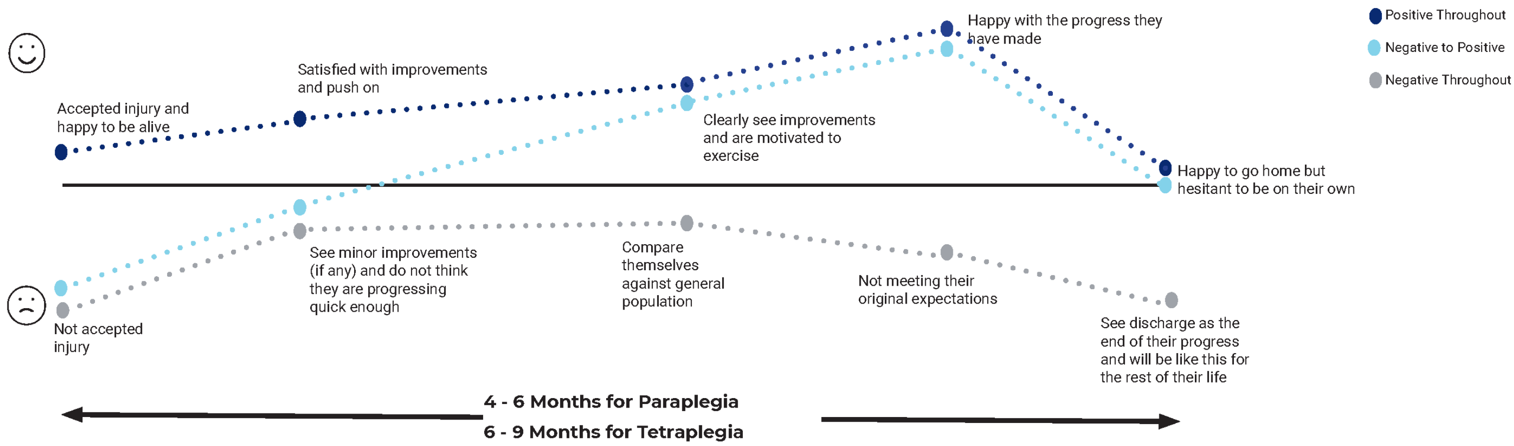


Figure 52. Patient Emotions Throughout Rehabilitation

them. They continue to be negative as they are not meeting their original expectation. They see discharge as the end of their progress and they will be at that capacity for the rest of their life.

The experience journey focuses on the negative patient as that is the patient that needs the most emotional help and encouragement.

While the emotions of the physicians and physiotherapists depend somewhat on the patient, for the most part they maintain positive. For physiotherapists, it can be physically and mentally draining at the beginning as it takes a lot of energy to get to know a new patient. As the patient is improving, physiotherapists feel joyful. They experience a slight dip when a patient is slow in progressing and is not at the level they should be. Through testing interventions, the physiotherapist can improve the patient's gait, which in turn improves their outlook. At the end, they are confident that the patient is ready to be discharged and is prepared to live on their own.

Similarly, at the beginning of rehabilitation, for physicians, it takes a lot of time, effort, and thought to develop the patient's treatment plan. Seeing the patient improving makes them feel cheerful. When the patient is upset that they are not meeting their original expectations, the physician does not want to diminish the patient's hope, but at the same time are realistic and know what is and is not possible for the patient to accomplish. Physicians have the same emotions as physiotherapists in testing interventions and discharging the patient.

STAKEHOLDER ANALYSIS

From the gait rehabilitation experience journey, the stakeholders in this project were identified (Figure 53). The key players of this project are the physiotherapist, physicians, and patients. They will be essential to have as allies and are needed to be engaged fully. The Convergence Team are affected by the project, but lack power. They will be consulted and informed throughout the project.

The context setters are Erasmus University Medical Center, orthosis experts, neuro/orthopedic surgeons, physiotherapist technicians, rehabilitation nurses, and sports physiotherapists. They are influential but initially uninterested. In doing so, they are just needed to be kept satisfied. The last group is the bystanders, which are the rehabilitation team and the patient's family. They only need to be monitored and informed.

A detailed stakeholder analysis can be found in Appendix P.

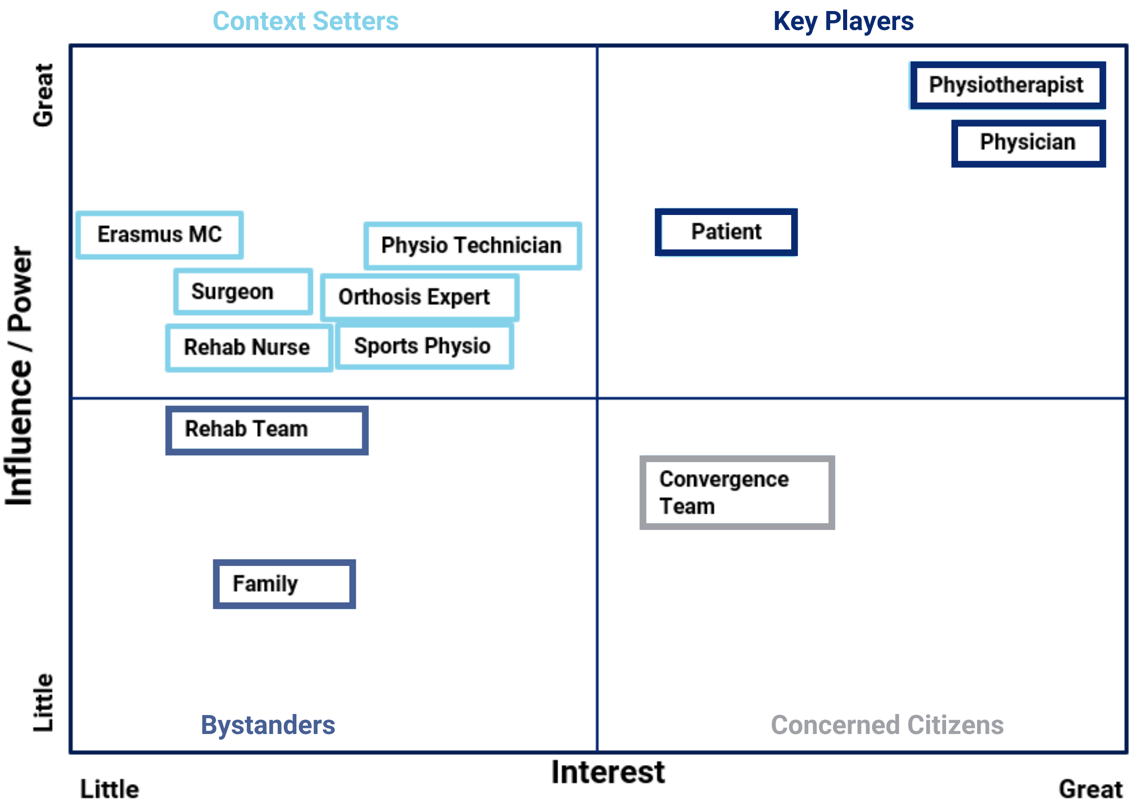


Figure 53. Stakeholder Analysis

Chapter 3

Design Opportunities & Direction

3.1 Opportunities for Implementation

From analyzing the user research results, opportunities in the gait rehabilitation journey that the Xsens system and user interface can be implemented were identified. Implementing the user interface system leads to an improvement in the patient, physiotherapist, and physician's emotions as well.

OPPORTUNITIES

From evaluating the results from the questionnaire, focus group, and interviews, opportunities were identified in the gait rehabilitation journey where the user interface could be implemented (Figures 54 and 51).

Each patient progresses at a different rate and has a different level of walking ability. Consequently, rather than categorizing the opportunities based on the time spent in gait rehabilitation, they were labeled according to the level of patient walking ability it can be used with. The levels of walking are no walking function, walking with assistance, and independent walking (Figure 55) (Bolliger et al., 2018).

With no walking function, the patient uses a wheelchair. In walking with assistance, patients start walking using parallel bars, progress to a walking aid, such as a walker, and then to leg braces and crutches. At the end stage, patients can walk without any assistance (Bolliger et al., 2018). There is no guarantee that patients will achieve independent walking in gait rehabilitation or at all in their life.

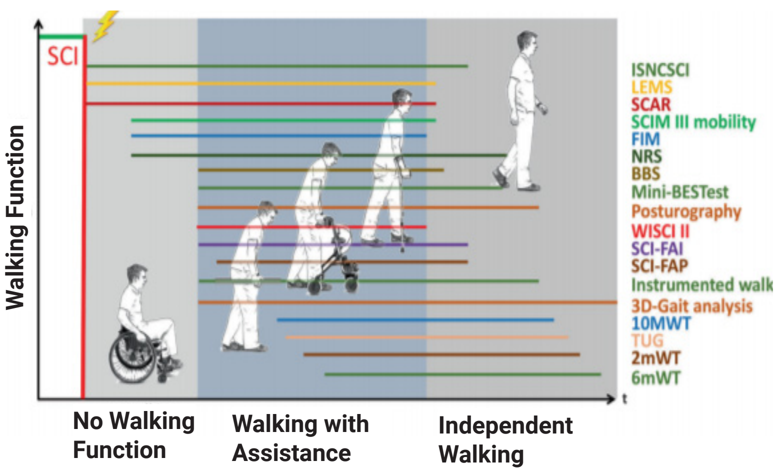


Figure 55. Levels of Walking & Tests That Can Be Conducted Accordingly (Bolliger et al., 2018)

Observation Period

At the beginning of rehabilitation, the Xsens system can be used to obtain a baseline measurement of the patient's gait. This allows for physiotherapists and physicians to see how much a patient has progressed throughout therapy. To use the system, the patient needs to be able to walk somewhat on their own. Consequently, the baseline measurement can only be collected for patients who can use a walker and higher levels of walking ability.

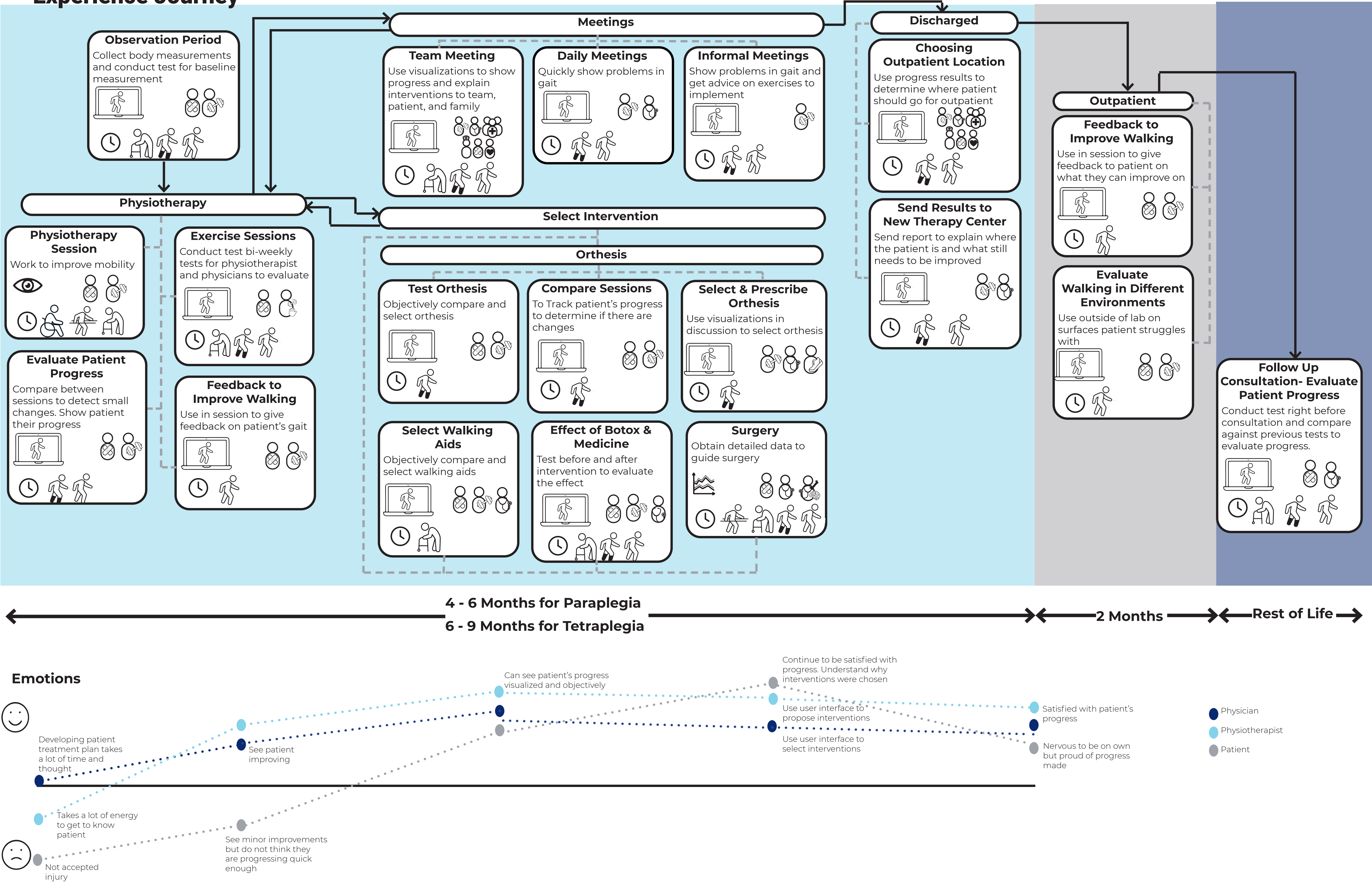
Physiotherapy

In the later stages of improving gait, it is difficult to detect small changes with the clinical eye when using braces and independently walking. Patients do not have visibly drastic improvements. Therefore, physiotherapists can use the Xsens system and user interface to detect these changes and show patients their progress, even when they think they have made no improvements.

Since physiotherapy technicians work with patients twice a day in exercise sessions, they could dedicate a session every two weeks to collecting gait measurements. This would allow physiotherapists and physicians to evaluate the results and track the patient's progress without having to sacrifice any of their time in physiotherapy sessions or appointments.

While the system is beneficial, for physiotherapy sessions with patients who use a wheelchair, parallel bars, or walker, the clinical eye will still win out. The abnormalities in gait are very noticeable at these stages and can be easily detected with the clinical eye. As the system would take more time than the clinical eye and not provide much additional benefit, physiotherapists will default to the clinical eye.

Opportunities for User Interface Experience Journey



Meetings

Physiotherapists and physicians can use the data visualizations in team meetings to show the patient's progress to the occupational therapist, psychiatrist, social worker, and nurses and help explain why an intervention is needed. Similarly, the visualizations can be used in daily meetings to show a particular issue that has arisen and in informal meetings to discuss what exercises should be conducted based on the gait assessment results.

Select Interventions

The Xsens system and user interface would be beneficial in selecting walking aids. It allows physiotherapists to test and objectively compare them. As orthosis are more customized than walking aids, the system would play an even more prominent role. Not only can it be used to compare orthoses and to discuss with the physician and orthosis expert what orthosis to use, but it can also be used to track a patient's progress. Doing so would allow physiotherapists and physicians to determine if there are any spasticity changes. This would potentially decrease the waiting time before an orthosis is prescribed.

Physicians can also use the system to test before and after botox or medicine is administered to evaluate the effects.

To help decide if surgery is needed and to guide surgery, physicians like to know the patient's EMG signals in gait and more detailed kinematic measurements than can be provided by the Xsens system. As a result, a laboratory gait analysis will most likely still be used in this case.

Discharged

Using the data taken throughout gait rehabilitation, the rehabilitation team can use the progress results to determine if the patient has made enough progress to go to outpatient physiotherapy at a center closer to home or if they should stay at the same rehabilitation center.

Additionally, suppose a patient does go to another physiotherapy center. In that case, their test reports can be sent over to the new center to explain where the patient is with their walking ability and what still needs to be improved.

Outpatient Therapy

As with inpatient gait training, the system could also give patients feedback to improve their walking. An additional benefit is that clinicians could use the system to evaluate the patient walking on different surfaces they struggle with, such as grass or stones.

Follow Up Consultation

Every year, the patient could undergo a gait assessment test. Since the results would be available immediately, the test could be done during or right before the consultation. This allows the physician to objectively see the patient's progress or decline from year to year. This would be a more long-term solution, with physiotherapy, selecting interventions, and meetings being short-term solutions.

EMOTIONS

Compared to the current gait rehabilitation process, when the Xsens system and user interface are implemented, patients, physicians, and physiotherapists experience more positive emotions.

While the patient may start out negative because they have not yet accepted their injury, their mood significantly improves when they can see their progress through the interface visualizations. The visualizations also allow them to understand better why the interventions were chosen and to feel more confident about the physician and physiotherapist's decisions. Even though they are still nervous about being on their own after discharge, they can clearly see their progress from the data visualizations and are proud of how much they have accomplished.

With physicians and physiotherapists, the beginning of rehabilitation follows the same pattern as the current process. Physiotherapists are mentally drained as it takes a lot of energy to get to know the patient. For physicians, it takes time and thought to develop the patient's treatment plan.

Through being able to see the patient's progress through visualizations, the physician and physiotherapist's moods are improved. By being able to use the system to select interventions objectively, they are more confident in their decisions as well.

3.2 Design Direction & Vision

The design direction was narrowed down to selecting interventions. The vision was then developed to help further guide the ideation process.

DESIGN DIRECTION

In evaluating the user research, it was found that the strongest opportunity was to implement Xsens Awinda and the user interface to select interventions. The most common reason physicians and physiotherapists currently use gait assessment is to select interventions. When asked when the system would be of added value, the most popular answers were selecting an intervention and detecting small gait differences that cannot be done with the clinical eye, which is also a significant part of selecting interventions. In doing so, there is significant want and need for objective gait assessment in selecting interventions.

In addition, with the system being something physiotherapists and most physicians have not worked with before, they may be hesitant at first to adopt it. Recently at Rijndam Revalidatie Westersingel, the body weight support systems of the Zero-G and G-Mill were purchased. Even though these systems can aid in gait training and analysis, physiotherapists are still hesitant to use them and use the clinical eye whenever possible. Likewise, if it is told to physiotherapists that they can use the system at any time during a physiotherapy session, they will be less inclined to use it. With this being quite broad, they may be unsure when exactly it is best to use it and consequently will continue to rely on the clinical eye. By associating the system with a specific case use and giving them more concrete instructions, they may feel more inclined to use it. Once they use it to select interventions and see the benefits, they will want to use it within their regular physiotherapy sessions.

Also, first associating using the system with selecting interventions will make scheduling using the system more accessible. Since initially there will be only one Xsens Awinda for all clinicians, it is not plausible for every physiotherapist to use it during their sessions. With selecting interventions, physiotherapists know far enough in advance when that will occur and then can sign up to use the system for that time.

VISION

With the design direction narrowed down to using the system to select interventions, the design vision was then developed (Figure 56):

> *To develop an **easy to use** user interface that aids physicians and physiotherapists in **selecting interventions** for patients with incomplete spinal cord injuries in an **objective** and **time efficient manne**r through **intuitive** data visualizations.*

Easy to Use

The system being easy to use is an aspect mentioned by almost all participants either in the questionnaire or focus group session. By being easy to use, the interface should not require extensive training to be able to operate it. A metaphor for easy to use that was mentioned by a participant is the design of a website. “In a bad website, you see all kinds of information and it is too much. But in a well-made website, you can see ‘Oh, that is where I need to go,’ and it just goes by itself.”

Objective

Objectively was mentioned in the questionnaire and focus group sessions as something that is missing from the clinical eye. With the system and interface, clinicians can present what occurred in the gait assessment unbiasedly and use this information to make decisions.

Time Efficient Manner

Time was expressed as a concern why the laboratory gait analysis is not currently used and as a potential barrier to adopting the system. If it takes an excessive amount of time to set up Xsens Awinda and/or operate the interface, physiotherapists and physicians will revert back to the clinical eye. As one physiotherapist noted, “If it is a hassle for the therapists, then using the clinical eye for simple questions will always succeed.”

Time efficiency also applies to receiving results after the test is conducted.

Intuitive

It should not require extensive background knowledge in order to be able to understand the visualizations. For physiotherapists and physicians, with limited training they should be able to understand all data presented. For patients and other rehabilitation team members, while they may not be able to analyze the data in-depth, they should be able to have a basic understanding of what the visualizations mean with no previous gait analysis experience.

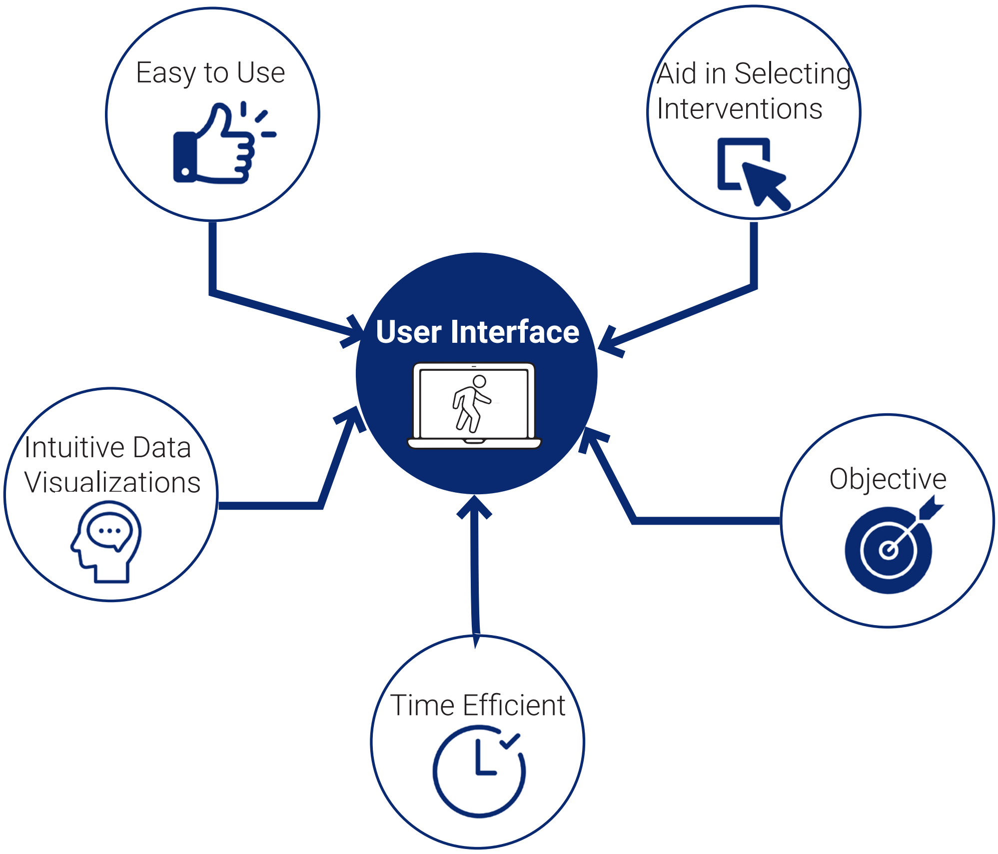


Figure 56. Elements of Design Vision

3.3 Program of Requirements

From the results from the user research, literature research, and design vision, a program of requirements was generated.

From the user research, literature research, and design vision, a set of requirements were developed. These requirements were used to aid in brainstorming and selecting ideas and concepts that fit the clinicians' wants and needs. The workable list of requirements that were used most often in concept development is featured in Table 4. The complete list of requirements is in Appendix Q.

Table 4. Program of Requirements

Vision			Source
1. Easy to Use	1.1.	The user interface can be operated independently with minimal instruction.	Focus Group
	1.2.	Physicians and physiotherapists can select and change the gait parameters and the testing result visualizations they would like to view with minimal effort.	
2. Selecting Interventions	2.1.	Physicians and physiotherapists can use the user interface to compare and select walking aids and orthoses.	Questionnaire Focus Group
3. Objective	3.1.	The user interface provides more objective information than is currently obtained with the clinical eye.	Literature Research on Clinical Eye Questionnaire
4. Time Efficient Manner	4.1.	After reviewing the testing results in the user interface for 5 minutes, physicians and physiotherapists can obtain an overview of the results.	Literature Research on Lab Gait Assessment Questionnaire
	4.2.	Physicians and physiotherapists can comprehensively interpret and analyze the results within 15 minutes.	
5. Intuitive	5.1.	The testing results are easier to view and interpret than in laboratory gait analysis.	Literature Research on Lab Gait Assessment Questionnaire Focus Group
	5.2.	Physicians and physiotherapists with minimal pre-existing knowledge on gait analysis can understand and interpret the results.	
	5.3	The user interface provides enough information to allow the physicians and physiotherapists to make an informed analysis, but not so much that it overloads them with information	
User Interface Design			
6. Ergonomics	6.1	To allow the visually impaired and color-blind to operate the interface, font sizing and contrast between text should abide by the Web Content Accessibility Guidelines (WCAG).	*About Face: Essentials of Interaction Design*
7. Usability	7.1	The operation of each screen in the user interface is self-evident.	*Don't Make Me Think* Jack Nielsen's Usability Heuristics
	7.2	Affordances are implemented throughout the user interface.	
	7.3	Be consistent and follow established conventions.	
	7.4	Minimize the number of steps needed to complete a function.	
8. Layout	8.1	Cohesiveness and flow is kept throughout the user interface.	*About Face: Essentials of Interaction Design* *Don't Make Me Think*
	8.2	The user interface layout should follow a logical flow.	
	8.3	The user interface contains an effective visual hierarchy.	
9. Aesthetics	9.1	The user interface and test results visualizations are aesthetically appealing and do not have a purely technical aesthetic.	Focus Group Jack Nielsen's Usability Heuristics
	9.2	The content and visual design are kept minimalistic as possible, and only essential information and elements are included	

Chapter 4
Concept Development

4.1 Defining Design Space

In order to narrow down what will be focused on in ideation, the problem was framed, and the scope of the parameters and visualizations was determined.

Even after defining the design direction and vision, the project scope still consisted of a great deal of aspects. Due to time limitations, it was not possible to tackle all aspects. To select which aspects to focus on, before ideation commenced, the design space was defined.

FRAMING THE PROBLEM

Selecting interventions was chosen as the design direction as it was the most substantial opportunity to implement Xsens Awinda and the user interface. As explained in Section 2.4, the category of intervention selection consists of orthosis, walking aids, surgical interventions, and botox and medicine. As it was not possible, due to time constraints, to develop the interface to have the capability to aid clinicians in selecting all the types of interventions, selecting orthosis was selected as the intervention to focus on.

Selecting orthosis was chosen because in the questionnaire on current experience with gait assessment, one of the top decisions clinicians made with the information from gait assessment was evaluating if an orthosis was needed and selecting orthosis. In the focus group sessions, selecting an orthosis was also one the most mentioned cases the system would be of added value.

Within selecting orthosis, there are still several ways the interface can be implemented (Figure 57). The user interface can be used to compare orthosis or to conduct tests to track patient's progress. The visualizations can also be used as a discussion tool between physiotherapists and physicians.

Since using the interface to compare orthosis and using the visualizations as a discussion tool would have the most significant and direct impact in selecting orthosis, they were selected to focus on in ideation. In later design iteration, using the interface to conduct tests to track progress will be included.

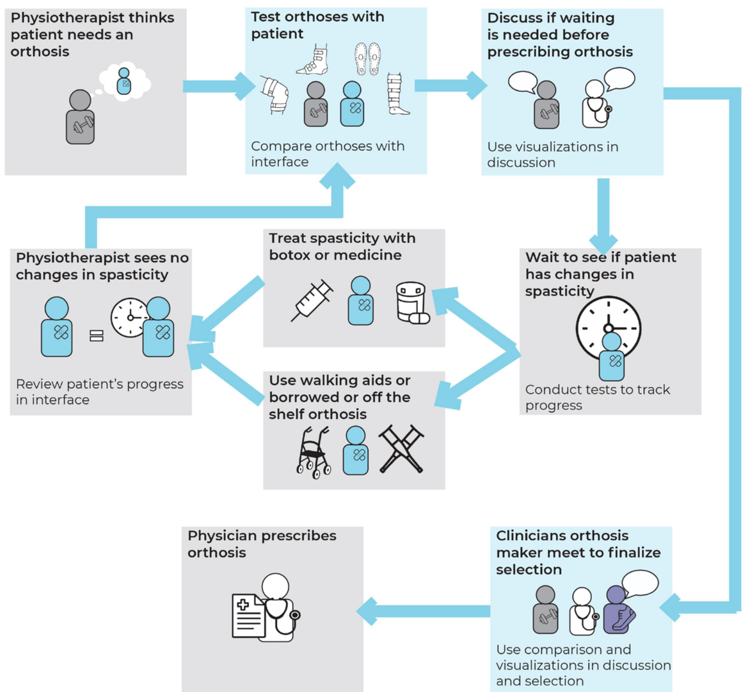


Figure 57. Selecting Orthosis Storyboard

PARAMETERS & VISUALIZATIONS SCOPE

As with framing the problem, due to time constraints, selections regarding parameters and type of visualizations had to be made (Figure 58). A further explanation on why and how this selection was made can be found in Appendix R.

.

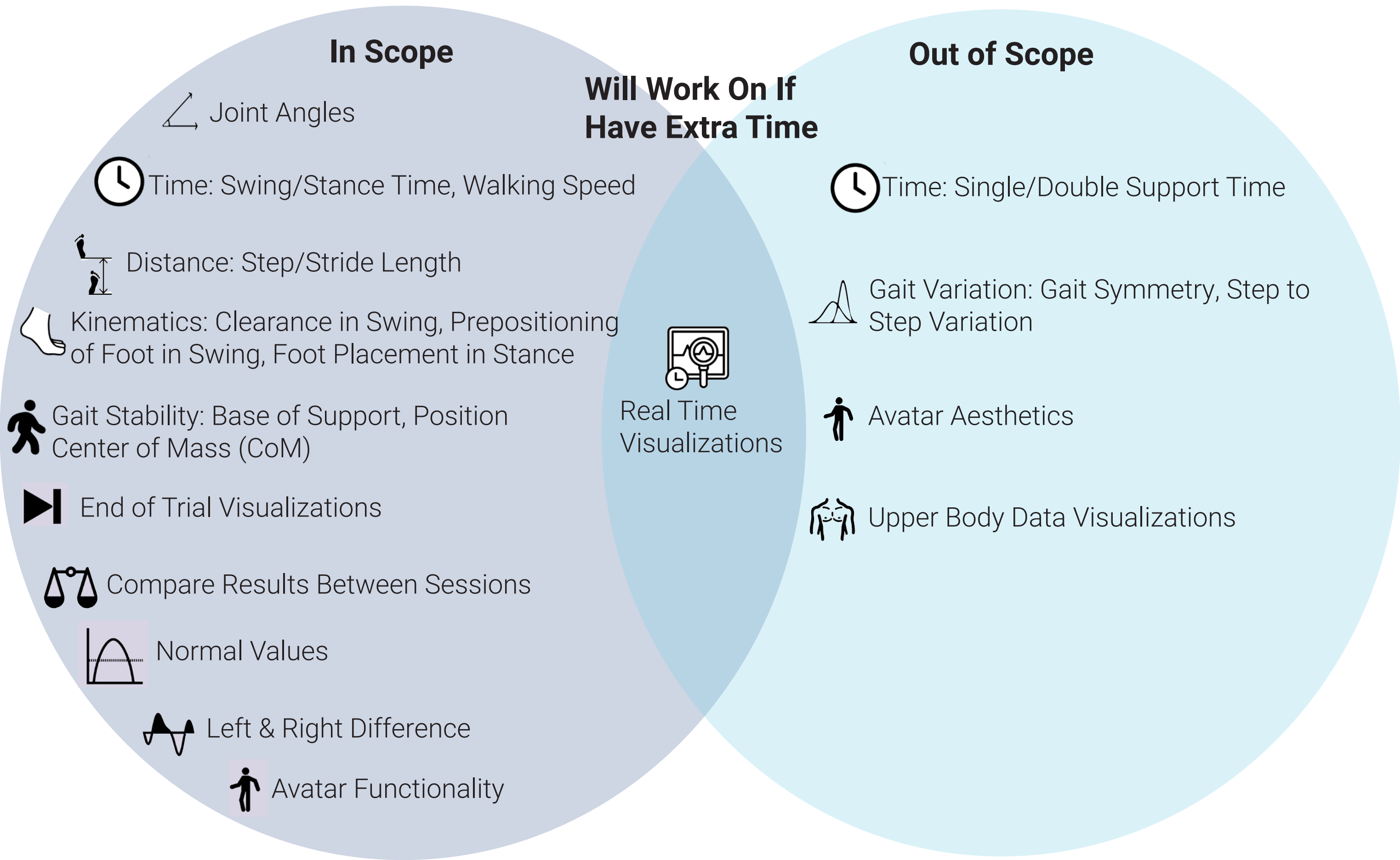


Figure 58. Parameters & Visualizations Scope

4.2 Visualizations Ideation

Ideas for the data visualizations were created through Wall Walks, collages, How-Tos, and Morphological Charts. To select which ideas to develop into concepts, they were evaluated by a feasibility analysis and Harris profiles.

In the first design iteration, ideation for test result visualizations and the interface layout were done separately. This was done as the requirements and type of ideation for each are different.

STARTING POINT

Each parameter type differed in terms of the desired visualizations and what information needed to be presented. Consequently, rather than ideating for all visualizations as a group, ideation was done with each type of parameter. For each type of parameter, the test data and normal value visualization and comparing between sessions were brainstormed. In doing so, there were ten categories of visualizations that were focused on in ideation (Figure 59)

IDEATION

Wall Walk

Ideation first began with a Wall Walk of the Affinity Diagrams developed from the questionnaire and the focus group sessions. A Wall Walk is when designers review all notes from user research to help explore the data and its implications for the design (Holtzblatt & Beyer, 2016) As the Affinity diagrams were reviewed, ideas were written down and drawn (Figure 60). This allowed the designer to look at the results as a whole and reminded them of ideas mentioned by participants.

Time	**Test Data & Normal** Numbers	**Comparison** Numbers & Graphs
Distance	**Test Data & Normal** Numbers & Graphs	**Comparison** Numbers
Kinematics	**Test Data & Normal** Graphs & Animations	**Comparison** Graphs & Animations
Joint Angles	**Test Data & Normal** Numbers, Graphs & Animations	**Comparison** Numbers, Graphs & Animations
Gait Stability	**Test Data & Normal** Graphs & Animations	**Comparison** Graphs

Figure 59. Visualizations to Ideate On

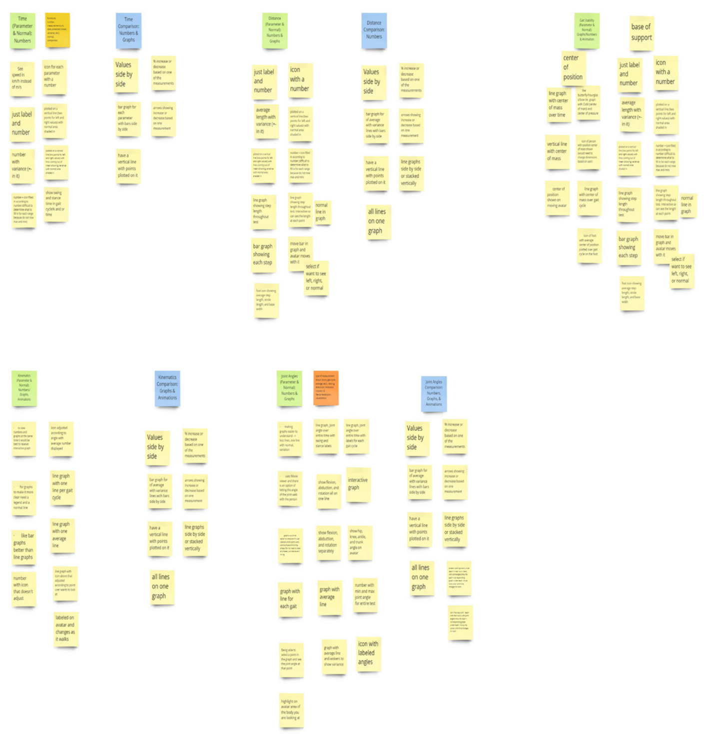


Figure 60. Ideas Generated from the Wall Walk

Collages

For each type of parameter, a collage was created of ways the parameters are currently visualized (Figure 61). Collages were also developed for comparing between sessions and visualizing the normal values. These examples were found from existing gait assessment software and running apps. Running apps were evaluated as they display similar parameters in a way that is designed to be understood by people with non-technical backgrounds and who have limited knowledge of gait assessment. The complete set of collages are in Appendix S.

These collages served as inspiration, and reviewing the collages allowed additional ideas to be generated.

How-Tos

How-Tos are problem statements written to help further explore the design space (Van Boeijen et al., 2014). How-Tos were created to develop any remaining ideas and build on and improve already generated ideas.

1. How to convey the message of the data in the visualizations without making it too technical and challenging to understand and such that clinicians with limited knowledge on gait assessment can understand them?
2. How to develop visualizations so that clinicians obtain enough information to evaluate a test effectively, without containing too much information?
3. How to provide objective information in an intriguing way?
4. How to compare all the parameters simultaneously, without overloading the clinician with information and making it too confusing?

Morphological Chart

After the three rounds of ideation, the ideas that were similar to each other were clustered and combined. To organize the ideas, morphological charts were created (Figure 62). Each type of parameter had a morphological chart and contained the type of visualizations desired by the clinicians. For example, time contained visualizations related to numbers and kinematics contained visualizations related to graphs and animations. The functions that were addressed in the morphological chart were:

- Type of Data Presented
- End of Trial Visualizations
- Real Time Visualizations
- Normal Value Visualizations
- Comparing Between Sessions
- Additional Features

The morphological charts for each parameter type are featured in Appendix T.

Time: Swing/Stance Time, Walking Speed

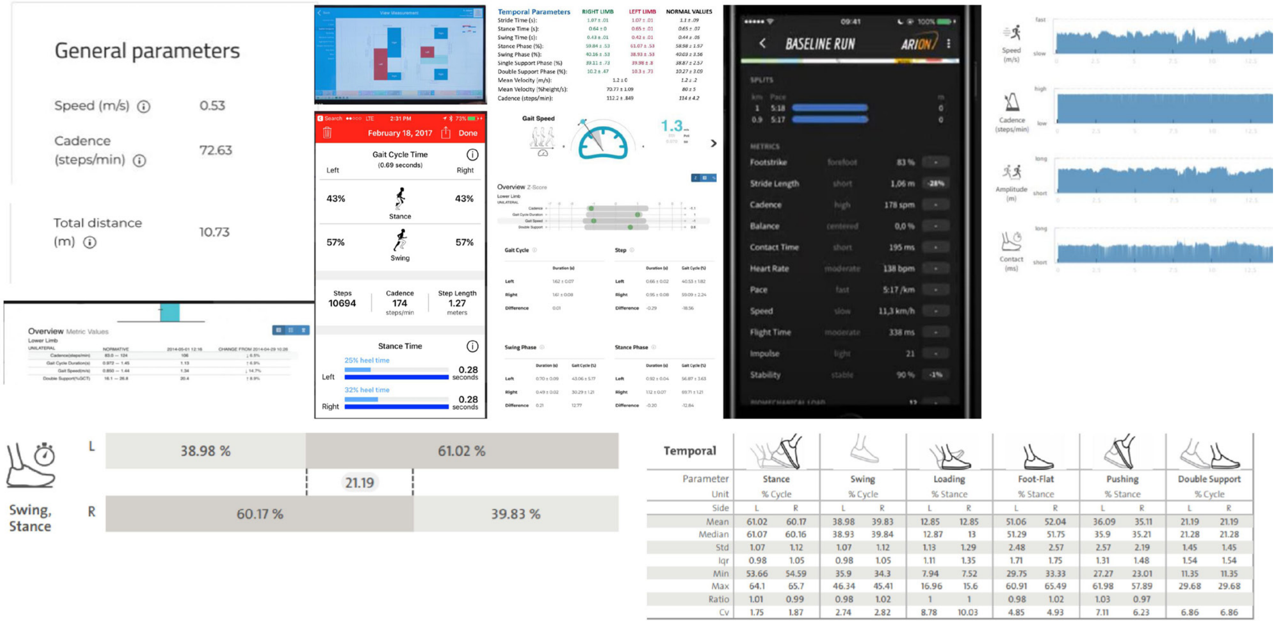


Figure 61. Collage for Time Parameter

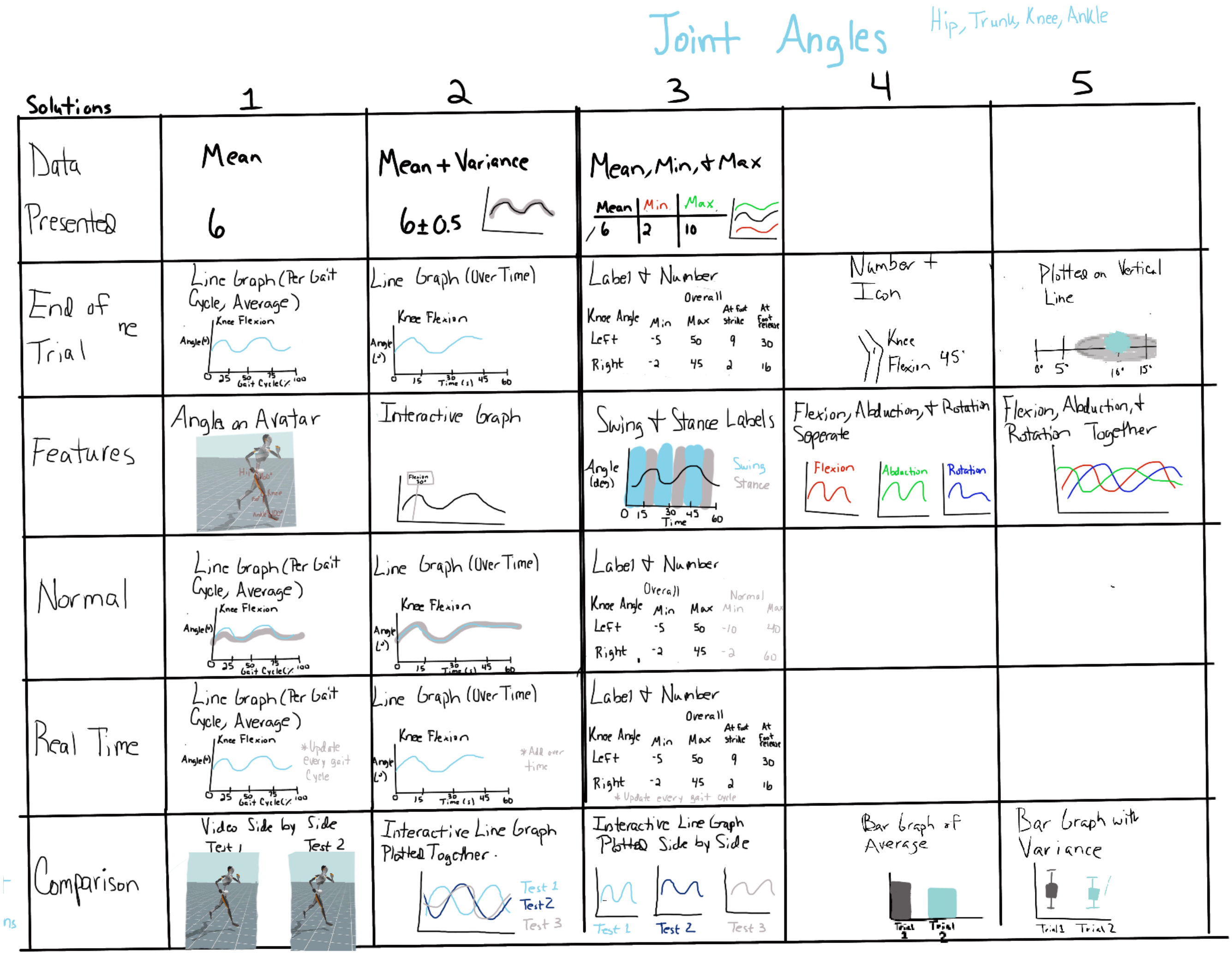


Figure 62. Morphological Chart for Joint Angles

EVALUATION & SELECTION

Feasibility of Ideas

As part of evaluating the ideas, the feasibility of the ideas presented in the morphological charts was evaluated with Convergence team members, Herwin Horemans, Daniel Lemus Perez, and Karin Postma. It was discussed what ideas can and cannot be created with the data provided by the Xsens MVN Analyze system. What was possible to develop with the future programming of the interface was reviewed as well. From a physiotherapist's perspective, Herwin and Karin were also able to give input on if clinicians would be able to understand the ideas.

Application of Feasibility Evaluation in Design

Time

- It is not useful to have a line graph measured over the gait cycle as for stance and swing time, there is only one measurement per gait cycle and walking speed does not change significantly over a gait cycle. It is more effective to plot the data over time.

- A scatter plot should instead of a line graph as the data is non-continuous.

- The animated icon might be difficult to program.

Distance

- As with time, there is only one measurement per gait cycle for step and stride length. It is more effective to plot the data over time.

- Use a scatter plot instead of a line graph as the data is non-continuous.

- Synchronizing the avatar with the graphs will be possible as long as it does not require the patient to only walk straight in order to follow the horizontal position of the graph's x-axis.

- Unsure if it is possible to zoom in and out of the avatar.

Kinematics

- Change the title of *Kinematics* as it can also be related to joint angles. *Foot Position* would be better as all parameters are related to the positioning of the foot and it is easier for the physiotherapists and clinicians to understand.

- All visualizations are feasible.

Joint Angles

- It is possible to detect the swing and stance phases using the data from Xsens MVN Analyze. It is not possible to detect gait subphases.

- Showing the minimum and maximum data is clinically very interesting.

- Graphing the data over time may not be as helpful as the graph will be too compressed for the clinician to see the data clearly. The clinician would have to be able to zoom in and out of the graph to interpret it.

- Making the graphs interactive is doable.

- Synchronizing the graphs and avatar is possible.

- If the joint angles are displayed on the avatar video, it would be difficult for the clinician to look at the angles without constantly pausing the video.

-Due to differences between tests, it would be difficult to sync the avatars. With the avatars being out of sync, if the avatars from two tests overlap, it would not be easy to see both avatars simultaneously. It would also be difficult to compare the avatars simultaneously in the video as they would be at different points in the gait phase. It would be easier to interpret if the avatar videos were side by side and could control each avatar video separately.

Gait Stability

- The base of support is similar to distance. In doing so, the same type of visualizations can be used for the base of support as distance.

- A butterfly/bow-tie graph is typically generated when walking on a treadmill and can only be used when the patient is walking straight for the entire test. As most tests will consist of the patient turning, using this type of visualization would produce inaccurate results.

- In addition to Position Center of Mass (CoM), Extrapolated Center of Mass (XCoM) will also be measured.

Evaluation of Ideas

To select which ideas to develop into concepts, Harris Profiles were used. Harris Profiles were used for each type of parameter to select the end of trial visualizations and the visualizations for comparing between sessions (Figure 63). In addition to taking into account the experts' input on feasibility, the following requirements were used in the evaluation. They are ranked from most to least important::

- 5.3. The user interface provides enough information to allow the physicians and physiotherapists to make an informed analysis, but not so much that it overloads them with information.
- 5.2 Physicians and physiotherapists with minimal pre-existing knowledge on gait analysis can understand and interpret the results.
- Experts' input on feasibility.
- 3.1 The user interface provides more objective information than is currently obtained with the clinical eye
- 9.1 The user interface and test results visualizations are aesthetically appealing and do not have a purely technical aesthetic.
- Interpret Data Time Efficiently:

    4.1. After reviewing the testing results in the user interface for 5 minutes, physicians and physiotherapists can obtain an overview of the results.

    4.2. Physicians and physiotherapists can comprehensively interpret and analyze the results within 15 minutes.

From each Harris Profile evaluation (Appendix U), two to three ideas were selected to develop into concepts (Figure 64). The concepts for each parameter type can be found in Appendix V.

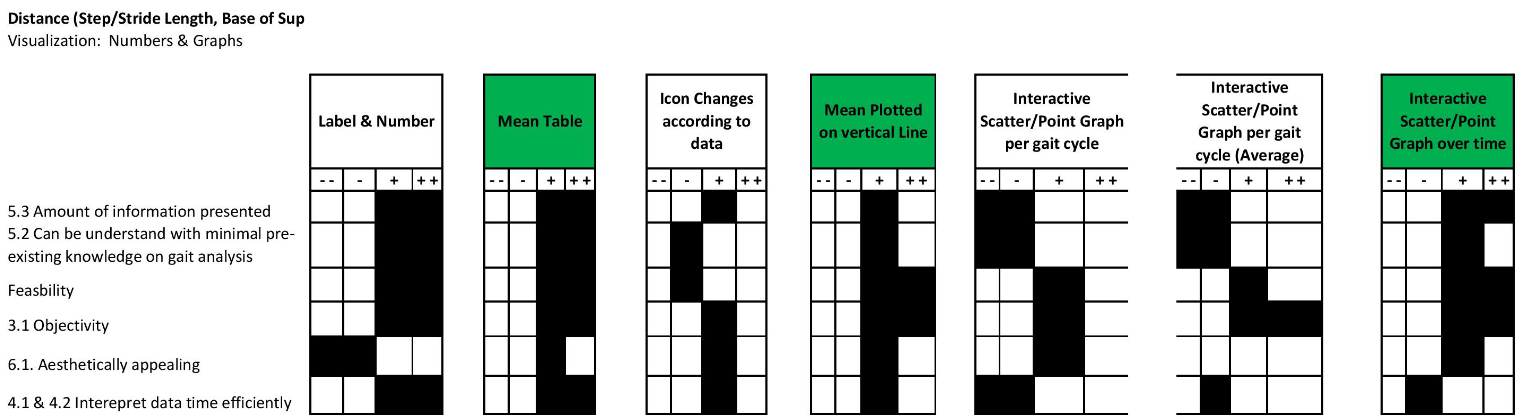
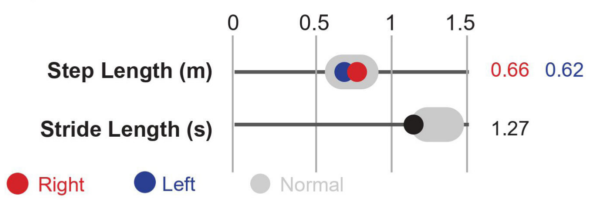


Figure 63. Harris Profile for Distance

Option 1 - Mean Table

Parameter	Right	Left	Normal Values
Step Length (m)	0.66	0.62	0.62
Stride Length (m)	1.27		1.36
Distance Walked (m)	10		

Option 2 - Mean Horizontal Plot



Option 3 - Scatter Plot over Time

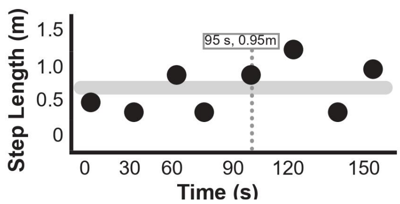


Figure 64. Test & Normal Value Visualization Concepts for Distance

4.3 Interface Layout Ideation

After defining the touchpoints, wireframe sketches were developed using the methods of Wall Walk, collages, and How-Tos. Through Harris Profiles, Ideas were selected to develop into concepts.

STARTING POINT

Defining Touchpoints

To map out the user's steps when using the interface, a combination of a service blueprint and flow map was developed (Figure 65). The blueprint maps out the seven touchpoints a clinician will go through when using the user interface. Within each touchpoint, the actions the clinician will carry out were arranged. By evaluating the front-end actions and features needed to support these user actions, the primary features necessary to be included in the interface were identified. Even though the focus of this project was on the interface front-end, assessing the back-end actions and support process helped establish requirements that should be addressed later in the programming of the interface.

Wireframe Sketches

Each touchpoint was brainstormed in terms of wireframes (Figure 66). Wireframes are illustrations of a page's interface that focus on the page's structure, information hierarchy, functionality, and content. Hence the wireframe sketches focus on the usability and functionality of the interface layout rather than the aesthetics (van Kuijk, 2021).

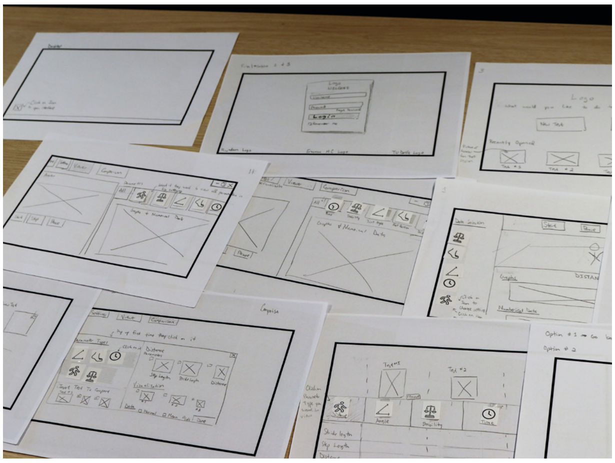


Figure 66. Wireframe Sketches

IDEATION

Wall Walk

Like in the visualization ideation, ideation of the interface layout first began with a Wall Walk of the Affinity Diagrams developed from the questionnaire and the focus group sessions.

As the Affinity diagrams were reviewed, ideas regarding features and aspects to be included in the layout were written down and drawn.

Collages

For each touchpoint, a collage was created of examples of existing applications (Figure 67). These examples were found from gait assessment software as well as applications and websites that fulfilled similar functions of the touchpoints. The complete set of collages are in Appendix W.

By reviewing each collage and incorporating the ideas from the Wall Walk, wireframes were then developed per touchpoint.

Data in Real Time & at End of Trial

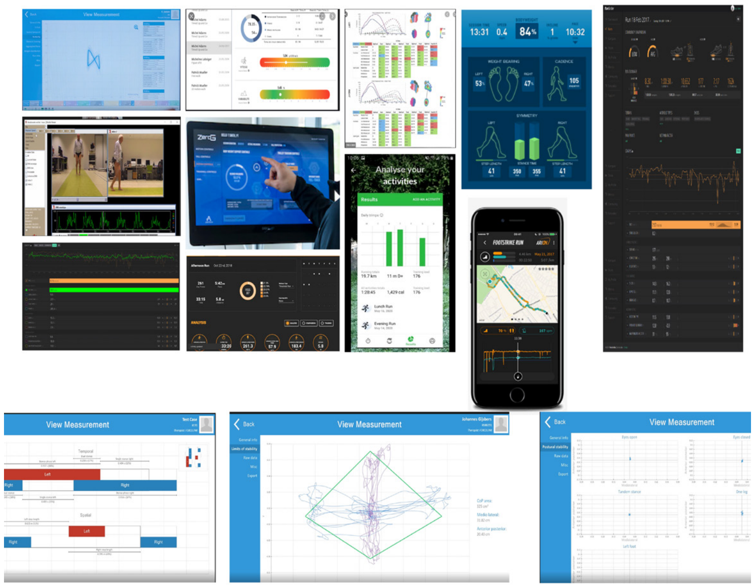
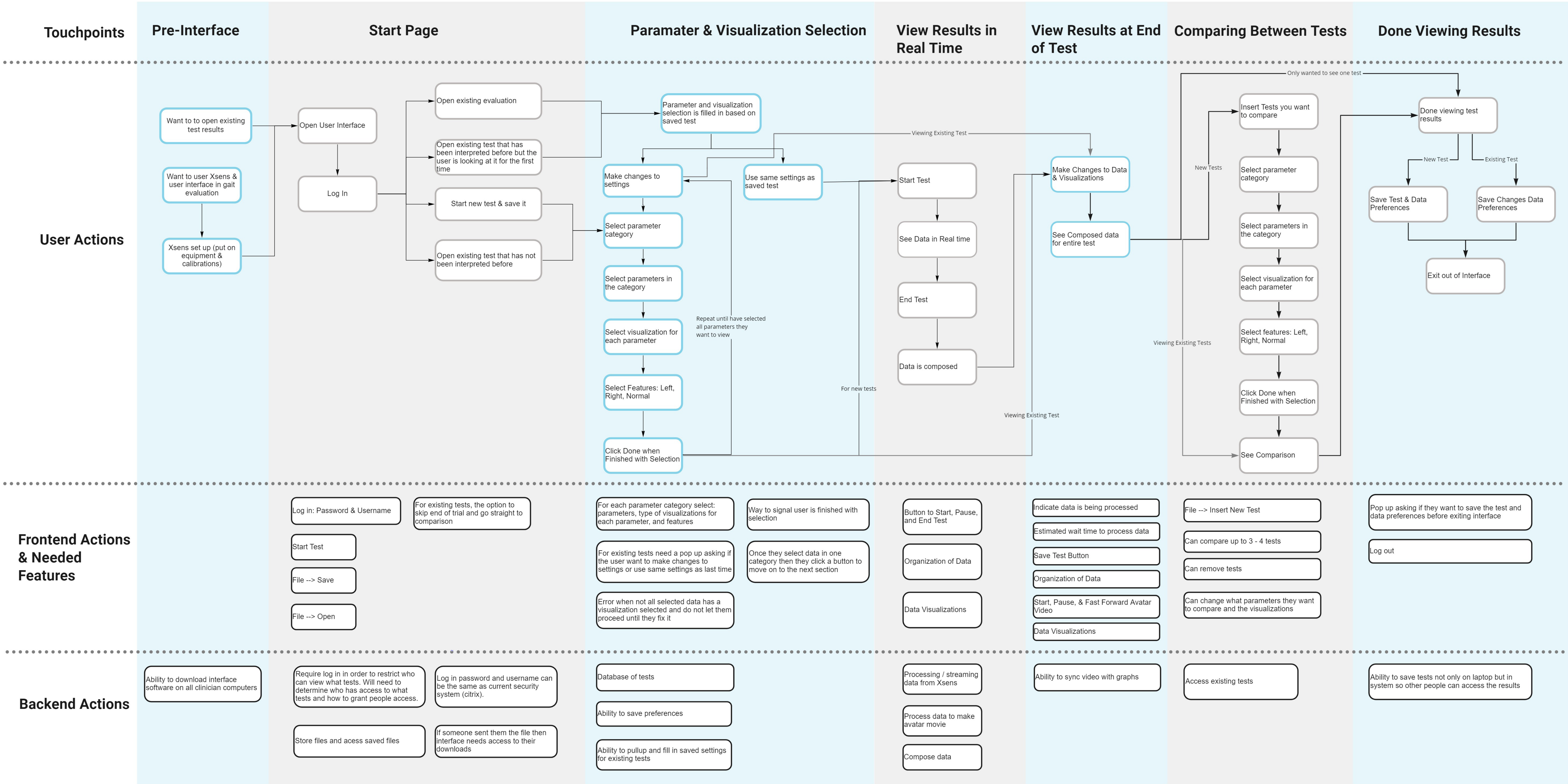


Figure 67. Collage for View Data in Real Time & At End of Trial Touchpoints

Blueprint of User Interface



How-Tos

The last stage in brainstorming was generating ideas based on several How-Tos:

1. How to design a user interface that after a short explanation, can be operated independently?
2. How to present information such that it can be viewed in a time efficient manner?
3. How to design an interface that provides enough information to clinicians to evaluate a test efficiently, without overloading them with information?
4. How to present the content such that it is still objective and the interface is easy to operate but does not have a purely technical aesthetic?
5. How to change the type of data and visualization the user wants to see, without making it too complicated or having it be in the way of other operations?
6. How to allow users to see all joint angles at once without overloading them with information?

From these brainstorming methods, an ample amount of ideas were generated (Figure 68).

EVALUATION & SELECTION

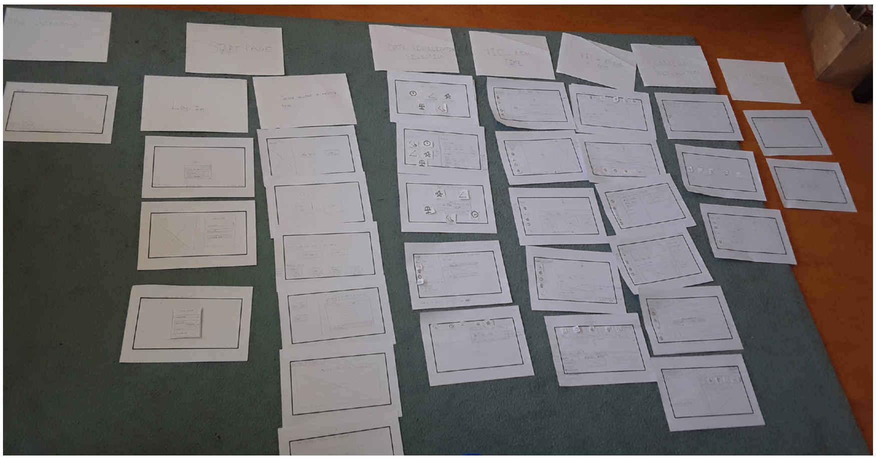
Harris Profiles were used to select which wireframes to develop further. This was done for each touchpoint (Figure 69). Since the functions of each touchpoint differ, so did the evaluation requirements and their level of importance. In no particular order of importance, below are all requirements used throughout the Harris Profiles:

- 1.1. The user interface can be operated independently with minimal instruction.
- 5.3. The user interface provides enough information to allow the physicians and physiotherapists to make an informed analysis, but not so much that it overloads them with information.
- 1.2. Physicians and physiotherapists can select and change the gait parameters and the testing result visualizations they would like to view with minimal effort.
- Interpret Data in Time Efficient Manner:

    4.1 After reviewing the testing results in the user interface for 5 minutes, physicians and physiotherapists can obtain an overview of the results

    4.2 Physicians and physiotherapists can comprehensively interpret and analyze the results within 15 minutes.

- 9.1 The user interface and test results visualizations are aesthetically appealing and do not have a purely technical aesthetic.
- 8.1 Cohesiveness and flow are kept throughout the user interface.



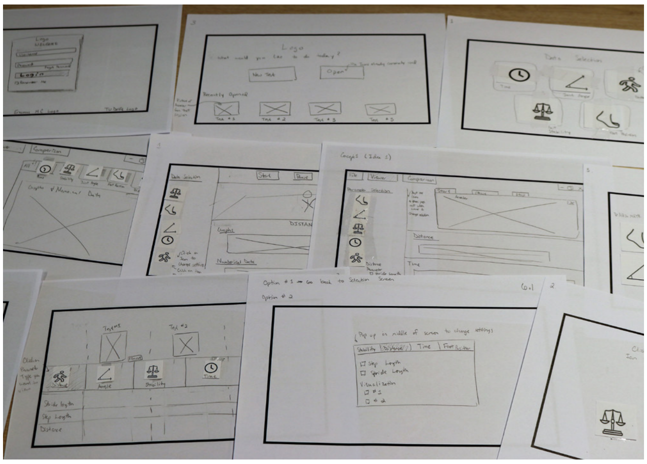


Figure 68. Sketches Organized per Touchpoint

- 7.4 Minimize the number of steps to complete an action.
- 2.1. Physicians and physiotherapists can use the user interface to compare and select walking aids and orthoses.

The Harris Profiles for each touchpoint can be seen in Appendix X. From the Harris Profiles, one to two ideas per touchpoint were selected to develop into concepts (Figure 70, Appendix Y). For touchpoints with two concepts, in one concept less information was presented to users but required them to do more steps. In the other concept, users are given more information to look at one time, but it takes fewer steps to operate.

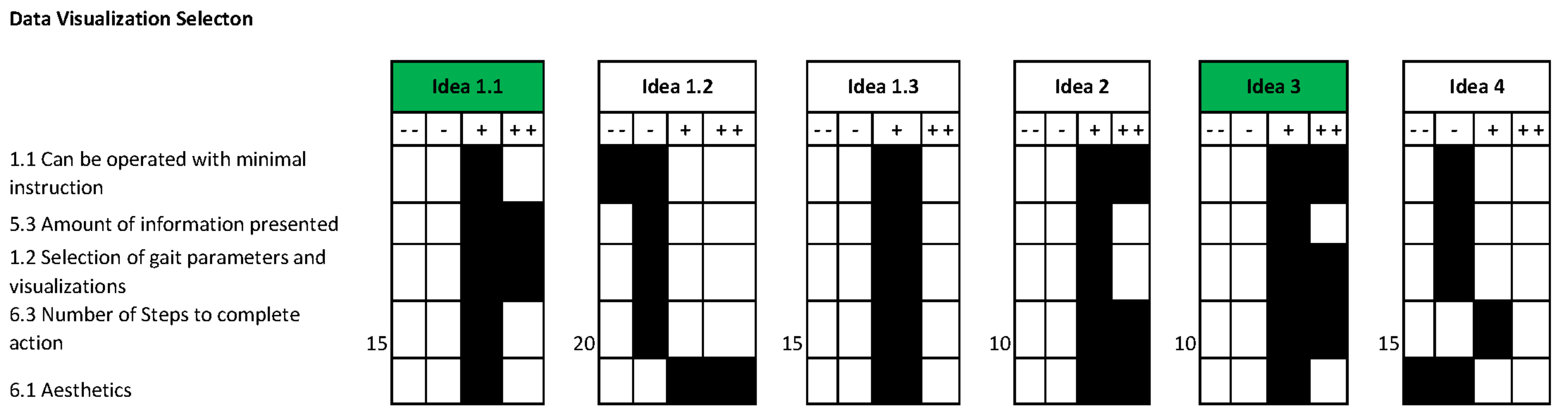


Figure 69. Harris Profile for Parameter & Visualization Selection

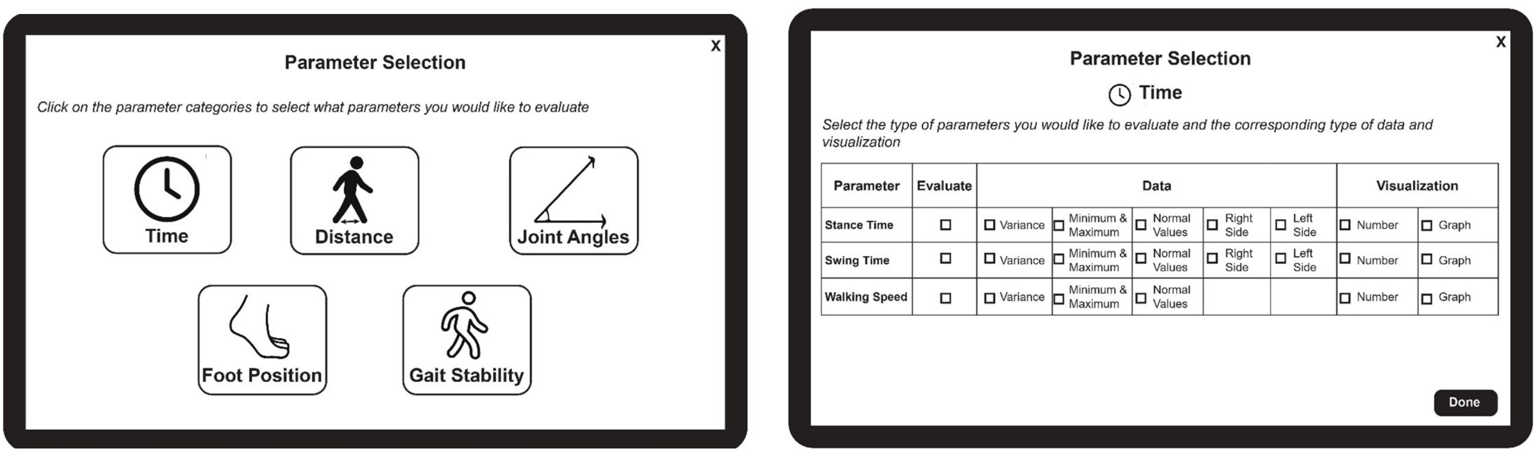


Figure 70. Parameter & Visualization Selection Concept 1

4.4 Concept Evaluation

The layout and visualizations concepts were evaluated through concept test sessions with three physiotherapists and two physicians. Using the feedback received in these sessions, the user interface design was finalized.

The focus of the concept test was to obtain feedback on the usability and function of the interface layout and how intuitive the visualizations were to understand. From the participants' feedback, the final design was developed. To allow the designer to be made aware of any significant concerns had by the clinicians that could be fixed before developing the final design, concept tests were conducted rather than only evaluating the concepts through requirements, such as Harris Profile or Weighted Objectives method.

RESEARCH QUESTIONS

Interface Layout

1. Which interface layout do physicians and physiotherapists prefer in terms of usability and functionality?
2. What do physiotherapists and physicians see as the advantages of the layout concepts?
3. What do physiotherapists and physicians see as the disadvantages of the layout concepts? What can be added or improved?

Visualizations

4. Can physiotherapists and physicians with minimal pre-existing knowledge on gait analysis understand the visualizations?
5. What do physiotherapists and physicians see as the advantages of the visualizations?
6. What do physiotherapists and physicians see as the disadvantages of the visualizations? What can be added or improved?
7. In order for a patient to better understand their gait, what parameters would physiotherapists and physicians like them to see?

METHOD

Participants

Three physiotherapists and two physicians who treat patients with spinal cord injuries and work for Rijndam Revalidatie participated in the concept tests. All participants previously participated in the questionnaire on current experience with gait assessment and the focus group sessions.

Procedure

There was one focus group session with the physiotherapists and another with the physicians. Each session lasted about one hour and was conducted in person at Rijndam Revalidatie Westersingel.

At the beginning of each session, there was a short presentation reviewing the goal of the project, how the Xsens Awinda System operated, and the results from the use research questionnaire and focus groups. After giving this recap, the purpose of the session was explained. A user scenario was also presented to clarify the scenario the concept test would focus on (Figure 80).

After the presentation, the interface layout was first evaluated for approximately 25 minutes. The visualizations were assessed in the remaining 25 minutes.

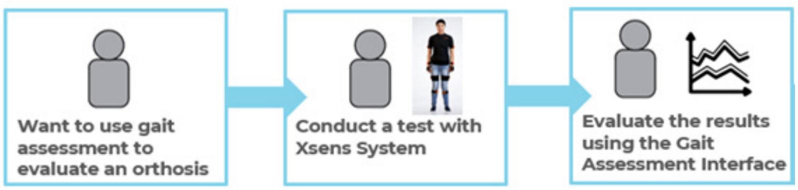


Figure 80. User Scenario

Interface Layout

Each participant was given a booklet (Figure 81, Appendix Z). On each page of the booklet, there was a wireframe corresponding to a touchpoint concept. For each touchpoint, the respective wireframe concept(s) were explained. As the wireframes were being explained, the participants could take notes on the pages. Using a Likert scale, participants were asked to rate each wireframe in terms of *"How easy it is to understand and operate?"* from very difficult to very easy (Figure 82).

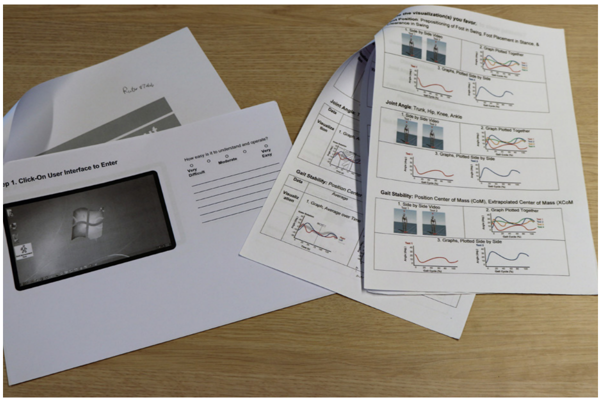


Figure 81. Interface Layout & Visualization Booklets

The concept was then discussed in terms of usability and its advantages and disadvantages. For touchpoints with two concepts, the participants also discussed what the participants liked the most about each concept. Also, if they preferred one concept or what combination of the concepts they would want to see in the final design.

This process was repeated until the concepts for all seven touchpoints had been evaluated

Visualizations

Each participant was given another booklet that contained the visualization concepts for each type of parameter (Figure 83, Appendix AA). For each type of parameter, the visualization concepts were explained. It was then discussed how intuitive the visualizations are to understand. Additionally, what the participants did and did not like about the visualizations and if they favored one. This was repeated until all end of trial visualizations and comparison visualizations had been evaluated.

At the end, participants were asked what parameters they think would be useful for patients to see to allow them to understand their gait pattern better.

Data Analysis

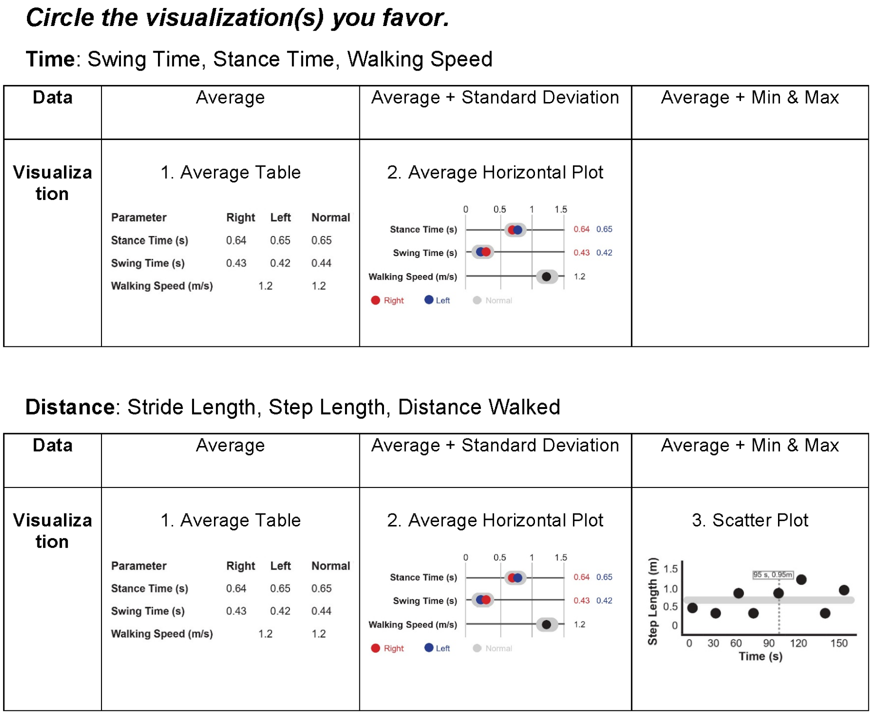
Notes were taken during the session. The audio of each session was recorded and transcribed afterward. At the end of each session, the packets were collected from the participants and their answers and notes were reviewed. The packets did not contain any personal or identifying information.

Step 2. Login

How easy is it to understand and operate?

○ Very Difficult ○ ○ Moderate ○ ○ Very Easy

Figure 82. Page from Interface Layout Booklet



Circle the visualization(s) you favor.

Time: Swing Time, Stance Time, Walking Speed

Data	Average	Average + Standard Deviation	Average + Min & Max
Visualization	1. Average Table	2. Average Horizontal Plot	

Parameter	Right	Left	Normal
Stance Time (s)	0.64	0.65	0.65
Swing Time (s)	0.43	0.42	0.44
Walking Speed (m/s)	1.2		1.2

Distance: Stride Length, Step Length, Distance Walked

Data	Average	Average + Standard Deviation	Average + Min & Max
Visualization	1. Average Table	2. Average Horizontal Plot	3. Scatter Plot

Parameter	Right	Left	Normal
Stance Time (s)	0.64	0.65	0.65
Swing Time (s)	0.43	0.42	0.44
Walking Speed (m/s)	1.2		1.2

Figure 83. Page from Visualizations Booklet

RESULTS

Interface Layout

Touchpoints 1. Entering User Interface, 2. Login, & 3. Start Page

For each of these touchpoints (Figures 84, 85, and 86), participants found the concepts to be very easy to understand and operate. Since the concepts are similar to how the participants use software programs and websites now, they are familiar with the functions and do not have any confusion on how to operate them.

"Looks straightforward"

Figure 85. Touchpoint 2. Login

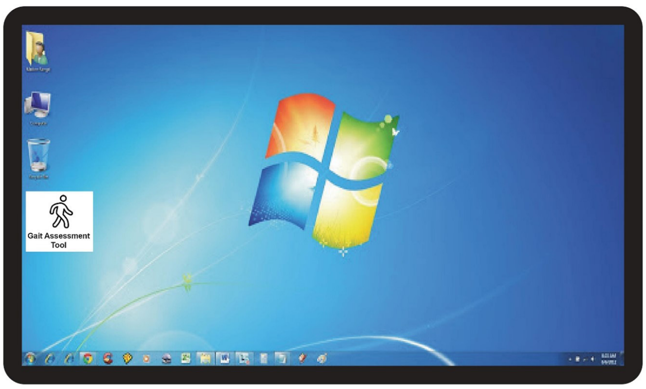


Figure 84. Touchpoint 1. Entering User Interface

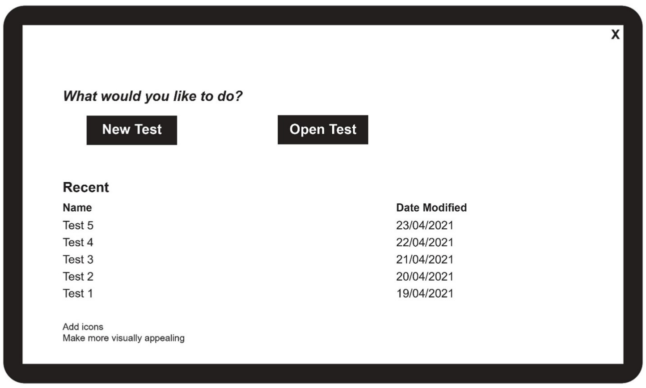


Figure 86. Touchpoint 3. Start Page

Touchpoint 4. Parameters & Visualizations Selection

All participants thought it would best to skip this step. Rather than having users select what visualizations they want to view, the interface should have a standard set of visualizations that all users first see. After users view the data, they can change the visualizations if they would like.

> *"I think it would be good to have like a standard. Then if you want something specific, then you can change it."*
>
> *"Yeah I think it's easy that you have a kind of standard for visualization. Also because it's less time consuming."*

In addition to being more time efficient, it would also make it easier for inexperienced users early on as they are learning about gait assessment. As they do not have a lot of previous experience with gait assessment, selecting visualizations may confuse them and they could get overwhelmed before even viewing the data. As they develop experience with gait assessment they can then customize the visualizations.

> *"As you get more experience in the system I think then you will have more specific questions. But I think it's good not to overwhelm people in the beginning and have something standard that is utilized. Then if you want something specifically different or you get more experience in viewing the outcomes, then you can go back to the system and change it."*

With the standard visualizations, the participants still want to be able to select the parameters they want to view as well as viewing left side, right side, and normal values. However, they do not feel that this has to be its own screen and can integrated into an existing step.

In terms of comparing the two concepts, participants preferred Concept 2 (Figure 87 and 88). Having everything on one screen makes it easier to use. The users can to switch between parameter category settings without extensive effort. However, they did not like that all parameters in a category had the same data and visualization settings. They would prefer to be able to select the data type and visualization for each parameter, like in Concept 1.

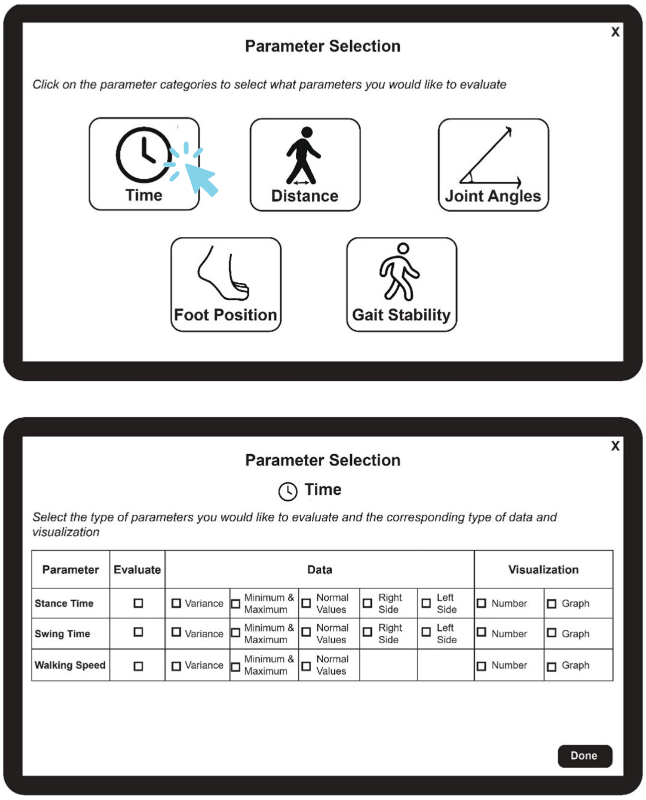


Figure 87. Touchpoint 4. Concept 1, Click on parameter type and then change data and visualization per parameter

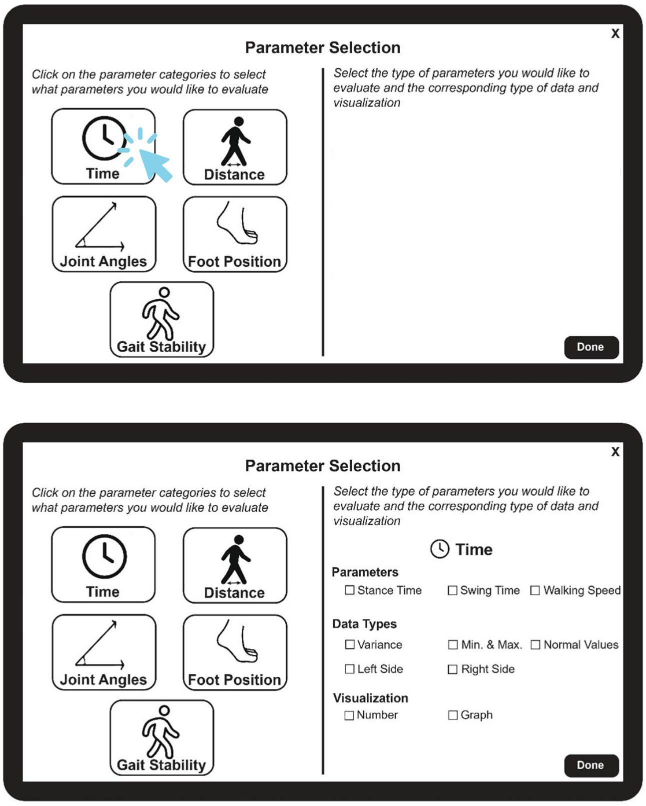


Figure 88. Touchpoint 4. Concept 2, Change data and visualizations per parameter type on one screen

Step 5. Viewing Data

In terms of what parameter categories are shown at one time, participants favour a combination of Concepts 1 and 2 (Figures 89 and 90). They do not want to automatically see all parameter categories at once, like in Concept 1, because this is too overwhelming. At the same time, with Concept 2 they also do not only want to be able to see only one parameter category at a time. This would make would be difficult to compare results between categories.

Participants would rather be able to select what parameter categories they want to view at one time and see two to three categories on their screen without needing to scroll. This would allow clinicians to control what they see, while sill being able to evaluate and compare parameters.

> *"Viewing parameters together leads to more insight."*

Participants liked that in Concept 1, with the mouseover column they can change the parameters they are evaluating on the same screen as the test results without it taking up space.

> *"The easy thing about having it here is that when you click on one (a parameter) then you can already see what happens, so I think that is better for the visualization."*

> *"I like this settings that you can change it easily next to your visuals and you can see what will change."*

Participants preferred for the avatar video to be made smaller in order to fit two to three parameter categories on the same screen. They did not have a preference whether the avatar was on the top of the screen or on the side; whatever position will allow for the most results to be seen. They did would like the avatar to remain in a fixed position on the screen so that when they scroll down they can still see it.

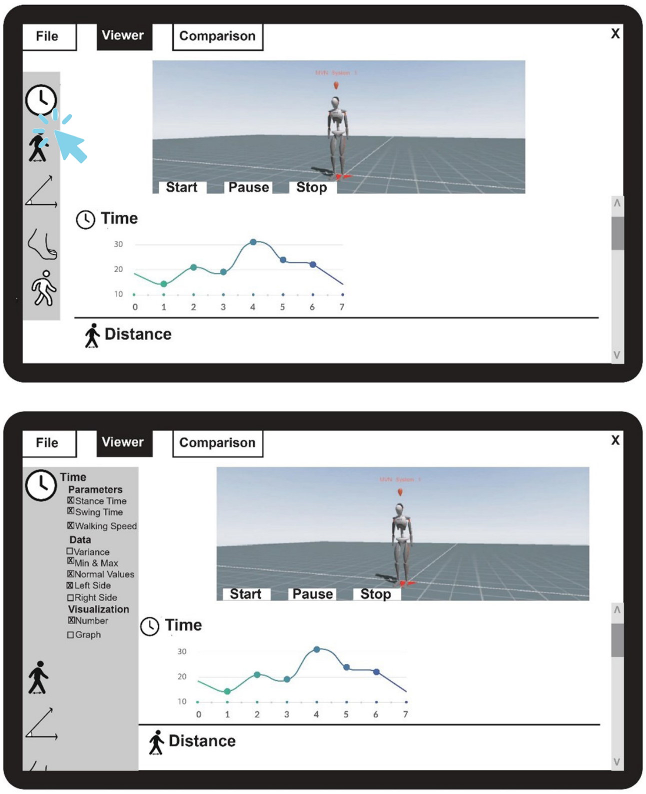


Figure 89. Touchpoint 5. Concept 1, Can view all parameters at one time and can change what parameters that are shown.

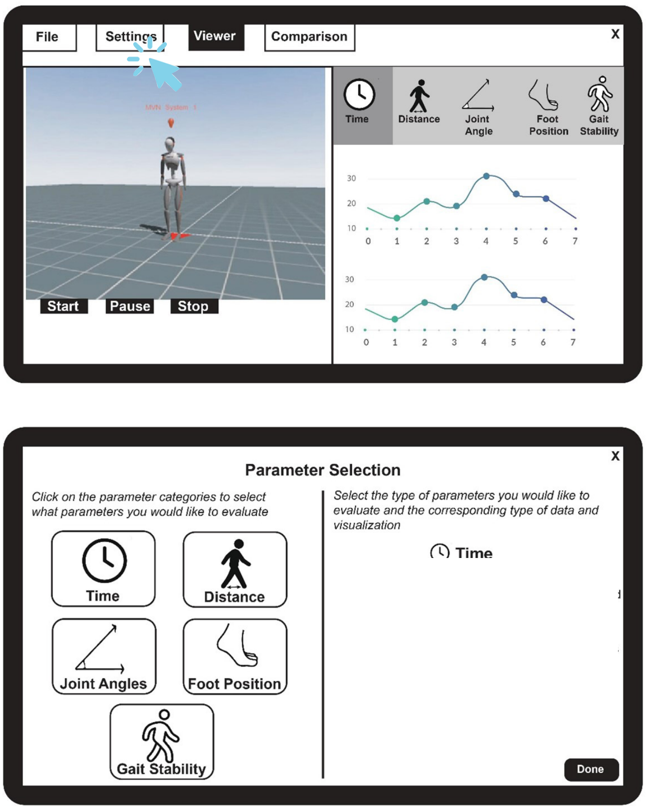


Figure 90. Touchpoint 5. Concept 2, Can view one parameter at a time and need to return to settings to change what parameters are shown

Step 6. Comparing Between Sessions

As with Steps 4, the participants want to have a standard set of visualizations and data type that they can then change later on.

> *"I agree with the having pre-sets. I think that might be a very helpful step."*

Similar to Step 5, they want to be able to select what parameter categories they see at one time and be able to see two to three categories on one screen without needing to scroll. Additionally, participants want to change the parameters they are evaluating on the same screen as the test results, like in Concept 1 (Figure 91).

Likewise, instead of having separate columns for each test (Figure 92), have all test results displayed on one visualization per parameter. This would make it easier to see the differences between test results.

> *"Having all results on one graph would be nice because then you can compare it."*

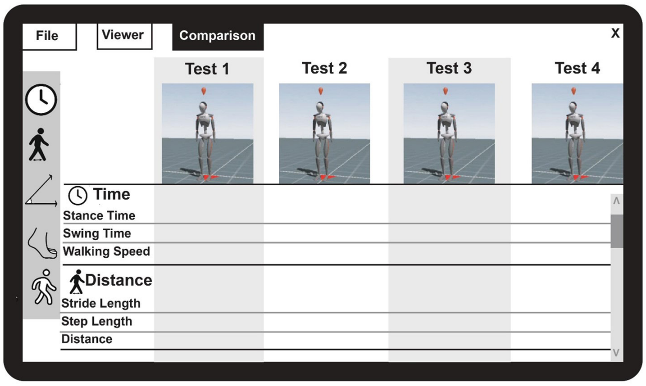


Figure 91. Touchpoint 6. Concept 1, Can view all parameters at one time and can change what parameters that are shown.

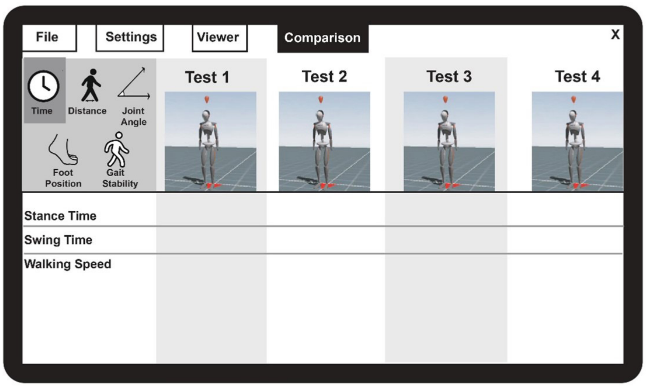


Figure 92. Touchpoint 6. Concept 1, Can view one parameter at a time and need to return to settings to change what parameters are shown

Overall Layout

Throughout the evaluation, it was mentioned numerous that in order for clinicians with limited gait assessment experience to want to and continue to use the interface, it needs to be kept simple. Simple in terms of how to use it as well as in terms of how much information is presented in the visualizations.

> *"What will make it (the interface) more accessible is it if you keep it simple. I think that's the key to success: to keep it as simple as possible."*

> *"It's better to keep it simple because we are simple people."*

Visualizations

Test Results & Normal Values

Data Types

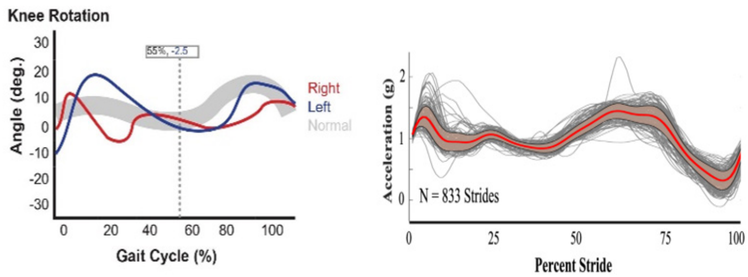
For each parameter, the data can be viewed in three ways, just the data presented, the data plus the standard deviation, and the data plus minimum and maximum values (Figure 93). The type of data participants would like for each parameter was evaluated at the same time as the visualizations.

Data

6.03

Data + Standard Deviation

6.03 ± 0.25



Data + Minimum & Maximum

	Average	Min.	Max
Right	6	2	10

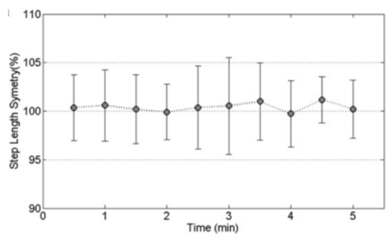


Figure 93. Data Types

Time, Distance, & Gait Stability (Base of Support)

Since the time, distance, and base of support contained almost all the same visualizations they were evaluated together.

Even though the average horizontal and table of average data show the same information, the horizontal plot was easier to interpret than the table because it was possible to see where the results are in respect to the normal values (Figure 94 and 95).

> *"It is easy to understand because you have the numbers, but you also have the visualization."*

The scatter plot is of added value in interpreting the gait pattern as it says something about every step in the test (Figure 96).

> *"I can imagine that if you have a patient and you assume that there is a lot of difference between steps, then it is interesting to see what the scatter plot says."*

Participants preferred for the average horizontal plot to be in the standard set of visualizations and the scatter plot as an additional visualization choice they can select later to evaluate.

> *"I would start with the horizontal plot. If I think that is quite normal then I don't have to look at the other ones. But if I see some big differences then I can look at the scatter plot and see where the problem is."*

In doing so, the standard data type will be just the data and standard deviation and the minimum and maximum will be in the additional settings.

In addition to plotting the data, showing the normal in the visualizations is extremely helpful in interpreting the results. It allows for clinicians to obtain an overview of the results without having to evaluate them indepthly. This was especially true for the physicians.

> *"First, I want to see if it (the data) is normal or not. When it is not normal then you want to see look further into the data. Also, if I get a result that seems normal, but with the clinical eye it is not normal then that is interesting to evaluate further too."*

The normal values are enough and showing the percentage the data is off from the normal values does not bring any added value.

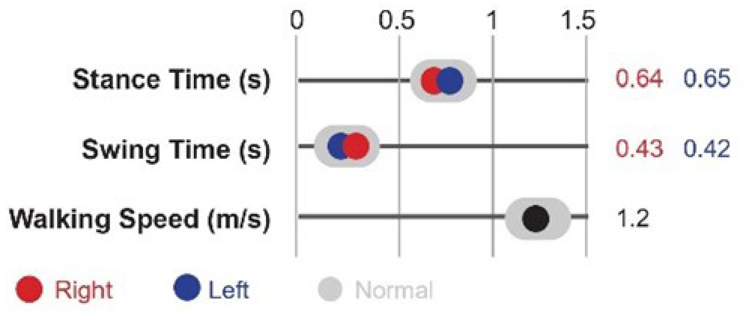


Figure 94. Average Horizontal Plot

Parameter	Right	Left	Normal
Stance Time (s)	0.64	0.65	0.65
Swing Time (s)	0.43	0.42	0.44
Walking Speed (m/s)	1.2		1.2

Figure 95. Average Data Table

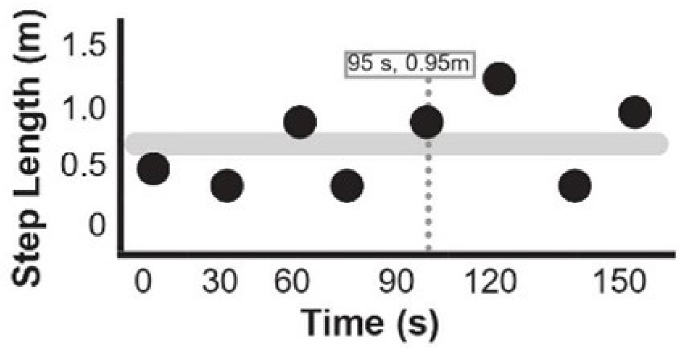


Figure 96. Scatter Plot

Foot Position, Joint Angles, & Gait Stability (Position Center of Mass)

As foot position, joint angles, and gait stability contain nearly the same visualizations, they were also evaluated together.

For foot position, the icon with the average is clear and easy to understand (Figure 97). The table of minimum and maximums for the joint angles was difficult to interpret (Figure 98). Participants preferred to see the data in graphs than only numbers.

Participants found the average over the gait cycle and data over time line graphs to be intuitive to understand (Figure 99 and 100). They also want to see a line graph of every step over the gait cycle as well. The line graph of every step over the gait cycle is easier to view and interpret than the line graph over time.

For all parameter categories, they would prefer to have the line graph of the average over the gait cycle in standard set of visualizations and the line graphs of the data over time and of every step over the gait cycle in the additional settings. They would first look at the average line graph over the gait cycle and then if they if they see something is off then they look at the other graphs to analyse the gait step by step. With this, the standard deviation and minimum and maximum data types would also be in the additional settings.

For the joint angle graphs, the physicians want the option to see all joints as well as abduction/adduction, flexion/extension, and rotation all on one graph or on separate graphs.

"Maybe there could be an option to tick each joint and then you can view it either as one graph or either two or three of them."

At times participants found it hard to give feedback on the visualizations. Since the line graphs are examples and were not made with real data, they found it hard to visualize what the graphs would look like in an actual test. It was also difficult to select a visualization they prefer because they are not used to interpreting gait assessment data.

"It can be hard because we are not very used to seeing data and interpreting them. Once you know how to interpret them then you know what you need"

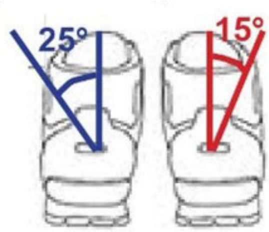


Figure 97. Icon with Average Data Displayed

Knee Angle (deg)	Overall		Stance Phase		Swing Phase		At foot strike
	Min.	Max.	Min.	Max.	Min.	Max.	
Right	-3.26	33.67	-0.15	15.60	-3.60	33.67	2.32
Left	-1.26	46.98	-1.26	31.81	0.63	46.98	8.90
Normal	-2.00	35.00	-1.00	25.00	-3.00	45.00	5.00

Figure 98. Table of Minimums & Maximums

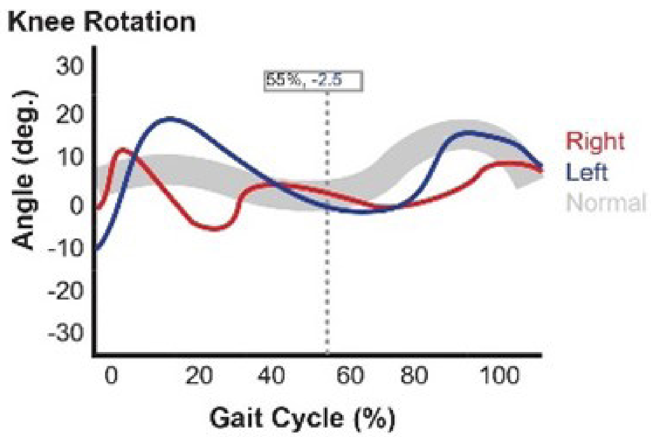


Figure 99. Average Over Gait Cycle

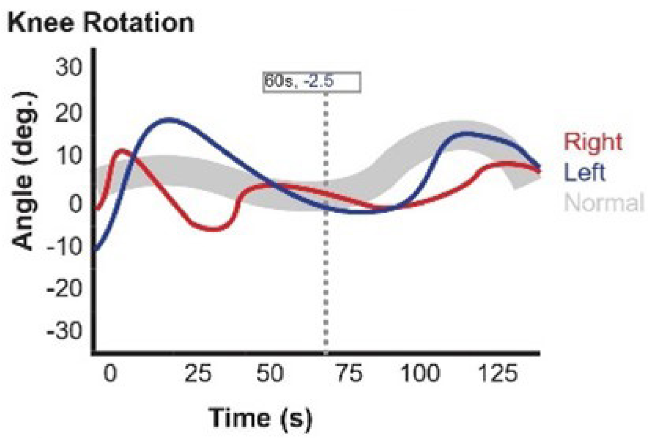


Figure 100. Data Over Time

Comparing Between Sessions

Time, Distance, & Gait Stability (Base of Support)

Participants did not like the average values table (Figure 101). They found it easier to compare tests when the numbers are given through a graphic, as in the bar graph of averages and the horizontal plot of averages (Figures 102 and 103).

The scatter plot gives useful information, but it is difficult to interpret because there are so many data points (Figure 104). Participants suggest having a separate scatter plot for each test. Alternatively, to make them easier to interpret, the scatter plots could be made larger to spread out the points and each test have a different data point shape and colour.

As with the previous visualizations, one of the most important features for the participants is being able to compare the data with the normal values.

The participants would like either the bar graph or the horizontal plot to be in the standard set of visualizations and the scatter plot for all parameters, including time, in the additional settings. The designer decided it would be best to use bar graphs instead of the horizontal plot as the bar graphs are easier to compare a lot of tests, while in the horizontal plots, the large number of dots may confuse clinicians.

	Test 1		Test 2		Test 3	
Parameter	Right	Left	Right	Left	Right	Left
Step Length (m)	0.66	0.62	0.70	0.64	0.64	0.62
Stride Length (m)	1.27		1.30		1.23	

Figure 101. Table of Average Values

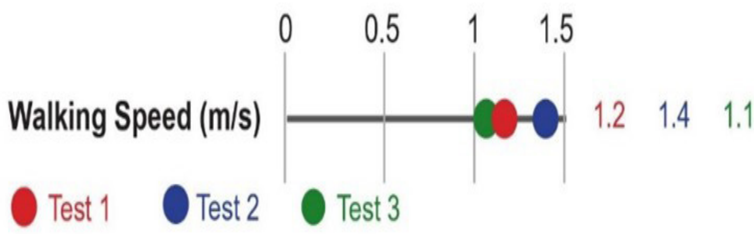


Figure 102. Average Horizontal Plot

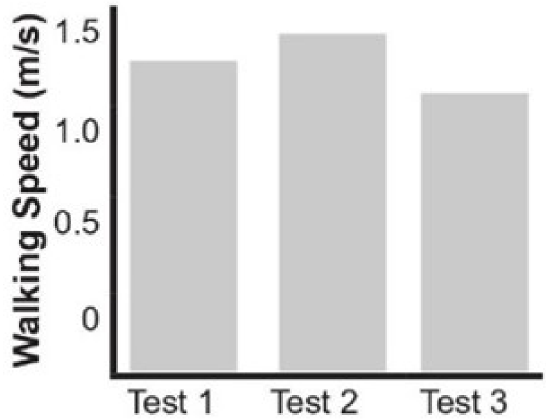


Figure 103. Average Bar Graph

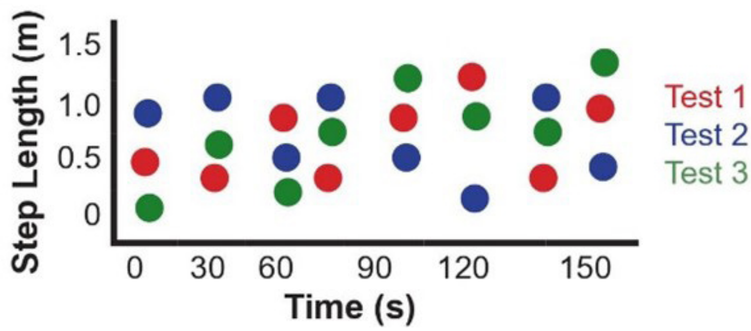


Figure 104. Scatter Plot

Foot Position, Joint Angles, & Gait Stability (CoM & XCoM)

Participants would like to be able to view the avatar videos along with the graphs (Figure 105). In doing so, they avatar videos and graphs would be on the same screen so they can compare the videos with the results in the graphs.

Same as the end of trial visualizations, they prefer for the line graph of the average over the gait cycle to be in the standard set of visualizations and the line graphs of the data over time and of every step over the gait cycle to be in the additional settings. In terms of viewing the test data all one graph or on separate plots, they would like to have all test data in the same graph for each parameter with check boxes next to graph so the user can select what they want to see at one time (Figure 106 and 107).

Patient Parameters

In the focus group session with the physiotherapists there was not enough time to discuss the section regarding what parameters clinicians want patient to be able to view, so it was only answered in the physician session. To allow patients to better understand their gait, physicians would want to show patients walking speed, step/stride length, distanced walked, prepositioning of foot in swing, and foot placement in stance. They think it may be useful to also show patients the joint angles, but they are unsure. It is not needed to show patients swing/stance time, position center of mass, and the base of support.

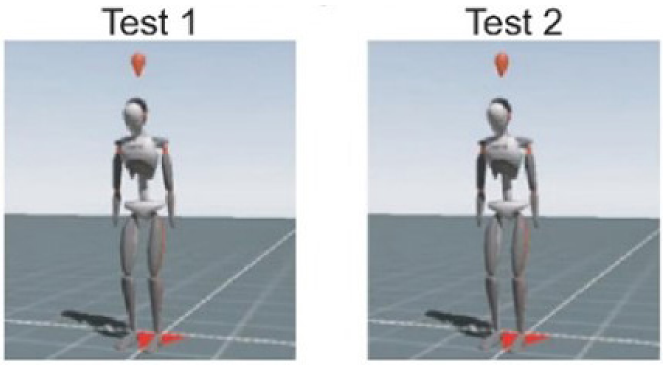


Figure 105. Side by Side Avatar Videos

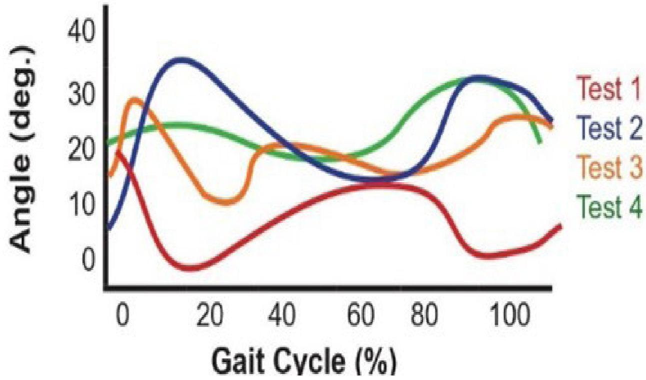


Figure 106. Test Data Plotted Together

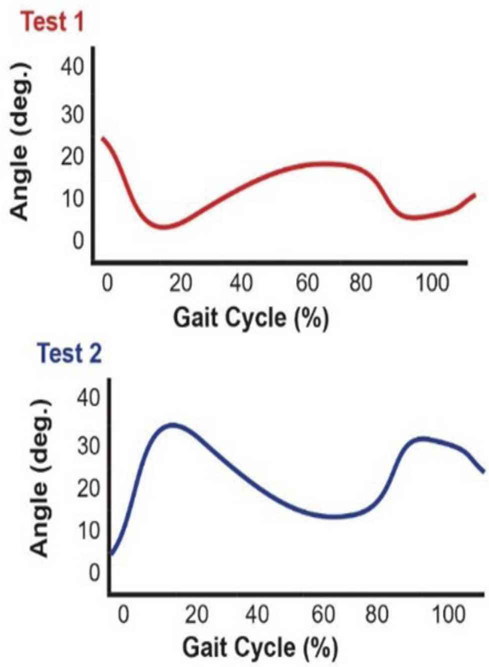


Figure 107. Test Data Plotted Separately

APPLICATION OF RESULTS IN THE DESIGN

Interface Layout

Touchpoints 1. Entering User Interface, Step 2. Login, & Step 3. Start Page

The content and general structure of touchpoints 1, 2 and 3 can remain the same. Participants gave positive feedback on their usability and functionality and did not give any significant suggestions for improvement.

Touchpoint 4. Parameters & Visualizations Selection

- The interface has a standard set of visualizations and data that the user will see. The user can change the data and visualizations if they want to. In doing so, touchpoint 4 can be moved to after touchpoint 5 or 6.

- Allow user to select what parameters they want to evaluate on the same screen as they are viewing the test results.

- The user can change the data and visualizations settings all on one screen and do not have to go back and forth between screens.

- The user can select the visualization and data type for each parameter.

Touchpoint 5. Viewing Data

- The user can select what parameter categories they want to see at one time. In doing so, they can see two to three parameter categories on one screen without needing to scroll.

- On the same screen as the test results, the user can select what parameters they want to evaluate.

- The size of the avatar will be decreased and the avatar will remain in a fixed position on the screen.

Touchpoint 6. Comparing Between Sessions

- As with Touchpoint 5, there will be a standard set of visualizations that can be changed later if wanted.

- The user can select what parameter categories they want to see at one time. In doing so, they can see two to three parameter categories on one screen without needing to scroll.

- On the same screen as the test results, the user can select what parameters they want to evaluate.

- Instead of having separate columns for each test, all test results will be on one visualization per parameter.

- To aid in the simplicity of the interface, the layout of touchpoints 5 and 6 will be the same. The types of visualizations will also be similar and how the user selects the parameter and parameter categories to view will be the same.

Visualizations

Test Results & Normal Values

Time, Distance & Base of Support

- The average horizontal plot will be the standard type of visualization, with the scatter plot as an additional option to change to later on.

- For data types, just the data will be in the standard visualizations and the standard deviation and minimum and maximum will be in the additional settings.

Foot Position, Joint Angles, & Gait Stability (CoM & XCoM)

- The line graph of the average over the gait cycle in standard set of visualizations and the line graphs of the data over time and of every step over the gait cycle in the additional settings.

- Standard deviation and minimum and maximum data types would also be in the additional settings.

- Users will have the option to be able to view all joints as well as abduction/adduction, flexion/extension, and rotation all on one graph or on separate graphs.

Comparing Between Sessions

Time, Distance, & Base of Support

- The normal values will be displayed on the visualizations such that it is easy to compare the test results with the normal values.

- The bar graphs of the averages will be in the standard set of visualizations and the scatter plot in the additional settings.

- The scatter plots will be easier to interpret through having a separate plot for each test, making the plots larger to spread out the points, and/or each test having a different data point shape and color.

Foot Position, Joint Angles, & Gait Stability (CoM & XCoM)

- The user will be able to view the avatar videos and visualizations at the same time.

- The line graph of the average over the gait cycle will in the standard set of visualizations and the line graphs of the data over time and of every step over the gait cycle will be in the additional settings.

- For each parameter, all tests can viewed in the same graph. There will be check boxes next to graph so the user can select what they want to see at one time.

- In patient version of the interface, the parameters of walking speed, stride/step length, distance walked, prepositioning of foot in swing, and foot placement in stance will be included. Joint angles may be included. Swing/stance time, position Center of Mass, and the base of support will not be included.

EVALUATION WITH CONVERGENCE TEAM

The interface layout and visualization concepts were reviewed with members of the Convergence Team, Herwin Horemans and Daniel Lemus Perez, to obtain feedback on the concepts' usability, functionality, and feasibility.

In terms of the interface layout, all concepts are possible to program and develop. The login feature is feasible, but may take additional effort as it also to pass the requirements of the security network currently implemented at Rijndam Revalidatie.

With the data provided by Xsens MVN Analyze and MATLAB, it is feasible to develop all of the concept visualizations. At the end of trial, it will not be an issue to develop the visualizations, but in real time it is a little more difficult. This is due to having limited time to process the data, which impacts the quality of the results and can lead to a delay in viewing the results.

It was also suggested to have the same type of visualizations for position center of mass and extrapolated center of mass as base of support. In addition, in the comparison visualizations, distinguish the tests not only in colours but also shapes to allow for color blind users to also use the interpret the visualizations.

4.5 Interviews with Incomplete Spinal Cord Injury Patients

Two incomplete spinal cord injury patients were interviewed to learn more about how the user interface can benefit SCI patients. From these interviews, information was gathered regarding patients' experience in gait rehabilitation, the features and content they would like in the user interface, and if they can understand the visualization concepts.

In the user research questionnaire and focus groups, it was expressed that the physicians and physiotherapists wanted to use the interface to provide visual feedback to patients. Furthermore, in the research regarding the work flow for incomplete SCI gait rehabilitation (Section 2.4), showing patients their progress in physiotherapy was a potential way to increase patient motivation.

The purpose of interviewing patients was to learn more about gait assessment from a patient's perspective and see if there is a need for them to view their progress throughout gait rehabilitation. Doing so aimed to identify if there are any needs currently unmet in gait rehabilitation and if the interface could fulfill these needs to make their rehabilitation experience better. Also, to assess if patients can understand the visualization concepts on an overview level and if there is any additional information patients would like to see in the interface that is currently not included.

RESEARCH QUESTIONS

1. From the perspective of patients with incomplete spinal cord injuries, what is their experience in gait rehabilitation? Do they want anything added or changed to improve their experience?
2. What features and content do incomplete SCI patients would like in the user interface? Would they want to see their gait rehabilitation progress?
3. Can patients with minimal pre-existing knowledge on gait analysis understand the gait assessment visualizations on an overview level?

4. METHOD

Participants

Two incomplete spinal cord injury patients who are currently undergoing inpatient rehabilitation at Rijndam Revalidatie Westersingel were interviewed. The designer was put into contact with the patients through two physiotherapists who participated in the concept evaluation focus group sessions.

Patient 1 was in his late 60s and had been at Rijndam since November 2020. Before retiring, he worked in the development of new products. Patient 2 was in her early 20s and had been at Rijndam since February 2021. She worked as a speech therapist.

Procedure

The interviews were conducted individually and took place at Rijndam Revalidatie Westersingel. Each interview lasted 45 minutes to one hour. The interview began with a short explanation of the project, the Xsens system, and the purpose of the interview. During the meeting, the participant was asked a series of questions (Appendix BB). Participants were also shown the visualization concepts to aid in the discussion (Figure 108).

Figure 108. Visualizations Shown to Participants

Data Analysis

Notes were taken during the interview. The audio of each interview was recorded and transcribed afterward.

RESULTS

RQ 1. From the perspective of patients with incomplete spinal cord injuries, what is their experience in gait rehabilitation? Do they want anything added or changed to improve their experience?

Both patients were satisfied with their experience in physiotherapy so far. The physiotherapists are straightforward and explain what they need to do in a way that is easy to understand. They found that a combination of both verbal and visual instructions is the best way to comprehend what should do. For example, in Patient 2's physiotherapy sessions, the physiotherapist uses a mirror so she can see what she is doing, which is very helpful

> *"Most of the time they (the physiotherapist) says to me what I need to do differently, or they just grab my hips and show me what I should. So, not only verbally but also when you feel it or when you see it, that's very helpful."*

When meeting with their physician, they are at times confused with what they are telling them. For Patient 1, he gets confused when the physician starts to speak in technical terms. Patient 2 understands the technical terms, but gets lost during the conversation as they explain everything verbally rather than using visuals.

RQ 2. What features and content do incomplete SCI patients would like in the user interface? Would they want to see their gait rehabilitation progress?

Both patients would be interested to see their test results on the interface. They think the avatar would be very interesting to look at and would help in the physiotherapy sessions.

> *"The physiotherapist indicates that you should stretch your knee more, but then it would be great if you could see it on the screen."*

Patient 2 believes it would also be interesting to be able to measure how much weight the patient puts on each leg and on the avatar to be able to highlight the area the physiotherapist or physician wants you to look at (Figure 109)

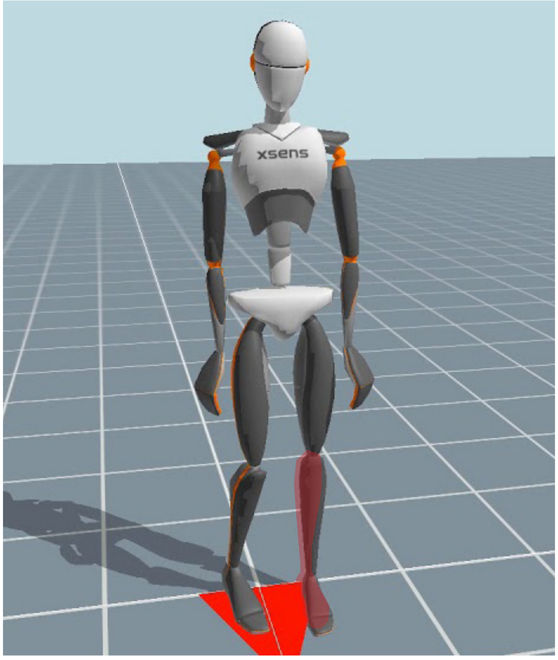


Figure 109. Avatar with Left Leg Highlighted

They expressed that rather than operating the interface on their own, they most likely see the interface being used as a tool for the physiotherapists and physicians to explain their gait pattern to them. The patients would also like the option of receiving a printout of the report if they wanted to review it later, but they do not think this option would be used often.

Patient 2 would want access to the interface to view her results whenever she would like. She did not think her family members would be interested in having access to the interface. Patient 1 did not feel it was necessary to have access to the interface. He believes he is currently kept up to date and there is no need to check his results constantly.

> *"Having your own app, people will open it many times. Check it too many times. There is a kind of system now where you can check all the results yourself, but I don't. With your physicians himself giving details and answering questions, it is far more motivating. I have never checked the results myself."*

Tracking Progress

Both patients are very interested in being able to see their progress. Their lung function and hand force are the only elements currently measured frequently and tracked, but they would want to see more of this. Viewing their progress could allow them to see how much they have improved and what they can continue to work on.

"Today I was in the Zero-G for the last half-hour and I saw that I'm still progressing. That's so motivating! That's incredible!"

"To see the progress in details, that's a beautiful thing that you can see them."

Tracking their progress would also be important in maintaining their motivation. For example, Patient 2 mentioned that she is usually very motivated but sometimes after team meetings, her motivation dips.

"My motivation is always quite high, but sometimes it gets low after a team meeting when they analyze on how you are doing and what they think you are going to achieve. And when they say 'I think you will achieve this and these things,' I get a little demotivated."

Even if they can't achieve everything they initially thought, seeing how far they have come could motivate them to continue to improve. The interface could also be used to track the progress a patient has made towards reaching a goal.

"Maybe it's nice to visualize like this your goal right now and after every measurement to see like oh you're this far as far, you're going to you're almost reaching your goal."

In addition to seeing their progress through visuals and graphs, they would also like it to be shown in terms of percentage or factor of increase. In terms of how often to test to track the progress, Patient 1 prefers once a month, while Patient 2 thinks it would be best to test every 1 to 2 weeks.

Patient 1, *"When I started here, they told me you have to think in months. In the end, I see that's true. And progress is in very small steps."*

Patient 2, *"I think if you do it (test) more frequently then you see more of your progress, but also then you see like 'Oh I need to I need to change this and work on that.' When you do it every month, you're not here that long, maybe you're here for like half a year, and then you only have six measurements."*

RQ 3. Can patients with minimal pre-existing knowledge on gait analysis understand the gait assessment visualizations on an overview level?

After a brief explanation of the visualization concepts, the patients could generally understand what they mean. They still did not fully understand how to interpret the visualizations but expressed that they can learn to understand them through the clinicians explaining the visualizations in more detail and with more time.

They found the avatar to be the most helpful in understand gait pattern with the concepts that just had a table of numbers to be the most difficult. The patients also liked that they could compare the results to the normal values, even though they know it is most likely possible they will never achieve the normal values.

"I think it's just good to see the normal because that's what you want to achieve. You already know that you maybe cannot achieve the normal but it is good to see where you are now and where you're going to go."

APPLICATION OF RESULTS IN DESIGN

Due to time constraints, tracking a patient's progress was not be a feature included in the interface for the next design iterations. In this project, it was also not possible to develop a separate interface for the patients to access. It is a recommendation to work on these features in the future development of the interface. As only two patients were interviewed, it is also recommended to conduct more interviews before developing the patient features for the interface. In the future development, the following is how the results from the interviews can be applied in the design:

- The user interface is used as a tool for physicians and physiotherapists for explanation and motivating patients.

- Convey information to patients in visuals rather than numbers.

- In the interface, clinicians will be able to track a patient's progress.

- Show patient's progress not only through graphs and visuals, but also in terms of percent or factor of increase.

- Clinicians will be able to give patients a printout of their results.

- Potentially develop a separate version of the interface for patients to have access to.

- Provide clinicians with the method to explain what the visualizations mean to the patients.

Chapter 5
Final Design

5.1 GAIT VISION

5.2 CONTEXT OF USE

5.3 DESIGN WITH REQUIREMENTS

5.4 SCREEN FLOW & FUNCTIONS

5.1 Gait Vision

Gait Vision is an easy-to-use interface that allows physiotherapists and physicians to assess gait objectively and time-efficiently. It provides more accurate and objective information than can be obtained with the clinical eye, in a way that is more intuitive and comprehensible for clinicians with minimal gait assessment experience than laboratory gait assessment.

The interface works in collaboration with Xsens MTW Awinda. Xsens wireless motion trackers are placed on the patient. The data from the motion trackers is transferred to Gait Vision, where it is then processed.

USE

Gait Vision can be used for patients with incomplete spinal cord injuries (SCI), neurological disorders (such as multiple sclerosis, cerebral palsy, and stroke), and prosthesis.

Clinicians can utilize Gait Vision to aid in selecting orthosis. It can be used to evaluate the effects of spasticity treatment and track patient's progress as well. Gait Vision also serves as a tool for clinicians to explain their gait assessment findings to patients, fellow clinicians, and other members of the gait rehabilitation team.

With Gait Vision, gait assessments can be conducted anywhere and do not have to be confined to a laboratory setting. This allows for testing to be conducted in more natural and realistic environments.

Interface

Through self-evident screen flow and actions, Gait Vision can be used by clinicians with minimal technical experience. The layout of the interface consists of two main sections, Viewer and Comparison. In Viewer, the user can view the patient's gait data while the test is occurring as well as after the test has concluded (Figure 110). In Comparison, the user can compare up to three tests (Figure 111).

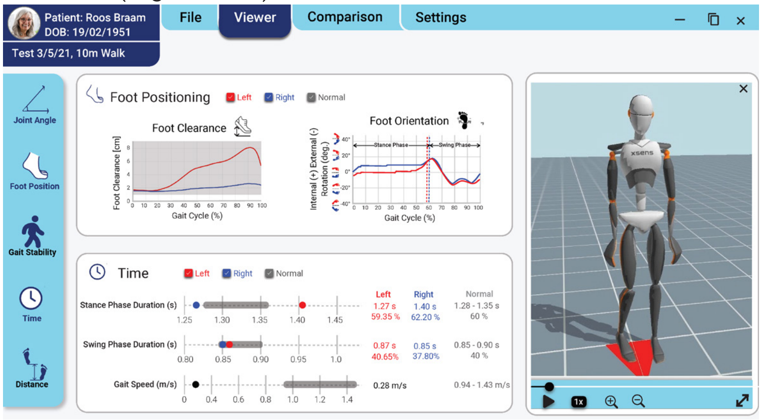


Figure 110. Viewer

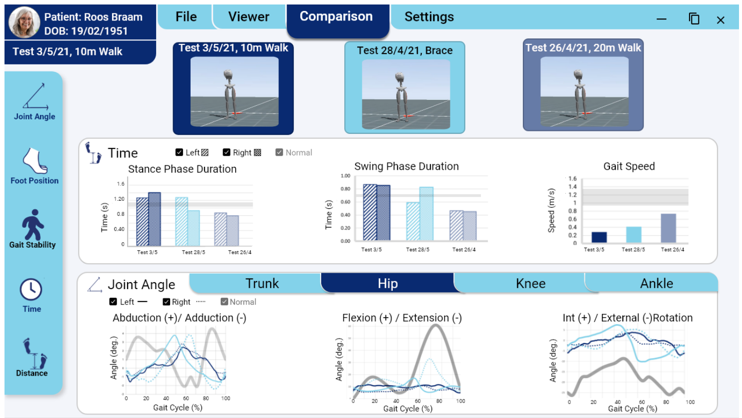


Figure 111. Comparison

Visualizing Gait

The patient's gait can be viewed through an avatar or intuitive graphs and charts. The graphs are designed to be understood by both clinicians with minimal experience with gait assessment and those who are more advanced. This is done by providing a standard set of visualizations that all users will first see upon entering Gait Vision (Figures 112 and 113).

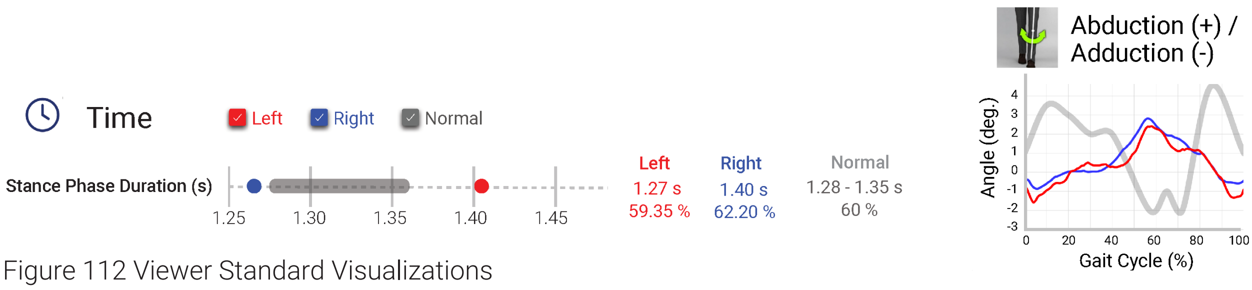


Figure 112 Viewer Standard Visualizations

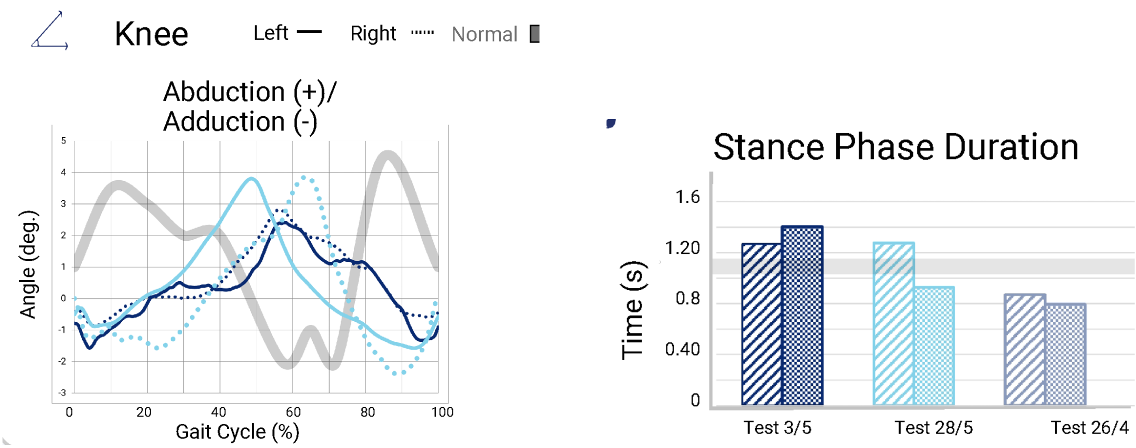


Figure 113. Comparison Standard Visualizations

As the user becomes familiar and comfortable with gait assessment, they can customize each parameter in terms of the type of data and visualization they would like to view (Figure 114). This allows for up to nine different types of visualizations that can be developed per parameter. The user can further customize what they see by having the ability for each parameter to turn the normal, left side, and right side data on and off (Figure 115).

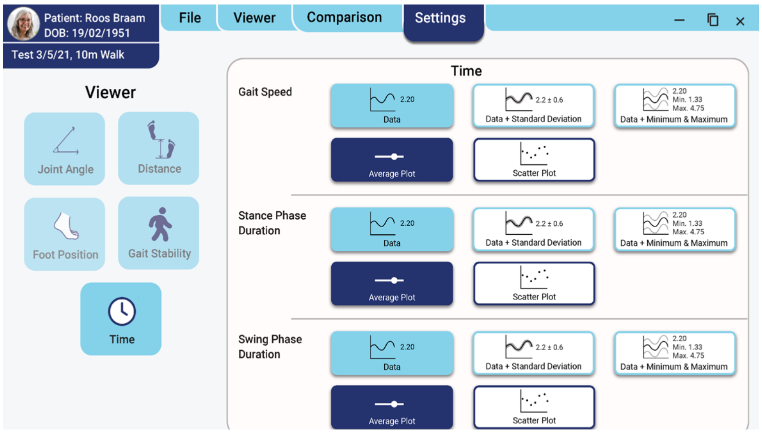


Figure 114. Settings

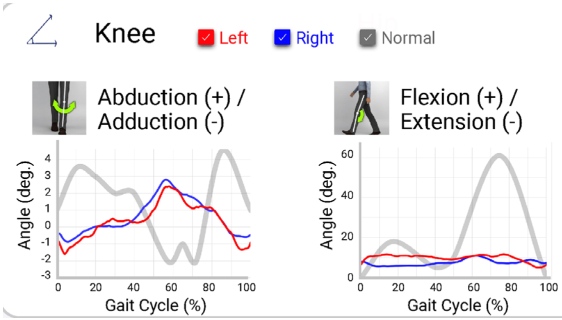


Figure 115. Turn Left, Right, & Normal Data On & Off

STAKEHOLDER BENEFITS

Clinicians (Physiotherapists & Rehabilitation Physicians)

Gait Vision allows them to obtain more accurate and objective information than with the clinical eye, in a way that is more accessible and less time consuming than current laboratory gait assessment. Clinicians can also use Gait Vision to explain problems in gait to patients and fellow clinicians.

Patient

Through being able to see their gait in Gait Vision visually, they can better understand where and how they can improve. The accurate and objective information clinicians are provided will also ensure that clinicians are recommending the proper intervention for them.

Rehabilitation Team (Occupational Therapist, Social Worker, Psychiatrist)

In team meetings, physiotherapists and physicians can use data visualizations to better explain why they selected an orthosis or intervention and to show a patient's progress.

Gait Rehabilitation Physiotherapy Team (Rehabilitation Nurse, Physiotherapist Technician, Sports Therapist)

Through the visualizations and avatar, they can better understand what needs to be worked on in the patient's sessions.

Neuro or Orthopaedic Surgeon

With Gait Vision, they can obtain additional information on a patient's gait that can be used to select surgical treatment and guide surgery.

Orthosis Expert

Gait Vision can be used in testing orthoses to select the best fit for each patient.

Convergence Project Team

Gait Vision contributes to reaching the goals set out in Convergence Project proposal of creating an easy-to-use interface that allows clinicians to access objective gait analysis data without needing engineering skills.

Erasmus University Medical Center

Gait Vision is a tool that helps clinicians to provide first-rate care to patients. It provides clinicians with information that can better inform their clinical decisions and improve the treatment of patients with incomplete SCI, prosthesis, or neurological disorders.

5.2 Context of Use

Gait Vision can be used with patients with spinal cord injuries, neurological disorders, and prostheses. Its operation consists of size primary touchpoints.

Clinicians can use Gait Vision to select ortheses for patients with spinal cord injuries, neurological disorders, and prosthesis. Since the motion trackers are wireless and the only other equipment needed is a laptop, testing can be conducted in anywhere, even outside (Figure 116).

Before using the interface the motion trackers are placed on the patient. Calibration is then conducted using Xsens MVN Analyze. After the calibration, the testing can begin (Figure 117).

Figure 116. Gait Vision Being Used To Conduct A Test Outside

Touchpoint 0. Set-Up

Place Xsens wireless motion trackers on patient

Calibrate system using Xsens MVN Analyse

Touchpoint 1. Login to Gait Vision

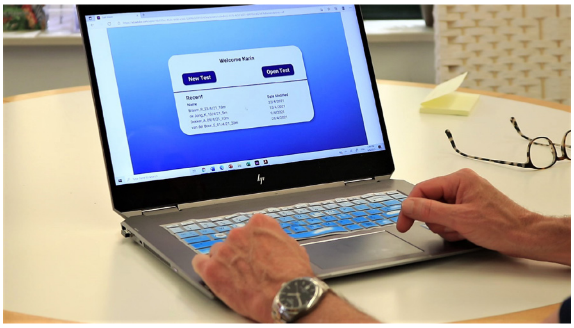
Enter Gait Vision and login using username and password

Figure 117. User Scenario

Repeat for until all ortheses have been tested

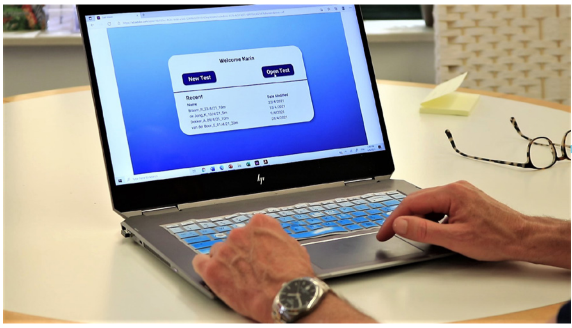
Touchpoint 2. Start Test

Start new test



Patient walks around

Open test that has already been conducted



Touchpoint 3. Viewing Data

View data results in real time while test is being conducted

End Test

View data after test has been conducted

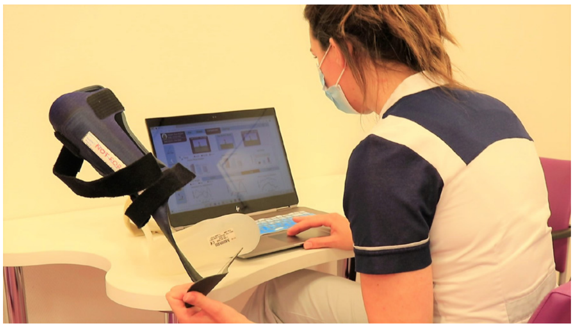
Show results to patient to explain their gait

Discuss results with other clinicians

Figure 117. User Scenario

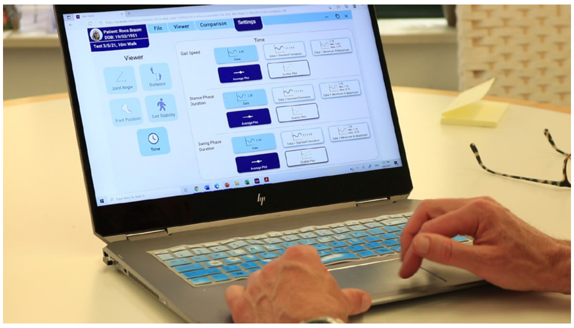
Touchpoint 4. Compare Results Between Tests To Select Orthesis

Can compare up to three tests.



Touchpoint 5. Change Parameter Settings

Can change the type of data and visualization for each parameter



Touchpoint 6. Finished

Save Test & Logout

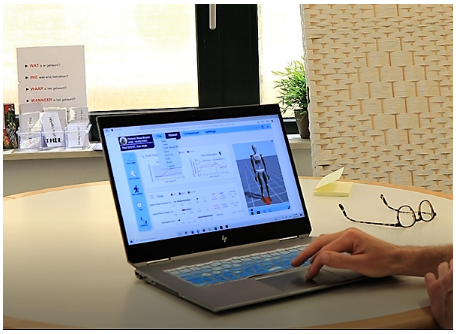


Figure 117. User Scenario

5.2. Design with Requirements

The interface design was created using the program of requirements as guidelines.

A significant aspect when designing the interface was using the program of requirements as a guideline. Below are a few examples of how they were applied.

Screen Size

All physiotherapists and physicians have laptops. To make it such that anyone can use the interface anywhere and they do not need access to a desktop, the interface was designed to work on a laptop (1366 x 768). Doing so makes accessing the data more accessible and it can be done anywhere by anyone. Also, a 1366 x 768 pixel format is more common than 1920 x 1080 and 1280 x 800 pixels and fits laptops with smaller screens, which is what the clinicians have.

9.1 The user interface and test results visualizations are aesthetically appealing and do not have a purely technical aesthetic.

The color palette was selected, not only as it is Erasmus MC's logo colors but also because it brings a more relaxed feel to the interface. The interface having pops of color does not make the user feel like they are operating a technical or medical product. The off-grey background also made the visualizations stand out more. The 60%, 30%, 10% color rule was followed throughout the interface, with off grey being 60%, light blue 30%, and navy blue 10%.

6.1 To allow the visually impaired and color-blind to operate the interface, font sizing and contrast between text should abide by the Web Content Accessibility Guidelines (WCAG).

All color combinations throughout the interface were checked according to the WCAG guidelines, and all exceeded the minimum values needed (Figure 118).

5.2. Physicians and physiotherapists with minimal pre-existing knowledge on gait analysis can understand and interpret the results.

Throughout the design, items were placed to help aid in the clinicians' understanding of the content. Icons were used to represent each parameter category (Figure 119). For parameters that were not as familiar to clinicians, such as foot orientation and joint angles, icons and diagrams were included to demonstrate what the graph values meant (Figure 120).

In the settings, rather than only have the data types and visualizations in words, icons were also created (Figure 121).

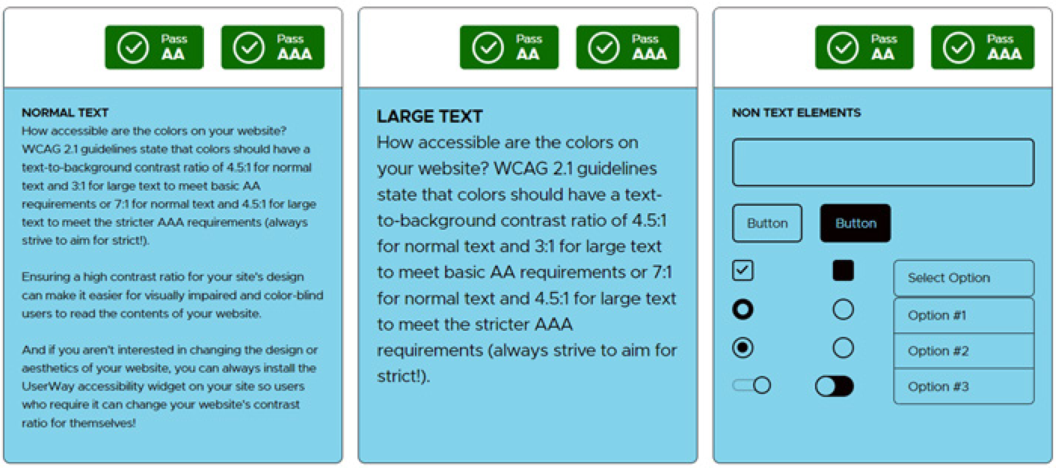


Figure 118. Text & Background Color Checked Against WCAG Guidelines

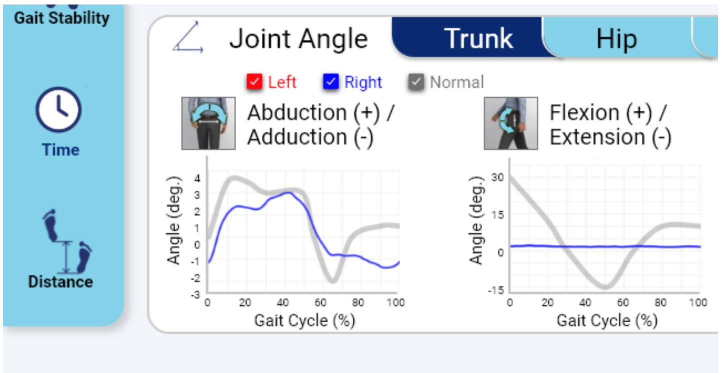


Figure 120. Parameter Icons and Diagrams for Each Joint

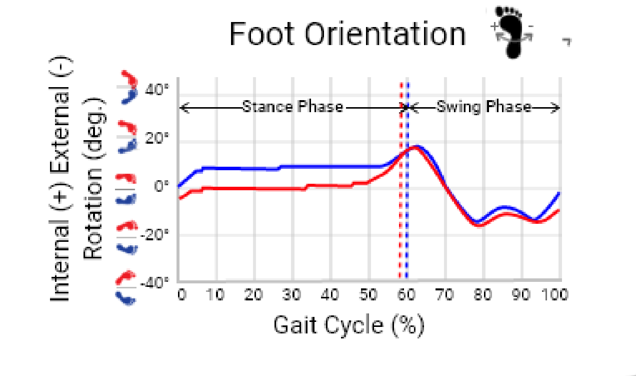


Figure 121. Icons Used to Represent the Change in Foot Rotation

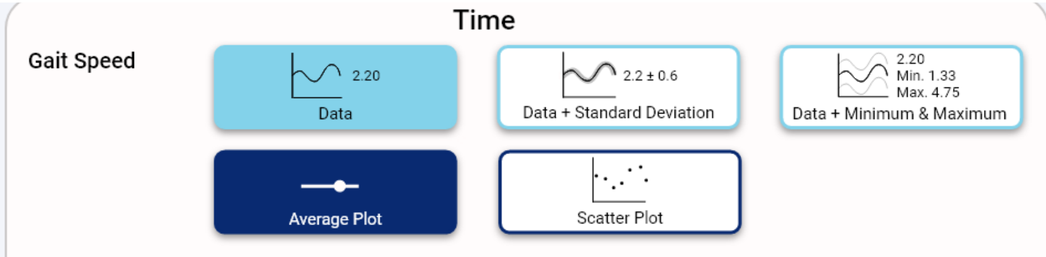


Figure 122. Icons For Each Type of Data & Visualization

8.2 The user interface layout should follow a logical flow. & 8.3 The user interface contains an effective visual hierarchy

The parameter menus categories were organized, with the top parameter category being what was the most wanted in the user research to the bottom category being the least (Figure 123). The tabbed top menu items were placed in the order that they would be used. The joint angle tabs went from trunk to ankle to emulate looking at gait from a top to bottom approach.

In the menu designs, attention was also paid to the hierarchal structure of the items.

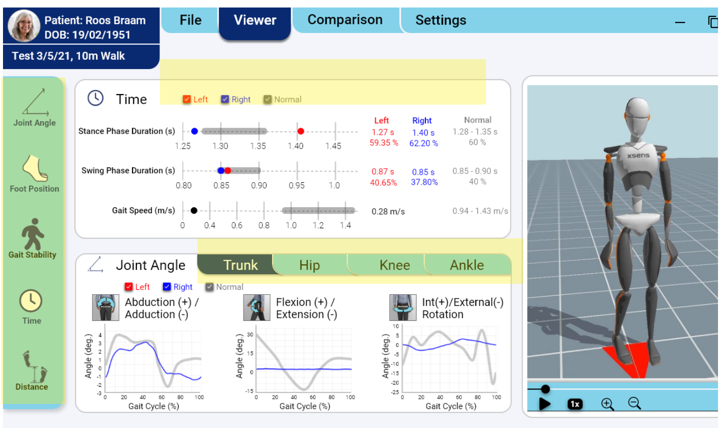


Figure 123. Menu Items Follow a Logical Flow

7.2 Affordances are implemented throughout the user interface.

To notify the user what they can and cannot click, all clickable items, such as the checkboxes and tabs, were shaded or highlighted (Figure 124).

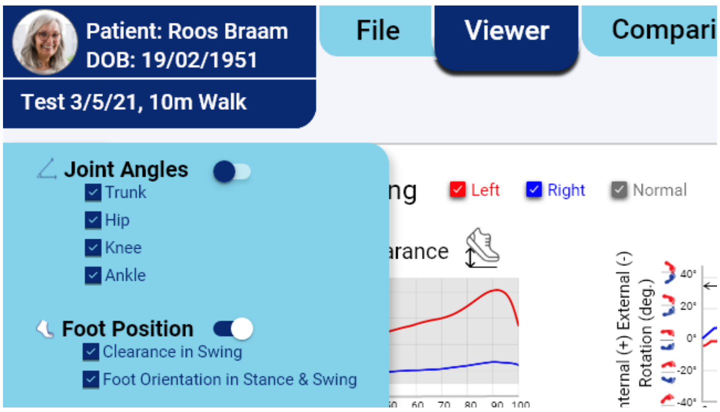


Figure 124. Used Shading to Notify User What Could be Clicked

7.3 Be consistent and follow established conventions.

In accordance with established conventions, to go from screen to screen, the menu was placed on the top. Checkboxes, slider bars, and buttons were used throughout the design as that is something the user is familiar with and know how they work

In the gait assessment test reports, the left data is typically red and the right data is royal blue. As to not confuse any users who had previous experience with gait assessment, the convention was carried on.

8.1 Cohesiveness and flow is kept throughout the user

The Comparison and Viewer screens were kept similar to keep this cohesiveness across the interpretation. Having the screen look and operate similarly also reduces how much the user has to learn and memorize.

5.4. Screen Flow & Functions

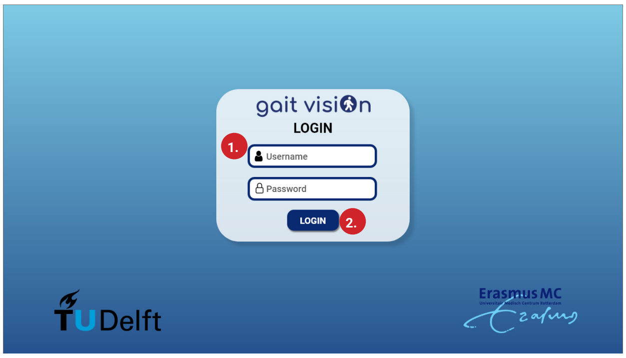
Through intuitive features and functions, clinicians can operate Gait Vision after minimal instructions.

Gait Vision will be operated on a laptop. In doing so, the interface is controlled with a mouse and keyboard.

Through implementing affordances and conventions, the interface can be operated with minimal instructions. A driving factor behind the design was also for the user to complete as few actions as possible. The operation of Gait Vision is further explained in Figure 125. The screen flow in Figure 125 is for viewing data at the end of a test. Viewing the data in real time would have a similar flow.

Touchpoint 1. Login

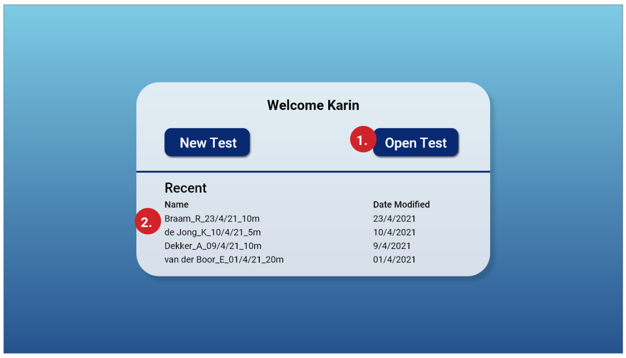
1.1 Login



1. Type in username and password, which is unique for each user
2. Click Login

Touchpoint 2. Open Test

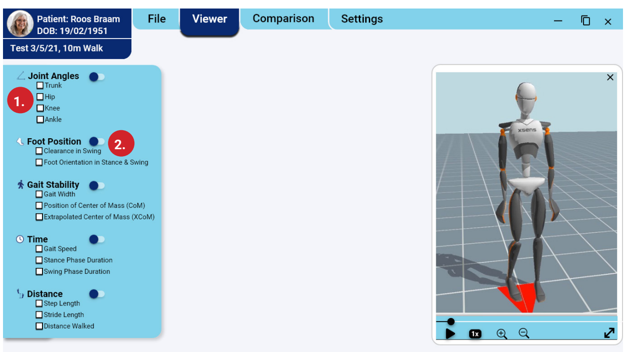
2.1 Open test



1. Click on button to open a test that has already been conducted
2. Or click on a test that has been recently viewed

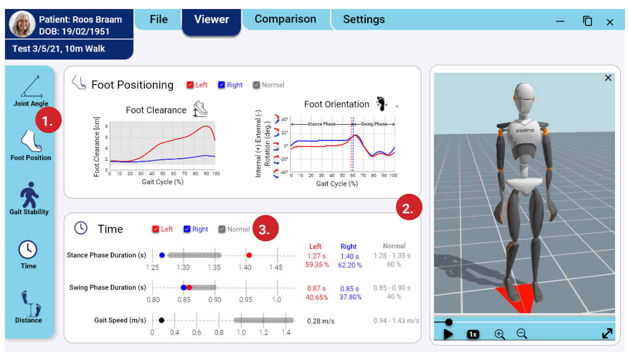
Touchpoint 3. Viewing Data

3.1 Select what parameters to view



1. Click on checkboxes for parameters that are wanted to viewed for the entire test
2. Click on slider button to view the parameter category

3.2 Evaluate test results

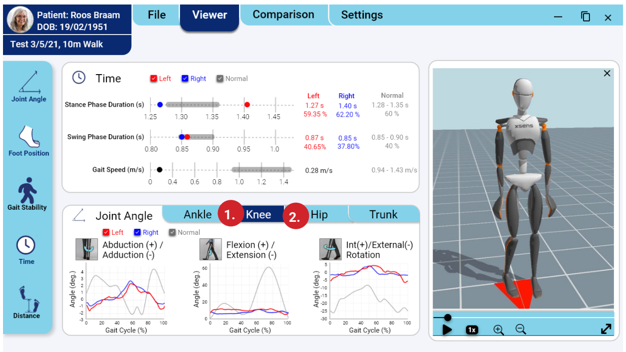


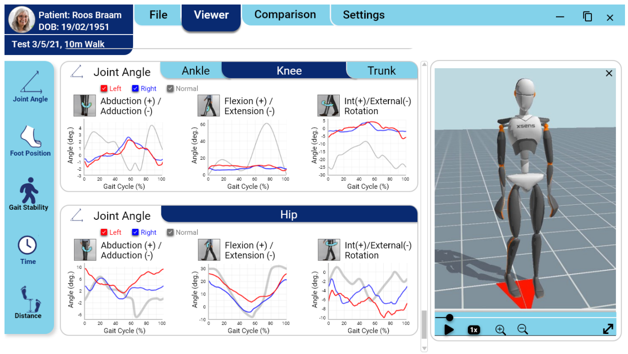
1. Hover over menu to change parameters
2. Scroll down to view more data
3. Click normal, left, and right checkboxes to no longer see the respective data

Figure 125. Screen Flow & Functions

Touchpoint 3. Viewing Data

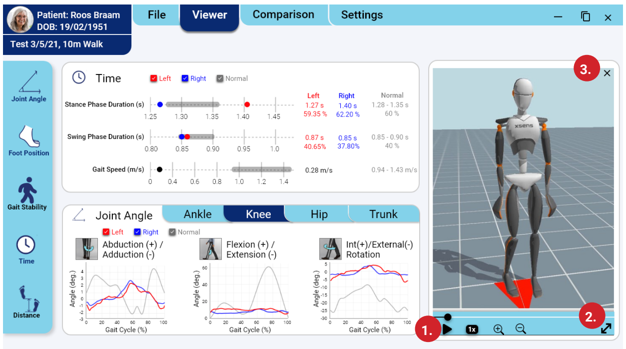
3.2 Evaluate test results

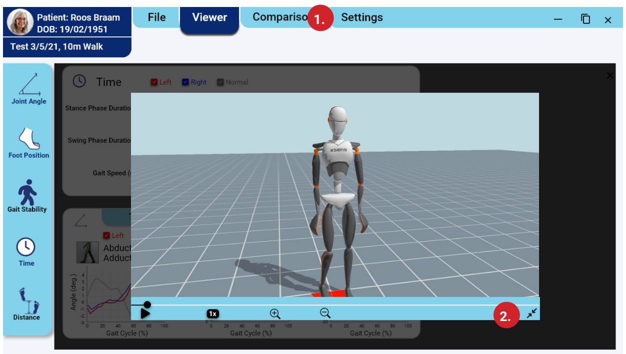




1. For Joint Angles, click on tabs to view to respective joint data
2. Drag tab downwards if want to view more than one joint at a time.

3.3. View avatar video



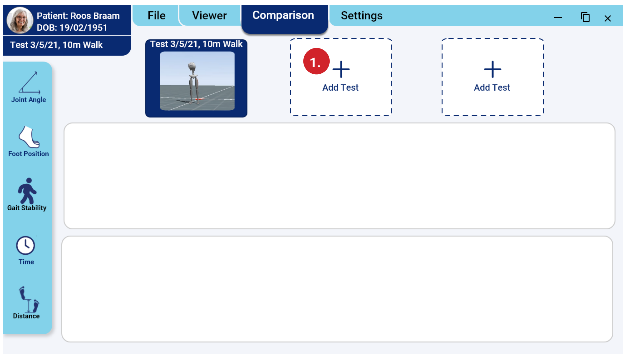


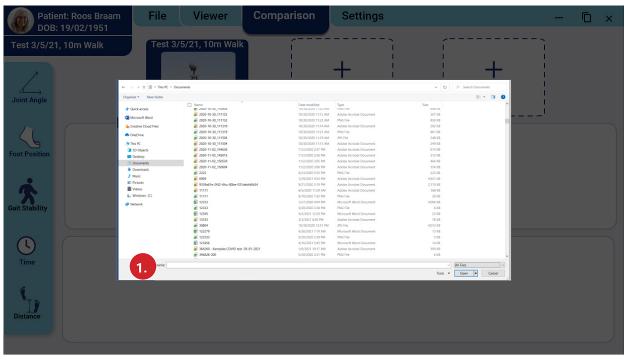
1. Click to play the avatar video, increase or decrease the speed, or zoom in.
2. Click to expand video.
3. Click to remove video from screen.

1. Click to play the avatar video, increase or decrease the speed, or zoom in.
2. Click to minimize video.

Touchpoint 4. Compare Results Between Tests To Select Orthesis

4.1 Add tests to compare





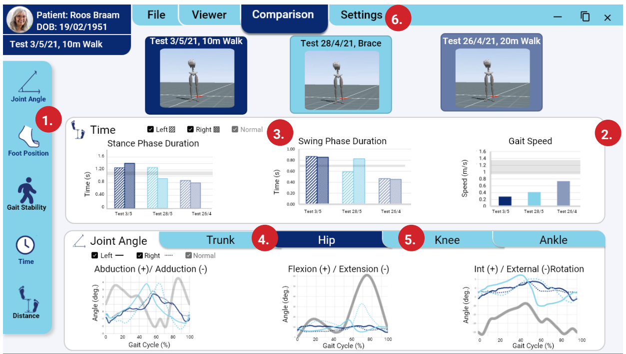
1. Click on *Add Test* button

1. Select test(s)

Figure 125. Screen Flow & Functions

Touchpoint 4. Compare Results Between Tests To Select Orthesis

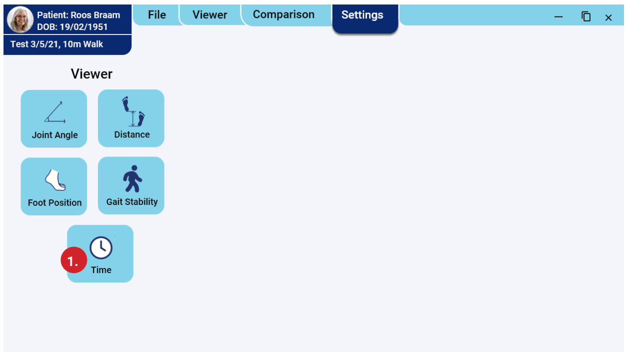
4.2 Compare test results



1. Hover over menu to change parameters.
2. Scroll down to view more data
3. Click normal, left, and right checkboxes to no longer see the respective data
4. For Joint Angles, click on tabs to view to respective joint data.
5. Drag tab downwards if want to view more than one joint at a time.
6. Click on Settings button to change the type of data and visualizations shown.

Touchpoint 5. Change Parameter Settings

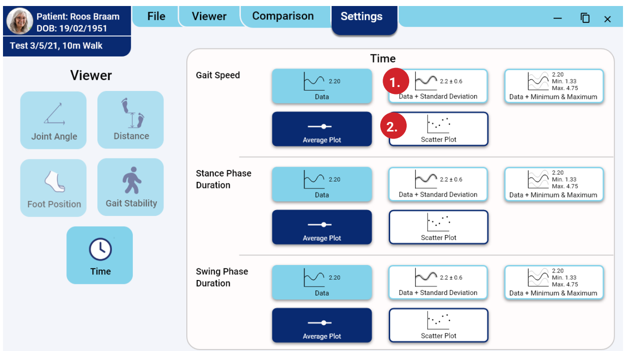
5.1 Select parameter category to change



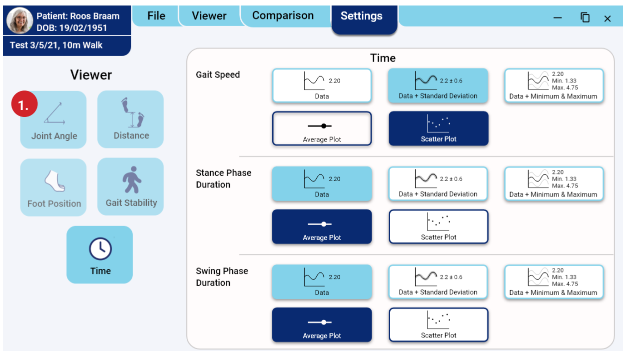
1. Click on parameter category that is wanted to be changed

Touchpoint 5. Change Parameter Settings

5.2 Change type of data and visualization



1. Click on desired data type.
2. Click on desired type of visualizations.

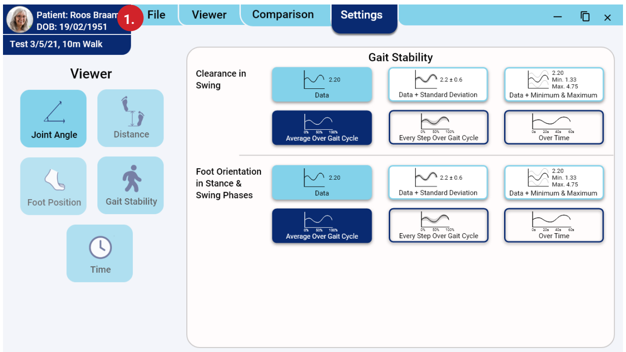


1. Click on additional parameter categories that are wanted to be changed.

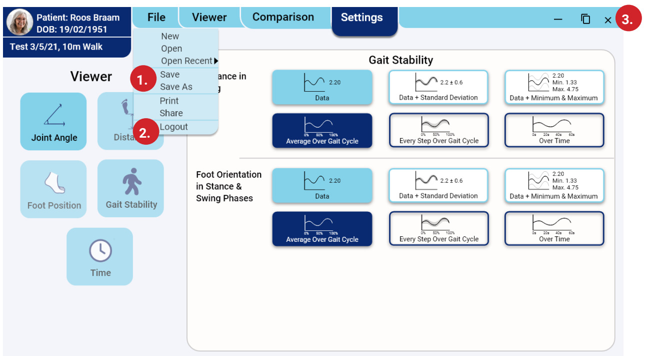
Figure 125. Screen Flow & Functions

Touchpoint 6. Finished using interface

6.1 Save test and logout



1. Hover over *File* button.



1. Click on *Save*
2. Click on *Logout*
3. Click to exit interface

Figure 125. Screen Flow & Functions

Chapter 6
Final Design Evaluation

6.1 EVALUATION OF FINAL DESIGN

6.1 Evaluation of Final Design

The interface prototype and visualization were evaluated with seven clinicians. Feedback was received on the interface and visualizations regarding usability, functionality, intuitiveness, and aesthetics. The advantages of the interface were identified as well as what can be improved upon. Testing was also conducted to compare gait assessment with the clinical eye versus with the interface. The interface was found to more objective than the clinical eye.

RESEARCH QUESTIONS

1. Interface Layout

1.1 Is the operation of the interface self-evident? Can the interface be operated with minimal instructions?

1.2 What do physiotherapists and physicians see as the benefits of using the interface?

1.3 What do physiotherapists and physicians see as barriers of using the interface? What can be added or improved?

1.4 In terms of usability, how do participants perceive and evaluate the proposed design?

1.5 In terms of aesthetics how do users perceive and evaluate the proposed design?

2. Data Visualizations

2.1 Are the visualizations self-evident? Can the visualizations be understood with minimal explanation?

2.2 Can the visualizations be interpreted objectively?

2.3 What do physiotherapists and physicians see as the benefits of using the interface?

2.4 What do physiotherapists and physicians see as barriers of using the interface? What can be added or improved?

3. Evaluation of Clinical Eye vs Interface

3.1 Can the interface be used to select interventions in a time efficient and objective manner?

3.2. Do physiotherapists and physicians assess gait differently when evaluating with the visualizations and avatar in the interface versus with the clinical eye? If so, how?

3.3 In comparison with the clinical eye, does the interface lead to an improved gait assessment?

3.4 Does the interface provide added value in selecting interventions over the clinical eye?

4. Added Value

4.1 If this product was offered in the next year would physiotherapists and physicians use it? If not, what would need to be changed in order for them to use it?

4.2 Do participants see the interface having any added value in gait assessment? How do participants envision the interface being used?

METHOD

Participants

Four physiotherapists and three physicians participated in the evaluation. The participants treat patients with spinal cord injuries or with neurological disorders and work for Rijndam Revalidatie. All previously participated in the user research questionnaire and focus groups, with four participants also taking part in the concept evaluation focus groups.

Procedure

The tests were conducted individually and all but one interview was in person. Each session lasted 45 minutes to 1 hour. The first 30 minutes were spent reviewing the interface layout and visualizations, with the remainder of the time evaluating the clinical eye vs. the user interface.

Interface Layout

Participants were asked to conduct a series of tasks using a workable prototype of the interface (Figure 126). The prototype was created using Adobe XD (Appendix CC). As the prototype was not connected to the Xsens system, it was not possible to show the test results in real time. Consequently the interface and prototype were tested for end of trial. The data used in generating the visualizations was collected by the designer.

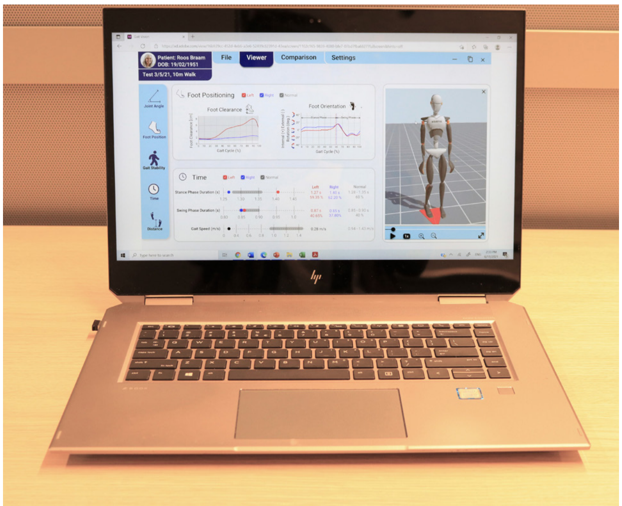


Figure 126. Gait Vision Prototype

The designer asked the participant to complete a series of actions in the interface (Appendix DD). After finishing all of the actions, the participant answered a System Usability Scale (SUS) questionnaire to evaluate the layout's usability and VisAWI questionnaire to evaluate the aesthetic of the layout (Figure 127, Appendix EE) ("Measuring and Interpreting", n.d.); "VisAWI", 2021).

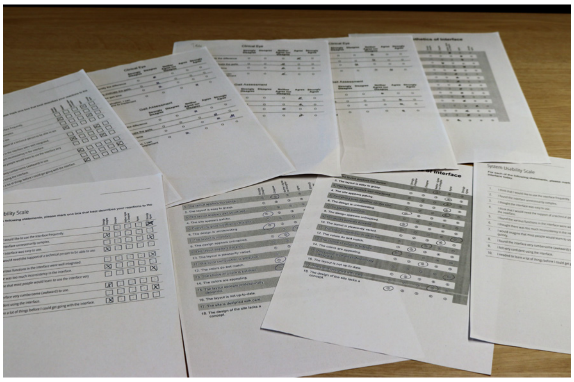


Figure 127. Filled in System Usability Scale & VisAWI Questionnaires

Visualizations

Participants were shown the visualizations for each parameter (Appendix FF) (Figure 128). There was then a discussion regarding how intuitive the visualizations were to understand and if the participant would want anything to be added or changed (Appendix DD).

Figure 128. Example of Visualizations Shown to Participants

Evaluation of Clinical Eye vs Interface

The participant was first showed two videos of a person walking who was imitating a SCI patient wearing two different types of orthosis (Figure 129). The designer and participant discussed what they saw in the videos and the then answered a series of questions (Appendix DD).

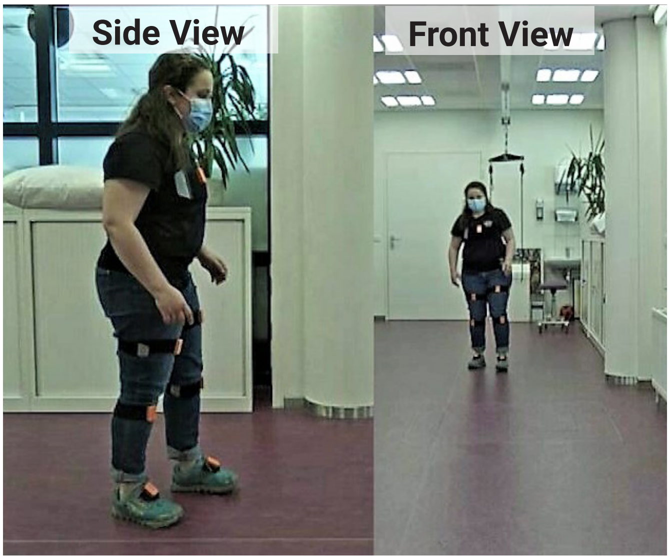


Figure 129. Video of Patient Walking Shown to Evaluate Clinical Eye

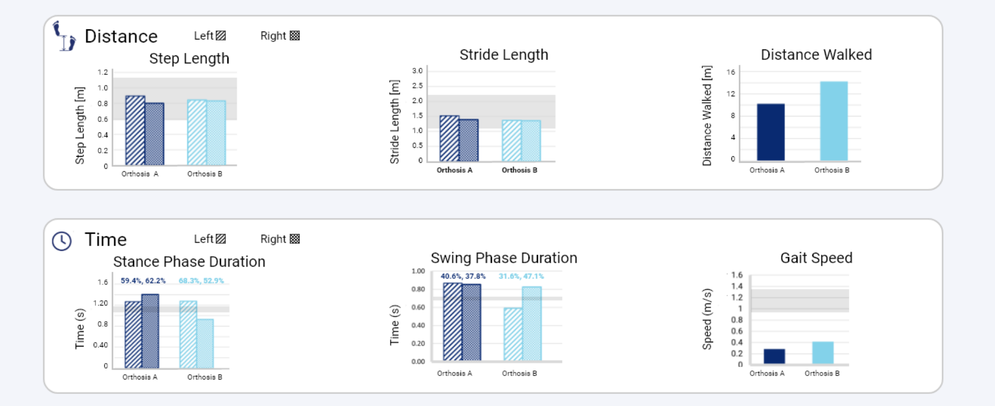


Figure 130. Data Visualizations To Evaluate Interface

Participants were then showed avatar videos and visualizations obtained from the data of the same videos shown previously (Figure 130, Appendix GG). The designer and participant discussed what they saw in the videos and the then answered a series of questions (Appendix DD)

Added Value

To conclude the interview, there was a discussion regarding if participants would want to use the system in the future and what they saw as the added value of the system (Appendix DD).

Data Analysis

Notes were taken during the session. The audio of each session was also recorded and transcribed afterward. At the end of each session, the SUS and VisAWI questionnaires were collected from the participants and their answers and notes were reviewed. The questionnaires did not contain any personal or identifying information.

RESULTS

Interface Layout

Touchpoints 1. Login & 2. Open Test

Participants could operate the screens without any instructions. They did not see anything that needed to be improved.

Touchpoint 3. Viewing Test Result at the End of Trial

Selection of Parameters & Parameter Categories To View

For 4 out of 7 participants it had to be explained the difference between the selecting the parameters through the check-boxes and turning on the parameter categories with the slider bars (Figure 131). After the brief explanation all were able to operate the interface.

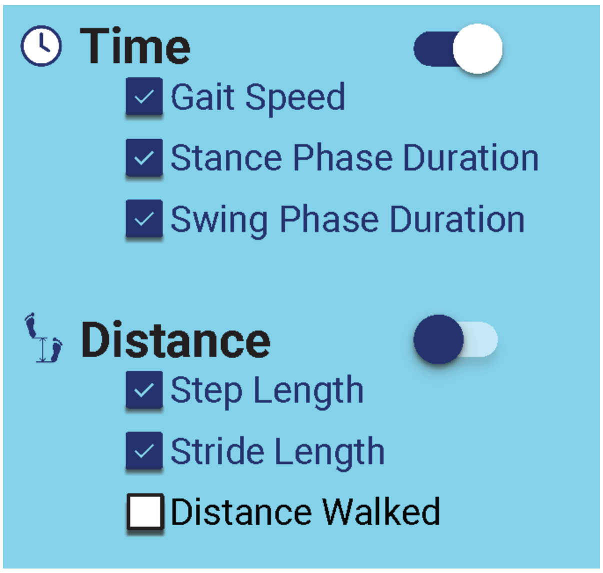


Figure 131. Parameter Checkboxes and Parameter Category Slider Bars

Viewing Test Results

Once the parameters and parameter categories were selected and appeared on the screen, the participants could get around on the screen to view all the selected parameters with no major issues.

> *"Wow, it looks nice. Very good. Really cool"*

> *"The interface is really good"*

For some participants it had to be explained to scroll down to view more visualizations. Adding a scroll bar to this section would solve this issue.

The joint angle visualization is different from the others as the user has to click on tabs to view each of the joints (Figure 132). A few patients mentioned that currently in gait assessment, they analyse in a bottom up approach, from the ankle to the trunk. The order of the tabs can be changed to reflect this.

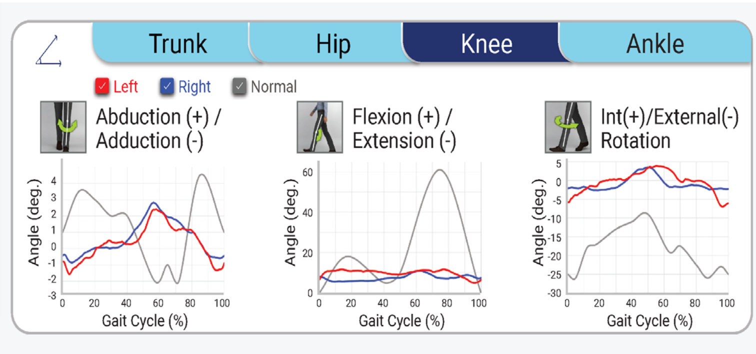


Figure 132. Click Tabs to View Joint Angles

Four of the participants were fine with keeping the joint angles, and flexion, rotation, and abduction in separate graphs. The other participants were unsure. Participants would however like to be able to see multiple joint angles at the same time. In doing so, the option to drag the joint tab down to view multiple joints at the same time is of added value.

Participants also did not have any issue enlarging the avatar video.

> *"Well, it's clear how it works because all videos are like that."*

Touchpoint 5. Comparing Between Tests

All but one participant was able to click on the *Comparison* tab without further explanation or instructions. Participants found the comparison section to be pretty clear and easy to understand. For some participants, it was not clear at first that the colours in the visualizations correspond with each of the tests (Figure 133). This problem can be solved by including a legend.

> *"For me it wasn't clear that these colours correspond because the colours are pretty much the same as the interface colour scheme. But now after you explain it, it is clear."*

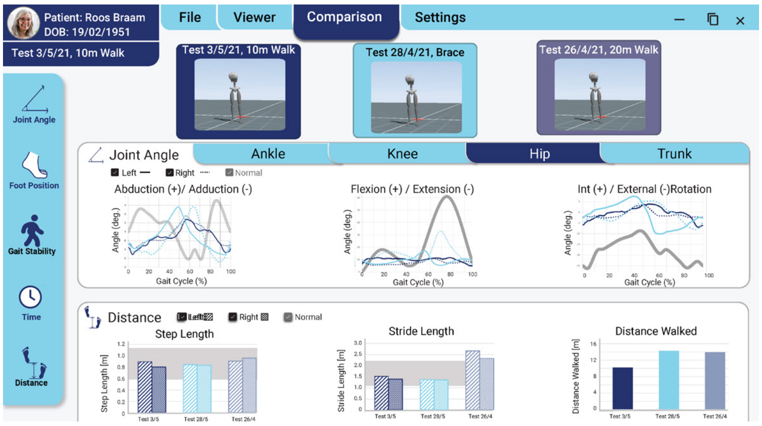


Figure 133. Comparison Section

Touchpoint 6. Settings

All but two participants can go *Settings* without additional explanation. Once in Settings, participants found how to change the data type and visualization for each parameter intuitive and easy to understand. Some patients were confused by the terminology of the visualizations. However they expressed that this is something they need to learn more about and is not necessarily something wrong with the interface.

Participants did not find it necessary to have separate settings for *Viewer* and *Comparison* and thought they could be combined.

Touchpoint 7. Done Viewing Test Results

All participants knew where to go to save the file and logout without any additional instructions.

Layout Aesthetics

In the VisAWI questionnaire, the participants rated the aesthetics of the layout quite positively (Figure 134). For all categories of general, simplicity, diversity, colourfulness, and craftmanship, participants rated on average around a 6 (Agree) or higher.

> *"I actually think it's really nice"*

"In general, the layout of the tool looks very easy and nice

Most participants also liked the color scheme of the layout.

"I really like the colours because it's really calming.

"I think that a positive thing is the use of colours but it's not too overwhelming. It has a good balance in using colours to point something out but not too overwhelming. Just the right balance."

Layout Usability

In the System Usability Scale, the average score was 85.8 and the median being 90 (Figure 135). Since a score of 64 and above means the layout is acceptable and 90 and above the usability is exceptional, the participants rated the usability of the layout quite positively as well.

"I think it's very intuitive. It has a lot of options, which is nice so you can choose which way you want to see the data. I like that you can compare, that's really nice. No, I'm actually quite enthusiastic"

"I think it's pretty easy to use. It is very well I think."

While some participants required some guidance to use the interface, they believe that they would be able to operate the interface independently after a quick training session.

"I think it's pretty clear. You should do it once and then it makes sense"

For a participant that gave the usability one of the lowest scores, they did not think use the interface was difficult to use. Rather, it was understanding the content in the interface that proved challenging. Since they had limited previous knowledge on gait assessment, they were unsure of what all the terminology with the parameters and visualizations meant. However, with some practice they think they will be fine.

"I actually don't find that the interface is complex, but I think the contents are."

"It's not about using the system. The system you made is easy. It is more about the content. Right now, it's a little bit difficult to interpret these aspects. I think it would help if we practiced with this."

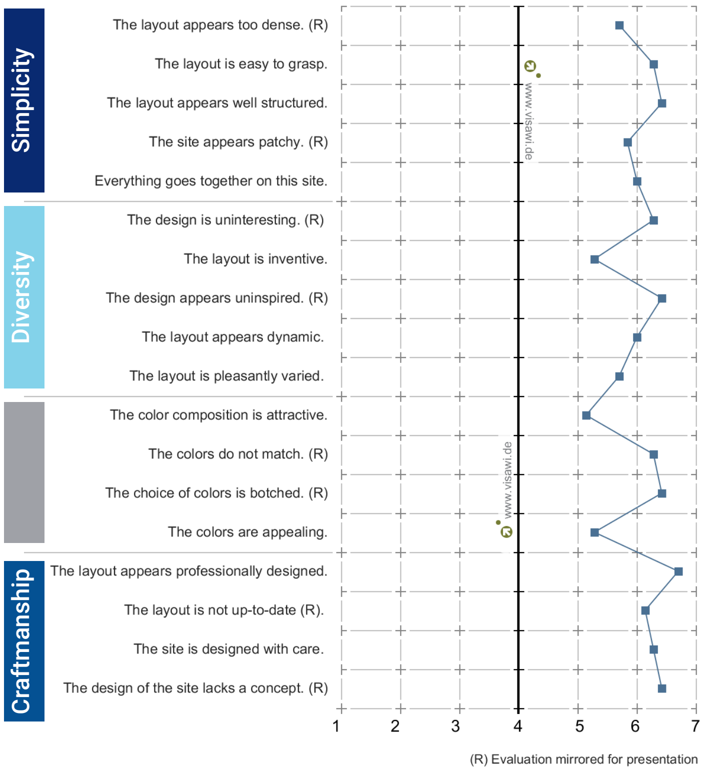


Figure 134. Average Results of VisAWI Questionnaire

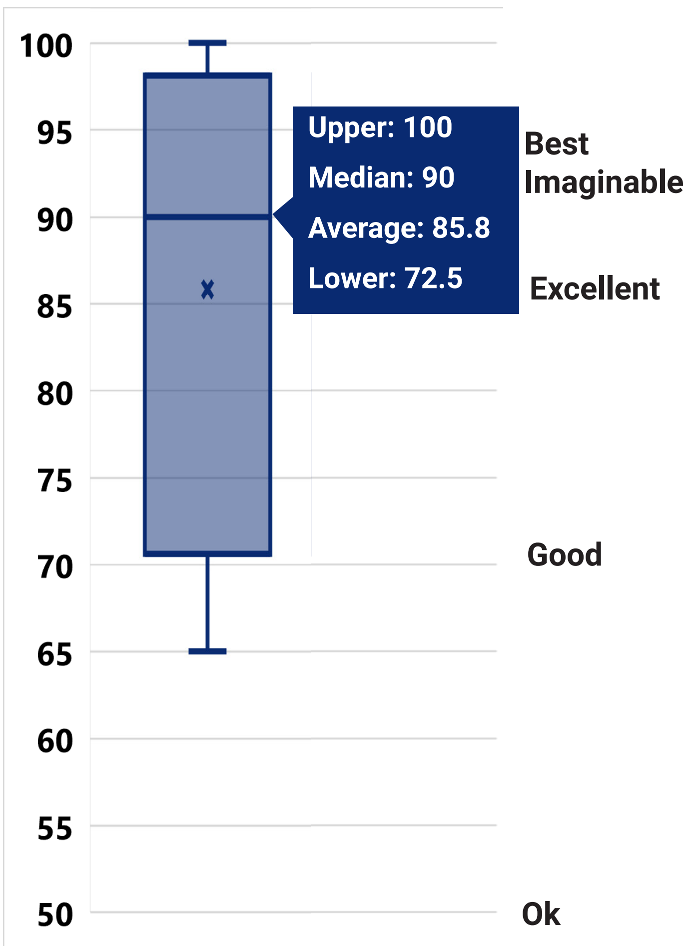


Figure 135. System Usability Scale Score

Visualizations

Time, Distance, & Gait Stability

Average Horizontal Plots

Participants found the standard visualization of the average horizontal plots easy to understand and intuitive (Figure 136). They especially liked being able to see if the test results were in or out of the normal values.

> *"Easy to understand in one glance."*

> *"I think it's clearer and with the blue and red dots you can obviously see that this is out of the normal."*

All participants were unsure of the meaning of position center of mass (CoM) and extrapolated center of mass (XCoM) and/or what the corresponding test results meant. This was in part due to them not being familiar with these parameters. To aid in the understanding, a visualization corresponding to the parameters showing what the test results mean can be created. For example, showing on a diagram what 0m means for CoM.

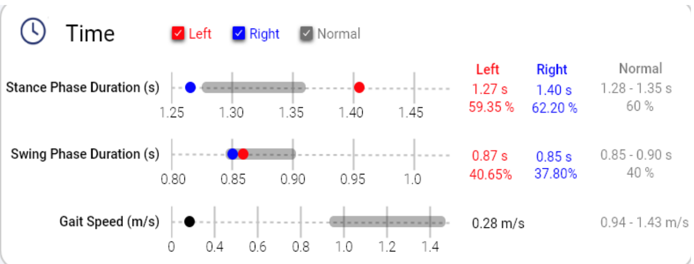


Figure 136. Average Horizontal Plots

Comparison Bar Graphs

The participants thought the graphs were pretty intuitive and objective (Figure 137).

> *"Like for now, I just have to check it for a few seconds and then I know what it means. For next time I would probably immediately understand."*

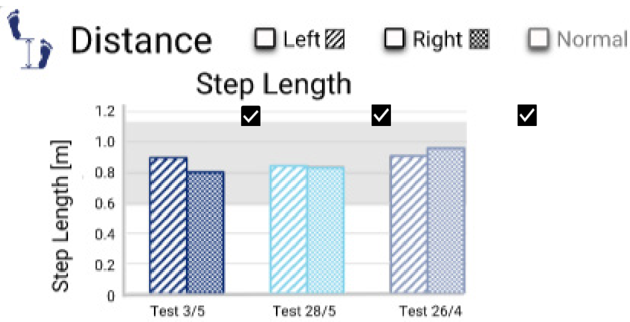


Figure 137. Comparison Bar Graph

They were not confused by the change of the left and right colors from the previous visualizations, and as mentioned previously would just like a legend to be added as a reminder what test corresponds to each other.

> *"It was pretty clear. It is in a logical way that you first have the left and then the right."*

Scatter Plot

They found the plots straightforward and easy to understand (Figure 138).

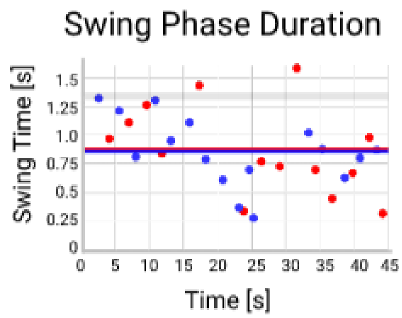


Figure 138. Scatter Plot

Foot Position & Joint Angles

Average Line Graph Over Gait Cycle

Overall, the participants found the average line graphs over the gait cycle intuitive (Figure 139).

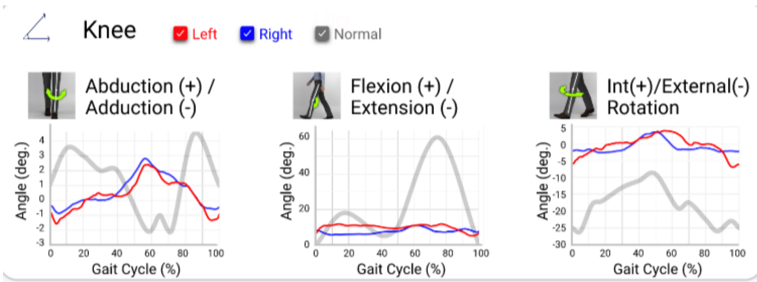


Figure 139. Average Line Graph Over Gait Cycle

To further aid in their interpretation of the graphs, they would like some additional features added. One of these features is labeling the stance and swing phases. Knowing when the patient is in stance and swing phase is extremely important in interpreting the data. However, they find this difficult to do by just looking at the graphs. In doing so, all participants wanted in the graphs, labels to distinguish between the swing and stance phases.

> *"Because now I'm at 60% gait cycle and I really don't know where I am in the phases."*

> *"I understand the gait cycle, but I am not sure what phase it is in."*

Five out of seven participants suggested syncing the avatar with the graphs to show on the graphs at which point in the gait cycle the avatar is.

> *"I think for me it's really helpful to see the avatar. Now I really have to think, 'Oh, so much abduction, where are we in the gait cycle' "*

> *"If you can see it in the phase and in the avatar it's a little easier to understand then just from graphs."*

Comparison Line Graph Over Gait Cycle

It had to be briefly explained what the colors and patterns of the lines correspond to, but then participants could interpret the graphs (Figure 140). Some participants at first found viewing all of the tests data to overwhelming, so they like the option of being able to turn right, left, and normal on and off.

> *"It can be nice to compare but it would also be nice to have the option to see them separately."*

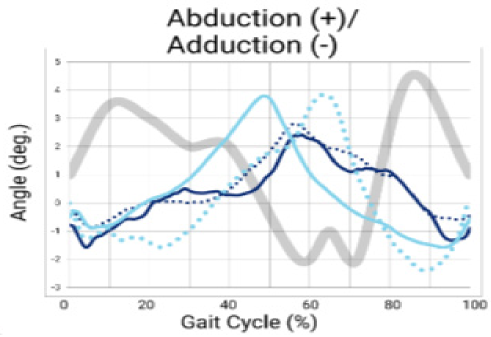


Figure 140. Comparison Line Graph Over Gait Cycle

Line Graph of Every Step Over Gait Cycle

Due to the large amount of lines in the graph, they found distinguishing between lines and between left and right was difficult (Figure 141). Being able to turn left and right on and off will help with this. One patient also mentioned that they would only want to analyse one step in the gait cycle, and only would want to see them all at one time if they are really different from each other.

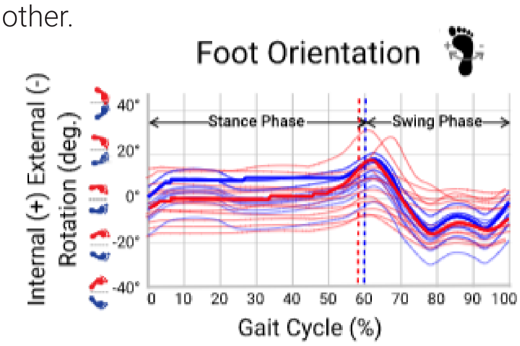


Figure 141. Line Graph of Every Step Over Gait Cycle

Line Graph Over Time

Out of all the graphs, participants found the line graph over time to be most difficult to understand. Since the graph is so condensed, it is difficult to interpret the results (Figure 142).

> *"I think the other graphs for the joint angles are useful but I don't think this one is."*

> *"This one I find a little bit annoying. I would not look at this. It looks like an EMG but it's not."*

To solve this problem, a feature could be added that allows the user to zoom in on a section of the graph.

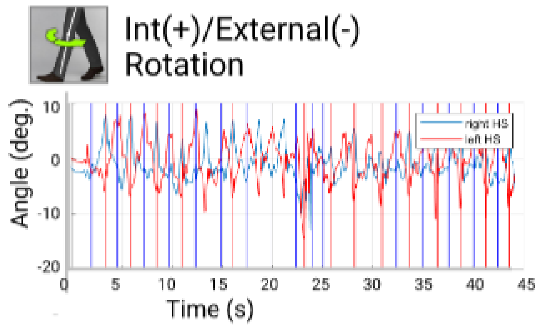


Figure 142. Line Graph Over Time

Avatar

Participants found the avatar to be extremely helpful in understanding the test results. The main thing they would add is to be able to rotate the avatar and zoom in and out. This could be done manually or through a set program of orientations that the user can choose from.

Evaluation of Clinical Eye vs Interface

In comparing the clinical eye and the interface to asses gait, most participants rated the clinical eye and the interface the same in terms of how easy it was to identify the difference between gaits, interpreting gait time efficiently, and being able to recommend a brace to implement. Participants did however rate the interface as significantly more objective than the clinical eye. One reason for this increase in objectively, is clinicians can see the patient walk clearer with the avatar due to there being less visual noise.

> *"I think the avatar was quite good. Better than I expected. There's also maybe a little less distraction with the avatar making it more clear."*

With the avatar and visualizations it was also possible for participants to see the small differences in gait.

> *"With the avatar I think it's easier to see the small differences. With endo and external rotation, I saw it better in the avatar then with the clinical eye.."*

> *"The main thing for me is some things you see for efficiently and more into detail because you cannot see it all with your clinical eye."*

Participants found the interface to be a tool to use to check assumptions they have made when evaluating with the clinical eye.

> *"When you firstly see the videos and then see the data you think, 'Oh, okay. I thought that was different.' Which is a good thing because then you evaluate your observations. It invites you to evaluate you own perceptions."*

> *"The data makes me wonder what I've seen, which is good."*

Added Value

If the interface would be offered in the next year, all participants said they would want to use it. However, they would use the interface in addition to the clinical eye and/or EMG.

> *"I think it is a great thing to have in addition to the clinical eye."*

> *"I'm actually kind of enthusiastic. The only question is, would it be complementary with an EMG, for example, because that is what we use a lot."*

They also would not use the interface for everyday treatment, but rather for special cases.

> *"Yes, I think I would use it (the interface) but not for a normal treatment. For an orthosis yes, but then I will take more time so I plan myself for one hour instead of 30 minutes, so I have time to evaluate it."*

> *"Not for every patient but with this technology I would use it a lot more than I do now. Right now, I make a video of a gait and then after a few weeks I do it again. With this system I think it might be a little bit easier to do."*

In addition to using the interface for selecting orthosis, participants believe it would also be helpful in selecting prosthesis and comparing what happens before and after a spasticity treatment.

Overall, the participants had positive feedback on the interface and are excited to be able to use it in the future.

> *"I'm really looking forward to it because I think it really adds something. I think we will be frequently using it."*

> *"I like the interface and I think it is easy and is better than what we have now"*

APPLICATION OF RESULTS IN DESIGN IMPROVEMENTS

Interface Layout

Touchpoint 3. Viewing Visualizations

- Add a scroll bar to the middle section (Figure 143).

- Change tab order to ankle, knee, hip, and trunk to represent bottom up evaluation approach (Figure 143).

Touchpoint 4. Comparing Between Sessions

- Include legend to indicate what color corresponds with each test (Figure 144)

Touchpoint 5. Settings

- Combine *Viewer* and *Comparison* settings (Figure 145).

Usability

- Educate clinicians on not only how to use the interface, but on gait assessment as well.

Visualizations

Average Horizontal Plot

- Add a diagram for XCoM and CoM to demonstrate what the numerical results mean.

Average Line graph over Gait Cycle

- Include labels to distinguish between the swing and stance phase (Figure 143).

-On Joint Angle visualization, label on axis where abduction/adduction, flexion/extension, and internal/external rotation is (Figure 144).

-Sync the avatar with the graphs to show on the graphs at which point in the gait cycle the avatar is.

Line Graphs over Time

-Allow user to zoom in on a section of the graph

Avatar

- User can rotate the avatar and zoom in and out. This could be done manually or through a set program of orientations that the user can then choose from.

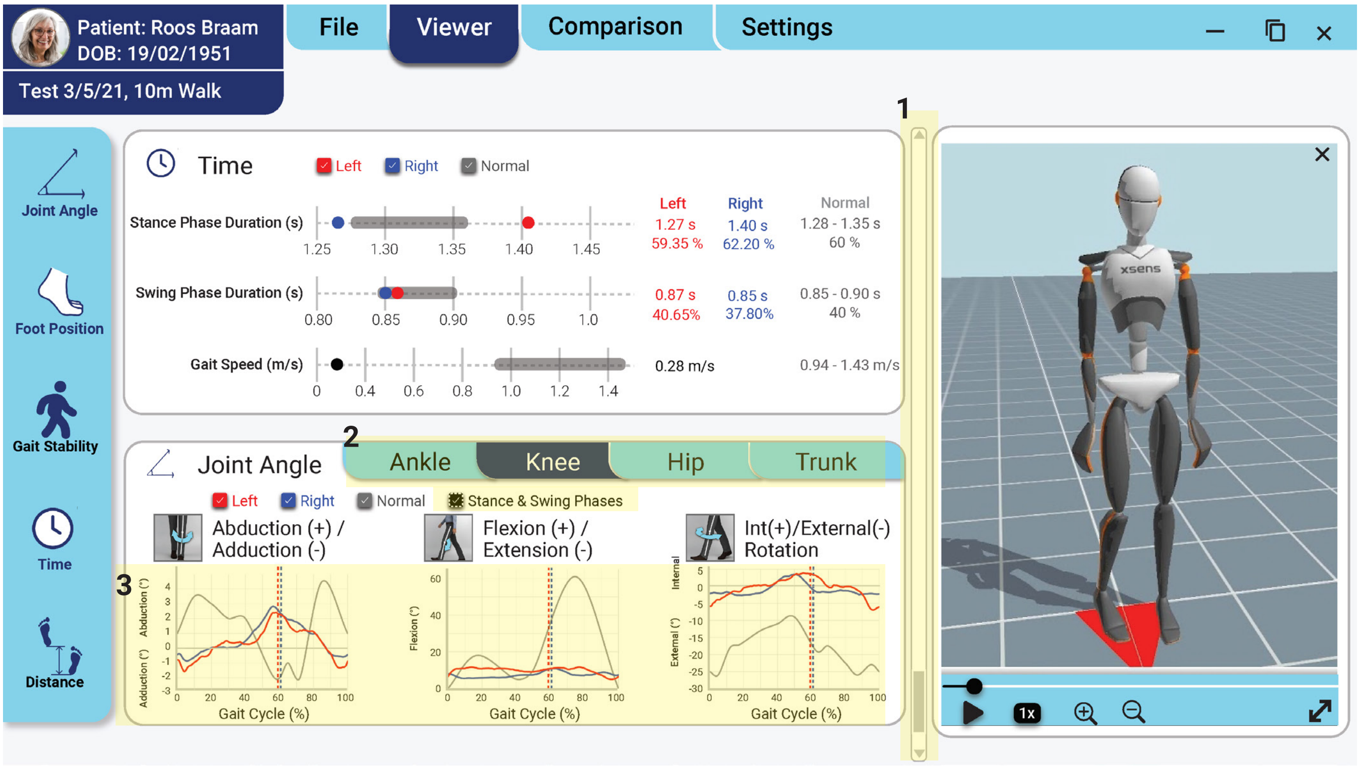


Figure 143. 1. Scroll Bar Added for Easier Navigation
2. Order of Tabs Change to Reflect Bottom to Top Analysis
3. Swing & Stance Added to Gait Cycle Graphs

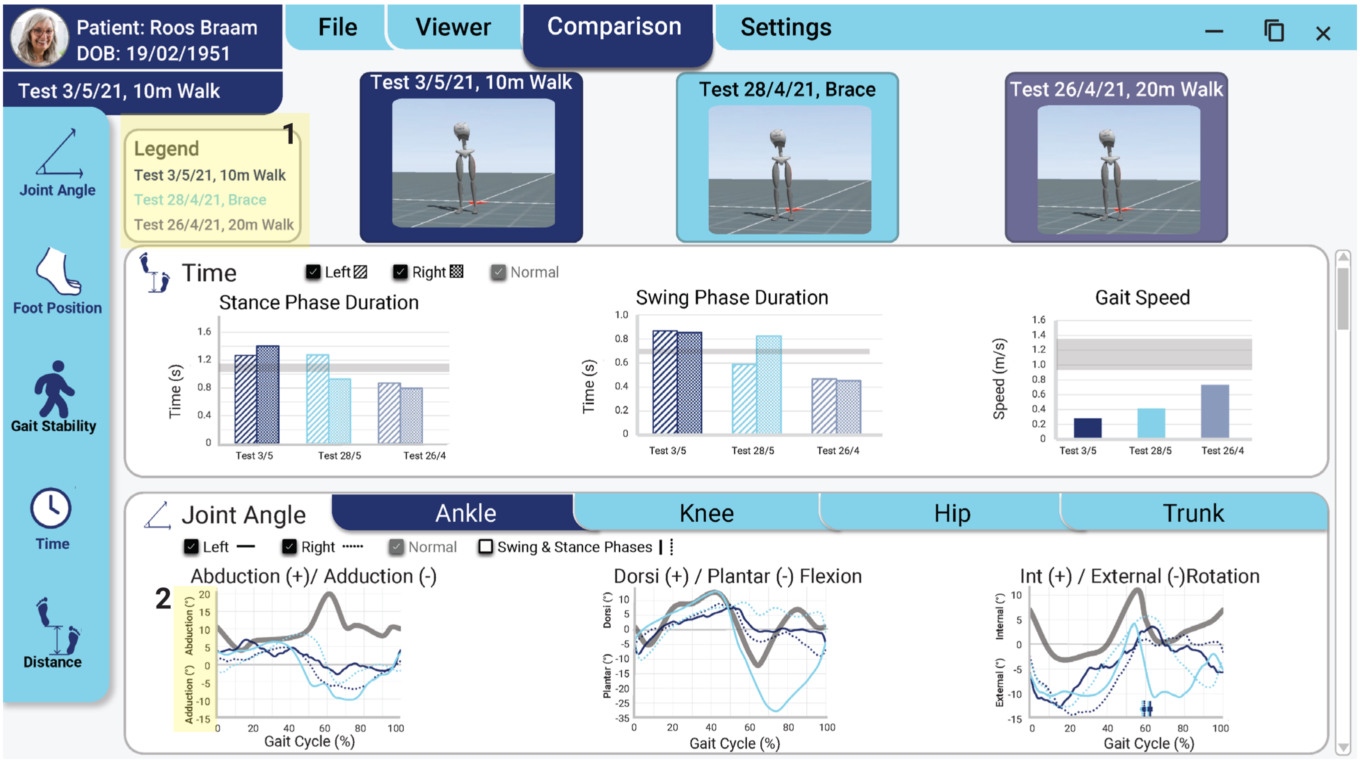


Figure 144. 1. Legend Added to Indicate Test Colors
2. Label on Axis Where Abduction And Adduction Are

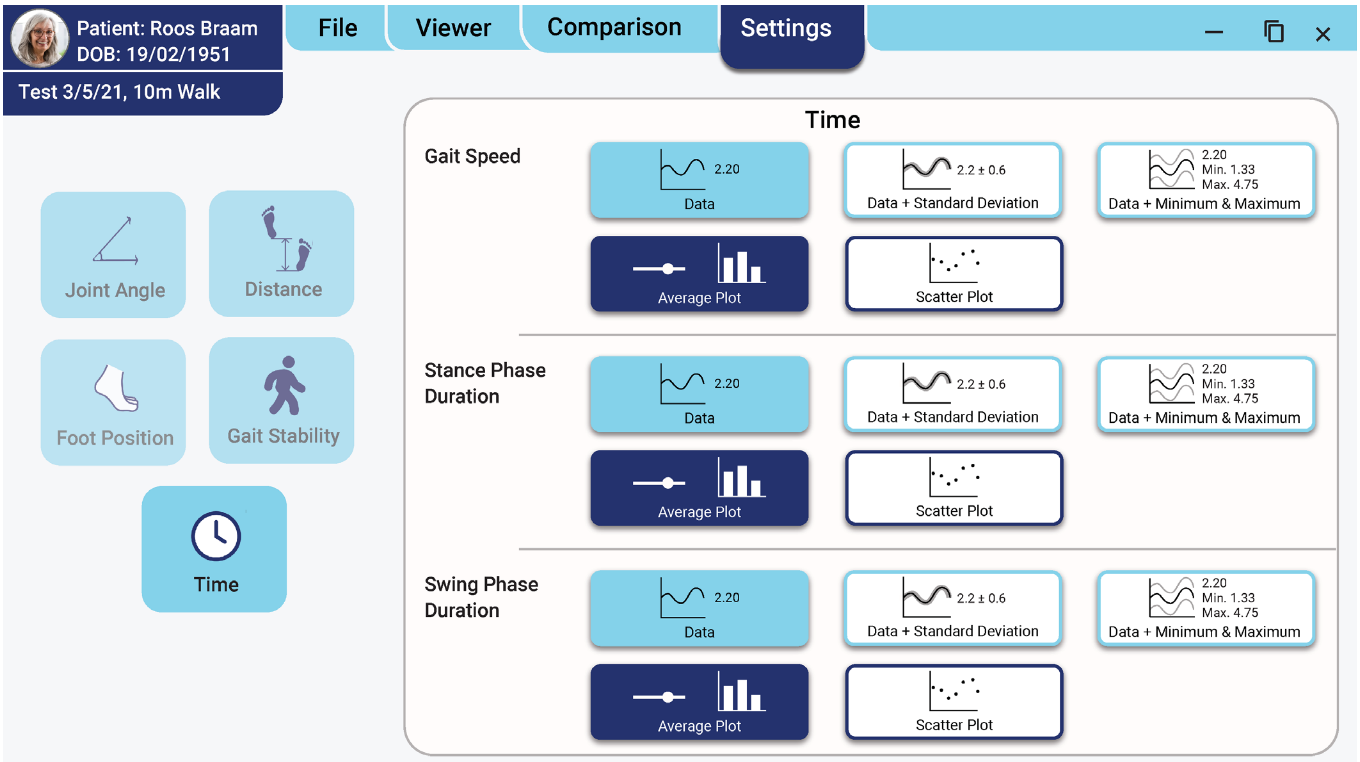


Figure 145. Combined Viewer & Comparison Settings

Chapter 7
Implementation

7.1 IMPLEMENTATION OF GAIT VISION

7.1 Implementation of Gait Vision

An implementation roadmap was created using implementation strategies developed using the Behavioural Change Wheel model, as well as taking into account the technological development of the interface and the corresponding finances.

The key to ensuring Gait Vision survives in the long term is developing an implementation plan. Taking into account the clinicians' wants and needs, implementation strategies were developed using the Behavioral Change Wheel Model (Appendix AG). One most impactful strategies is educating clinicians about gait assessment and how to operate the interlace. Another important strategy is recruiting clinicians to join these classes and to use the interface.

These implementation strategies were then used to create a roadmap for implementing the system (Figure 146). The roadmap is broken down into five horizons and takes place over the span of ten years (2021 – 2031).

STAGES OF IMPLEMENTATION

Horizon 1, 2022

By 2022, a functional version of Gait Vision is developed, and planning for implementing the system begins. During this time, classes are being taught on gait assessment, and recruitment of the first participants is beginning.

Horizon 2, 2023

From 2022 to 2023, the first group of participants uses Gait Vision and the Xsens system. These participants serve as models for future and potential participants. The participants continue to take part in gait assessment classes. They are trained in how to use the interface and how to set up the motion trackers.

Horizon 3, 2025

Training classes for Gait Vision expand to any clinicians within the Erasmus MC and Westersingel locations who want to participate. In addition to using Gait Vision to select orthosis, it is also used to track a patient's progress. An additional aspect of the implementation is ensuring the system is placed in a location all clinicians can conveniently access.

Horizon 4, 2028

Using Gait Vision has been integrated into the Rijndam Revalidatie's protocol, making it a part of the clinicians' established routine. A separate interface for patients to view their test results has been developed.

Horizon 5, 2031

Gait Vision is no longer just used at the Erasmus MC and Westersingel locations. It has expanded to five Rijndam Revalidatie outpatient locations that treat patients with incomplete spinal cord injuries, neurological disorders, or prostheses. The system is used by the orthopedic and sports medicine department at Rijndam Westersingel as well. Clinicians can now operate the interface from a phone, making it even more accessible to use and view results at any time.

TECHNICAL DEVELOPMENT & FINANCES

The most significant technological developments of the interface will occur in the first two horizons, as that is when an operable interface will be built. A more detailed breakdown of the technological implementation and interface development can be seen in Appendix II.

In reviewing the financial costs of the implementation roadmap, the Xsens software subscription was found to be one of the highest costs at € 3,025.00 per year per subscription

(Appendix JJ). As the number of users expands, so will the number of subscriptions needed. To reduce these costs, by Horizon 4 (2028) a software program will be developed by the Convergence Team that performs the same functions as the Xsens software. While the development costs will initially be higher than the yearly subscriptions, as no additional costs are needed after development, it will be more financially beneficial in the long run.

In the final stage of the implementation plan, the goal is for Gait Vision to help guide clinicians through interpreting the test results. This also includes detecting what areas the clinician should focus on and possibly suggesting interventions to implement. This can be done through artificial intelligence. Through machine learning, the test results collected from the previous ten years of tests can be used to develop algorithms to help guide clinicians and give suggestions on interventions (Frankenfield," 2021). Implementing artificial intelligence would allow clinicians to have even less knowledge on gait assessment, and yet still obtain objective and valuable results.

Finally, thinking beyond Horizon 5, in the future, augmented reality could be integrated. Through the display of a phone or Ipad, the data results could be projected onto the patient in real-time as they are walking (Figure 147).

Figure 147. Example of Augmented Reality

Implementation Roadmap

Horizon		Horizon 1, 2022	Horizon 2, 2023	Horizon 3, 2025	Horizon 4, 2028	Horizon 5, 2031
Goal		Develop functional interface and prepare implementation of the system	Introduce system to small group of clinicians to aid in selecting orthoses.	25% of clinicians at Rijndam Westersingel and Erasmus MC use system to aid in selecting interventions and tracking patient progress	The system is integrated into the established routine of clinicians at Rijndam Westersingel and Erasmus MC. The system is used in evaluation and to facilitate conversation and understanding between clinicians and patients	The system is used at 7 Rijndam Revalidatie locations. The system aids in evaluation through providing guidance. The system is integrated in yearly check up appointment
Implementation Interventions	Education	Begin to educate on gait assessment	Continue gait assessment classes. Training on using interface and Xsens Provide examples of how to use the system to evaluate orthosis Have a support person participants can contact when having difficulty	Expand education and training to all those who want to participant Create manual / tutorials on how to use the system as well as for specific scenarios Informational packet on what the parameters mean and how to interpret the visualizations	Develop education and training material for patients	Develop material such that education and training can be lead by people outside of the Convergence Project Team
	Recruitment	Talking at monthly meetings and send emails about becoming a participant Prepare implementation material	Select mix of physicians and physiotherapists across departments Encourage clinicians to talk to each other about their experience using the system Provide examples of the added benefit of using the system	Integrate using system into selecting orthosis routine Having a meeting once a month where clinicians can come and have their questions answered. Place the system in such a location that is easy to access by all departments	Integrate system into protocol clinicians and physicians have to follow. Integrate into protocol taking courses to learn about gait assessment	At new locations implement interventions from the previous stages.
Devices to Operate Interface						
System Function		Selecting Interventions	Compare Before and after intervention (botox)	Track Patient Progress	Provide feedback to improve walking Aid in patient understanding and participation	Testing conducted to track yearly progress
Interface Capabilities		• View End of Trial • Can select parameters & parameter categories • Comparison with 2 Tests • Workable Interface without aesthetics • View Avatar in fixed position	• View Real Time & End of Trial • Workable Interface with aesthetics • Can change settings • Comparison with 3 tests • Rotate Avatar	• Track Patient Progress • Secured login per user • Can change settings • Can print out report • Can send test file	• Separate interface for patients • Can add tests to patient's records	• Provide feedback to aid in interpretation for inexperienced clinicians

Chapter 8
Conclusion

8.1 Future Recommendations

Recommendations were made to aid in the further development of Gait Vision.

Even though a great deal of work was accomplished, there are still actions that need to be taken in order for Gait Vision to be usable by clinicians. The following recommendations are ordered from highlight to lowest priority.

Develop Functioning Interface

The prototype created was only a mockup of the interface and did not contain any coding. The next version of the interface should be able to receive data from the Xsens system. With the next iteration, the improvements mentioned in Section should be implemented. The interface should be translated from English to Dutch, as that is the native language of almost all potential users.

In addition, it is recommended to develop the gait variation visualizations, viewing the data in real-time, and how the avatar will look and operate. As no drastic changes are needed to be made to the interface design, no additional testing must be conducted before the functional interface is developed.

Education

A limitation through the user testing was that the participants had limited prior knowledge of gait assessment. In doing so, they provided feedback on the data visualizations in terms of aesthetics but could not give a definite answer whether they completely understood them. For a more accurate evaluation of the visualizations and to aid in the implementation of Gait Vision, the clinicians should be educated on what the parameters contained in gait assessment mean and how to interpret them properly. This education can be in the form of classes, online tutorials, or a booklet.

In addition to being educated on gait assessment, before using the interface independently, the clinicians need to be trained on using Xsens, such as how to attach the motion trackers correctly, and on operating Gait Vision.

Evaluate Gait Vision In Terms of Time-Efficiency

In the evaluation of the final design, there was not enough time to properly compare the clinical eye assessment versus Gait Vision. The clinical eye videos could only be evaluated once each at full speed and the test results in Gait Vision scanned. In doing so, it was not possible to evaluate if the test results can be interpreted in a time efficient manner (Requirements 4.1 & 4.2).

When the interface is next evaluated, it is recommended to redo the testing of the clinical eye versus Gait vision. Participants should be given as much time as they need to evaluate the clinical eye videos and the visualizations and avatars in Gait Vision. When evaluating with Gait Vision, the participants can be timed to determine if an overview of the testing results can be obtained in 5 minutes and a comprehensive interpretation in 15 minutes. If possible, setting up the system, with putting on the motion trackers and calibration, should be included in this timing

Develop Patient Features

In order to get a better idea of the needs and wants of incomplete SCI patients, more patients need to be interviewed. After doing so, either a separate interface for the patient can be developed, or features could be added to the interface to satisfy patients' wants and needs. In addition to the patient features, tools should be added to aid in clinicians explaining the results to the patients. The patient being able to see their progress of time should be designed as well.

Design PDF & Printable Test Report

With the current design, in order for a clinician to view the test results, they need to have access to the Gait Vision software. Consequently, if they wanted to send the results to someone who did not have the software or upload to a patient's file, this is not possible. Since the layout of the interface is very interactive, it would be challenging to print out the test results with the current design. Therefore, it is recommended to develop a version of the test results that can be sent as a PDF or printed out.

8.2 Reflection

My motivation for first choosing this project was my interest in medical and impact-driven design. I am passionate about designing products with a purpose and that make a lasting impact on people's lives. Despite not having any prior experience with user interface design and no clue what gait assessment was, the possibility to design a product that could improve someone's life is what drove me to select it.

From conducting literature research, I not only gained a better understanding of what gait and gait assessment are, but I also learned about user interface design. I never knew so much went into developing a user interface, and it gave me a greater appreciation for application and website development. Even though this project phase was quite daunting because the project's scope was still quite extensive, it allowed me to develop a solid base to build off of.

Conducting user research and user testing was an aspect of the project I enjoyed the most. It allowed me to develop my interpersonal skills and integrate co-creation, something I did not have much prior experience with. Interacting with physiotherapists and physicians was a critical part of my project. The exposure I was able to have with them was key to developing a final design that not worked in a rehabilitation environment, but the end users desired as well. Through talking with the clinicians, I saw my project from a new perspective and discovered things I would never have thought about if I had only based my evaluations on literature research.

Through having this contact with the clinicians, I improved on my time and project management skills. Within three iterations of user sessions, I met with 18 clinicians. Four of those clinicians participated in two of those iterations, and four participated in all three sessions. With each iteration came contacting potential participants, arranging when and where to meet, and the numerous emails that came in between. Due to the clinicians' tight schedules, all meetings had to be arranged at least three weeks in advance, which took some forward-thinking in my project planning.

With managing my user research, I also had to manage the other stakeholders in my project. Throughout my masters, I have done mostly group projects, so it was a unique experience having to be in charge of all aspects of a project. Even though it took some getting used to and I was met with a few bumps in the road, I could see myself getting better and better with my time and project management as the project progressed.

When it came to developing the final design and building the prototype, I pleasantly surprised myself. In addition to developing the user interface, I had to design the data visualizations. In the end, I was able to develop an interface that was aesthetically pleasing, semi-operatable, and contained visualizations that clinicians could easily understand.

In the end, from this project, I not only grew as a designer but as a person. It was the most intense project I have ever worked on, but it was also one of the most rewarding. Looking back, I am extremely proud of all the work I have done and it was a great way to conclude my studies.

Chapter 9

Works Cited

Chapter 9. Works Cited

6 Gestalt Principles in UX Design. UX Hints. Retrieved 1 June 2021, from https://uxhints.com/visual-ui-design/gestalt-principles/.

Ayyappa, E. (1997). Normal human locomotion, part 1: Basic concepts and terminology. JPO: Journal of Prosthetics and Orthotics, 9(1), 10-17.

Barry, P. (2021). 13 Tips For Improving Landing Page Design. UX Planet. Retrieved 7 March 2021, from https://uxplanet.org/13-tips-for-improving-landing-page-design-849801372da4.

Birch, I., Vernon, W., Walker, J., & Young, M. (2015). Terminology and forensic gait analysis. Science & Justice, 55(4), 279-284.

Bolliger, M., Blight, A. R., Field-Fote, E. C., Musselman, K., Rossignol, S., Barthélemy, D., ... & Steeves, J. (2018). Lower extremity outcome measures: considerations for clinical trials in spinal cord injury. Spinal cord, 56(7), 628-642.

Burkhard, R. A. (2005). Knowledge visualization: The use of complementary visual representations for the transfer of knowledge. A model, a framework, and four new approaches (Doctoral dissertation, ETH Zurich).

Complete vs Incomplete Spinal Cord Injury: What You Need to Know. Spinalcord.com. (2020). Retrieved 25 February 2021, from https://www.spinalcord.com/blog/complete-vs.-incomplete-spinal-cord-injuries.

Comprehensive Gait and Balance Analysis. APDM. Retrieved 15 March 2021, from https://apdm.com/mobility/.

Contrast Checker. UserWay. Retrieved 7 March 2021, from https://userway.org/contrast/000000/ffffff.

Cooper, A., Reimann, R., Cronin, D., & Cooper, A. (2014). About Face: The Essentials of Interaction Design. John Wiley and Sons.

Coutts, F. (1999). Gait analysis in the therapeutic environment. Manual therapy, 4(1), 2-10.

Dai, A. (2018). 6 Bad UI Design Examples & Common Errors of UI Designers | Hacker Noon. Hackernoon.com. Retrieved 7 March 2021, from https://hackernoon.com/6-bad-ui-design-examples-common-errors-of-ui-designers-e498e657b0c4.

Dul, J., & Weerdmeester, B. (2008). Ergonomics for beginners: a quick reference guide. CRC press.

E, M. (2017). Gait Analysis & Gait Cycle [Video]. Retrieved 19 February 2021, from https://www.youtube.com/watch?v=5mDbF1zHHjw.

EM040 - Human Gait Phase Detection using Convolution Neural Network-Based Prediction Engine. InnovateFPGA. (2021). Retrieved 1 June 2021, from http://www.innovatefpga.com/cgi-bin/innovate/teams.pl?Id=EM040.

Foot Clearance. EPFL. Retrieved 17 March 2021, from https://www.epfl.ch/labs/lmam/page-125471-en-html/page-125544-en-html/page-125556-en-html/page-73893-en-html/.

Frankenfield, J. (2021). Artificial Intelligence (AI). Investopedia. Retrieved 15 June 2021, from https://www.investopedia.com/terms/a/artificial-intelligence-ai.asp.

Gait Analysis in Cerebral Palsy. Physiopedia. Retrieved 21 March 2021, from https://physio-pedia.com/Gait_Analysis_in_Cerebral_Palsy?utm_source=physiopedia&utm_medium=search&utm_campaign=ongoing_internal.

Gait Disorders. Cleveland Clinic. Retrieved 19 February 2021, from https://my.clevelandclinic.org/health/symptoms/21092-gait-disorders.

Horemans, H., & Lemus Perez, D. (2021). Convergence Project. Presentation.

Horemans, R. (2021). Laboratory Gait Analysis Process [In person].

Jacinto, L. J., & Silva, M. R. (2018). Gait analysis in the context of spasticity management. In Advanced Technologies for the Rehabilitation of Gait and Balance Disorders (pp. 471-487). Springer, Cham.

Krug, S. (2014). Don't Make Me Think, Revisited. New Riders.

Lam, T., Eng, J., Wolfe, D., Hsieh, J., & Whittaker, M. (2007). A systematic review of the efficacy of gait rehabilitation strategies for spinal cord injury. Topics in spinal cord injury rehabilitation, 13(1), 32-57.

Learn what MVN Analyze can do for you in 10 minutes. Xsens. Retrieved 25 May 2021, from https://content.xsens.com/mvn-analyze-online-demo?_ga=2.191034090.1979966324.1612953959-2114081271.1612953959.

Measuring and Interpreting System Usability Scale (SUS). UIUX Trend. Retrieved 16 May 2021, from https://uiuxtrend.com/measuring-system-usability-scale-sus/#calculation.

Morrison, J. B., & Zander, J. K. (2008). Determining the appropriate font size, and use of colour and contrast for underwater displays. SHEARWATER HUMAN ENGINEERING NORTH VANCOUVER (BRITISH COLUMBIA).

MTw Awinda. Xsens. Retrieved 20 March 2021, from https://www.xsens.com/products/mtw-awinda.

Nielsen, J. (2005). Ten usability heuristics.

Nielsen, J. (2020). 10 Usability Heuristics for User Interface Design. Nielsen Norman Group. Retrieved 7 March 2021, from https://www.nngroup.com/articles/ten-usability-heuristics/.

Nijendijk, J. H., Post, M. W., & Van Asbeck, F. W. (2014). Epidemiology of traumatic spinal cord injuries in The Netherlands in 2010. Spinal cord, 52(4), 258-263.

normal values. Dictionary.com. Retrieved 25 March 2021, from https://www.dictionary.com/browse/normal-values#:~:text=n.,now%20replaced%20by%20reference%20values.

Osterthun, R. (2021). SCI Gait Rehabilitation Process [In person].

Osterthun, R., Post, M. W. M., & Van Asbeck, F. W. A. (2009). Characteristics, length of stay and functional outcome of patients with spinal cord injury in Dutch and Flemish rehabilitation centres. Spinal Cord, 47(4), 339-344.

Paulich, M., Schepers, M., Rudigkeit, N., & Bellusci, G. (2018). Xsens MTw Awinda: Miniature wireless inertial-magnetic motion tracker for highly accurate 3D kinematic applications. Xsens: Enschede, The Netherlands, 1-9.

Pirker, W., & Katzenschlager, R. (2017). Gait disorders in adults and the elderly. Wiener Klinische Wochenschrift, 129(3), 81-95.

Post, M. W., Nooijen, C. F., Postma, K., Dekkers, J., Penninx, F., van den Berg-Emons, R. J., & Stam, H. J. (2017). People with spinal cord injury in the Netherlands. American journal of physical medicine & rehabilitation, 96(2), S93-S95.

Postma, K. (2021). SCI Gait Rehabilitation Process [In person].

Schepers, M., Giuberti, M., & Bellusci, G. (2018). Xsens mvn: Consistent tracking of human motion using inertial sensing. Xsens Technol, 1-8.

Silva, L., Stergio, N. (2020). Chapter 7 – The basics of gait analysis. Biomechanics and Gait Analysis, 225-250.

Simon, S. R. (2004). Quantification of human motion: gait analysis—benefits and limitations to its application to clinical problems. Journal of biomechanics, 37(12), 1869-1880.

Spinal Cord Injury - Symptoms and causes. Retrieved 24 February 2021, from https://www.mayoclinic.org/diseases-conditions/spinal-cord-injury/symptoms-causes/syc-20377890

Spinal Cord Injury 1990 Case Definition. (1990). Retrieved 19 February 2021, from https://wwwn.cdc.gov/nndss/conditions/spinal-cord-injury/case-definition/1990/

Spinal cord injury and how it affects people. Back Up. Retrieved 6 March 2021, from https://www.backuptrust.org.uk/spinal-cord-injury/what-is-spinal-cord-injury.

Spinal Cord Injury Rehabilitation. Retrieved 25 February 2021, from https://stanfordhealthcare.org/medical-conditions/back-neck-and-spine/spinal-cord-injury/treatments/rehabilitation.html

Spinal Cord Injury: Types, Symptoms, Causes & Treatment. Cleveland Clinic. Retrieved 12 March 2021, from https://my.clevelandclinic.org/health/diseases/12098-spinal-cord-injury.

Symptoms of Spinal Cord Injury. Retrieved 25 February 2021, from https://stanfordhealthcare.org/medical-conditions/back-neck-and-spine/spinal-cord-injury/symptoms.html

Tesio, L., & Rota, V. (2019). The motion of body center of mass during walking: a review oriented to clinical applications. Frontiers in neurology, 10, 999.

Types of Spinal Cord Injury (SCI). Retrieved 25 February 2021, from https://stanfordhealthcare.org/medical-conditions/back-neck-and-spine/spinal-cord-injury/types.html

Vallery, H. and Ribbers, G., 2019. Format Proposal Convergence Call Erasmus MC - TU Delft.

Van Boeijen, A., Daalhuizen, J., van der Schoor, R., & Zijlstra, J. (2014). Delft design guide: Design strategies and methods.

van der Veeken, M. (2021). SCI Gait Rehabilitation Process [In person].

van Kuijk, J. (2021). ID4256-17 16 & 17 UI design variables. Lecture, TU Delft.

VisAWI. Visawi.uid.com. (2021). Retrieved 14 May 2021, from https://visawi.uid.com/.

What is User Interface Design?. The Interaction Design Foundation. Retrieved 7 March 2021, from https://www.interaction-design.org/literature/topics/ui-design.

Xsens Tutorials. Xsens. Retrieved 25 March 2021, from https://tutorial.xsens.com/.

Master Thesis

Rebekah Kempske

July, 2021