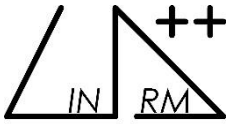

LINarm++
Affordable and Advanced LINear device for ARM rehabilitation

Deliverable RIF
Report on RIF visit outcome

Contractual delivery date	31.10.2016 (month 18)
Actual delivery date	16.11.2016 (month 18 + 16d)
Version	1.0
Dissemination level	PU
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1 Executive summary

A team made of 5 representatives of the LINarm++consortium joined in Volterra at the Bioengineering Lab at the Auxilium Vitae RIF to finalize the integration of the device and to perform functionality and usability tests. The tests last a whole week starting from October the 17th to October the 21st. The first two days were spent for the integration of LINarm++ sub-systems; the last three days were dedicated to test the functionalities of the system and its usability on a group of 12 physical therapists.

At the end of day two, all LINarm++ submodules and functionalities were successfully integrated. During the next three testing days, the functionality tests were performed and successfully completed. The tests consisted on different trials during which subjects performed reaching movements against gravity and hand-to-mouth movements using LINarm++ in different control (assistive) modalities. The reaching movement was tested even with the virtual environment, with different levels of assistance, which were automatically adjusted on the subject's performance using the Patient Model.

Almost all functionalities and subsystems worked properly. In particular, all subjects could perform both the reaching and the hand-to-mouth movements in passive and active modalities using different velocities and end-effector stiffness. The LINarm++ FES subsystem, which was tested successfully in the previous days by CNR, unfortunately, could not be used due to electrical issues of the FES system. During all trials, biological signals were recorded using the acquisition system integrated in the handle, which was developed by UL. In the case of the hand–to-mouth movement, a different handle was used, which was mounted on a turning joint enabling the execution of this special movement, which occurs on a round hand trajectory. In this case, subjects hold the handle with the integrated acquisition system with the contralateral hand to allow the recording of the biological parameters.

After tests, all subject were given the System Usability Scale (SUS), a simple ten-item scale giving a global view of subjective assessments of usability. They were invited to also report positive and negative matters along with some suggestions.

SUS results were positive; the average total score was (75±13)/100. Generally, the possibility to perform functional movements at physiological velocity was appreciated. Most of the physical therapists would use the system once available. Particularly, the hand-to-mouth movement was considered innovative and important from a rehabilitation point of view. By contrast, most of the physical therapists outlined that the actual active control of the systems is too heavy and not suitable for patients at this state.

Finally, we report the mechatronic system needed some maintenance because of a problem at the mechanical transmission system. Specifically, the cable-based transmission got stuck due to excessive forces applied at the end-effector by the users.

In conclusion, all functionalities were completely integrated in LINarm++ and tests of functionality could be successfully performed. The tests results are promising; the physical therapists seem to like the system and stated they would use it when available for medical therapies.

2 Introduction

At the end of the project, it was due to visit the RIF at Volterra to finalize the integration of all LINarm++ and to perform some tests of usability. Therefore, five representatives of the Consortium joined at the Auxilium Vitae Hospital in the Bioengineering Lab directed by Eng. Stefano Mazzoleni. Once the integration was completed, here they could perform all usability and functionality tests with the help of rehabilitation professionals of the Auxilium Vitae. This document describes the activities performed during the staying in Volterra and reports the main results.

Chapter 3 deals with the integration of the functionalities of the system. Specifically, the integration work is described along with the main issues encountered and the solutions found.

In Chapter 4, the trials performed on twelve physical therapists to test the functionalities of the system are reported. Specifically, a description of the performed movements will be given. Further, the results of the tests will be reported and discussed shortly.

Chapter 5 aims at describing the System Usability Scale (SUS), a questionnaire, which was given to the physical therapists to assess the usability of LINarm++. In Subsection 5.1, the use of SUS along with a discussion of the scoring will be presented. In subsection 5.2, the SUS results on the LINarm++ testing will be reported and discussed shortly.

In Chapter 6 conclusions are drawn.

Figure 1: The LINarm++ team at the Bioengineering Lab (left panel) and at dinner in Volterra (right panel).

Figure 2: A physical therapist testing the system (left panel); engineers and physical therapists all together at lunch (right panel)

3 Technical integration

This Chapter deals with the technical integration work which was performed at the Auxilium Vitae RIF by CNR and UL. The work consisted in verifying the functioning of all LINarm++ sub-systems and in fixing encountered issues. As reported in the previous deliverables the LINarm++ system consists of a series of modules developed by different partners. During the two first days at the RIF, the team of engineers verified all modules matched the desired software and hardware specifications.

HARDWARE COMPATIBILITY

Firstly, the hardware compatibility between the handles and the LINarm++ device was checked also taking into account the movements to be tested. The mechanical connection developed by CNR, a simple flange enabling an easy and fast install of the handles used for different movement (see Figure 3), was mounted and tested. Both the sensorized handle realized by UL and the hand-to-mouth handle realized by CNR could be easily installed. No further tests were needed as the system has been mechanically tested previously by CNR.

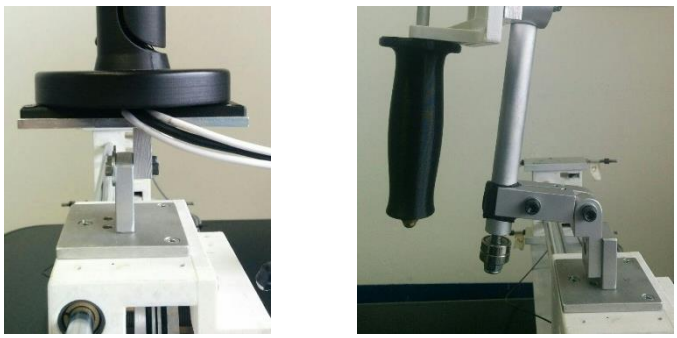

Figure 3. Mechanical connection enabling an easy and fast install of the handle for reaching (left panel) and for the hand—to-mouth movement (right panel)

The new cylindrically-shaped physiological handle developed by UL was assembled and tested for functionality (see Figure 4). Handle platform design includes easy-to-use on-off mounting mechanism for both hemispherical and cylindrical handle. Some problems arose while trying to limit the passive rotation of the handle, to reduce the tear on the electrode connection cables. This was solved by adding a mechanical limit to the handle platform. Both the sensorized handle realized by UL and the hand-to-mouth handle realized by CNR could be easily installed. No further tests were needed as the system has been mechanically tested previously by CNR.

Figure 4 Cylindrically-shaped handle developed by UL integrates sensors for measuring skin conductance, photoplethysmography, skin temperature and grasping force

The LINarm++ architecture system consists of a series of modules, realized by different partners (see deliverable D2.1). All software modules communicate through a manager module. The proper functioning of all LINarm++ software interfaces needed to be verified. Therefore, firstly the functioning of the communication modules was verified through a series of operating checks of all the communications channels. Some of these tests had already been performed during the integration week, which previously took place in Ljubljana. During the tests at the Auxilium Vitae RIF, the coherence of the communication protocol was tested for each module, even verifying how the different modules do react to data sent. Main encountered issues regarded the communication among the Virtual Reality environment module, the Patient Model and the LINarm++ manager. The CNR and UL personnel cooperate to solve the problems met. All issues were solved through software debugging and writing of new routines.

Once all the communications problems were solved, some debugging of the ROSbag plugin of the ROS framework and functionality tests were performed. Final tests regarded the assistance algorithm able to guide and assist the patient to the target given by the VR module. This algorithm, already presented and described in deliverable D2.1 and D2.2, provides an assistance force whose intensity is function of the assistance level computed by the Patient Model., the distance between target and player, and the required time to reach the target.

Patient model developed by UL had to be calibrated for use with the new environment and setup. Thresholds for the decision tree algorithm had to be established by empirical testing. Series of tests were performed at different conditions invoking maximal and minimal values of biomechanical parameters, success and physiological signals. With these tests we were able to determine the threshold values and also validate the proper functioning of the model. Some problems arose while trying to port the Matlab based algorithm between PCs, but this was solved by group effort of CNR and UL by installing additional software.

Some tests regarding both the hardware and the software, were finally performed for some minutes, using different movements and control modalities to verify the global functioning and the reliability of the system.

4 System functionality testing

LINarm++is a multisensory and multimodal device for neuromuscular rehabilitation of the upper limb, designed to enable enriched rehabilitation treatment in both clinical and home environments. The system focuses on the integration of a wearable neuromuscular electrical stimulation system, a virtual rehabilitation scenario, a low-cost unobtrusive sensory system and a patient model for adapting training task parameters. It also monitors the user behaviour during each single session and its evolution throughout the entire training period.

This Chapter consisted in two subsections. In Subsection 4.1 the performed tests are described along with main matters; in Subsection 4.2 main results are reported and shortly discussed.

4.1 The testing trials

The testing trials were based on the execution of mainly two functional compound movements, namely the reaching against gravity and the hand-to-mouth. These two gestures were selected for rehabilitation because they are promising in promoting the recovering of shoulder and elbow joint movements that are prerequisites for the use of the hand in ADL, such as eating and reaching for objects. The reaching against gravity consisted in a compound movement made of shoulder flexion and elbow extension. The no-assisted reaching movement is shown in Figure 5; the LINarm++ assisted reaching movement against gravity is shown in Figure 6.

Figure 5. The reaching movement against gravity.

Figure 6. The LINarm++ assisted reaching movement against gravity.

The hand-to-mouth movement consists of a coordinated movement of shoulder and elbow flexion. The no-assisted hand-to-mouth movement is shown in Figure 7, the LINarm++ assisted hand-to-mouth movement is shown in Figure 8.

Figure 7 The no-assisted hand-to-mouth movement.

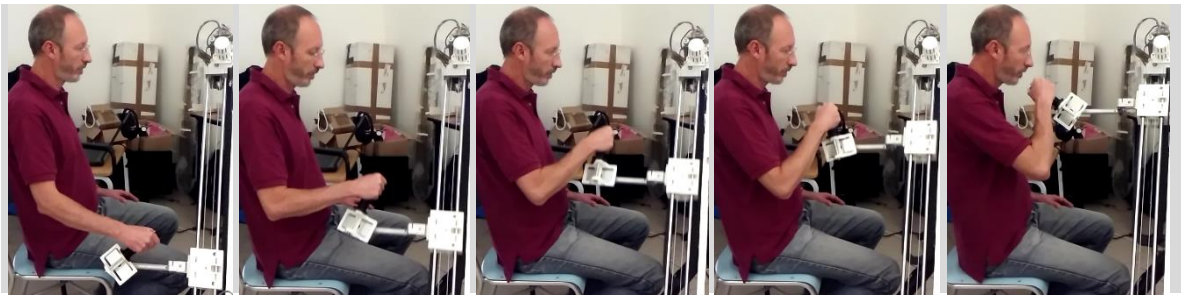

Figure 8 The LINarm++ assisted hand-to-mouth movement.

Both LINarm++ assisted movements were performed in the passive (fully-assisted) modality (the robot drove the subjects arm independently of the applied forces) as well as in active modality (the subject actively performed the movement by pushing/pulling the end-effector handle. During movements, the end-effector stiffness was changed on-line to test this functionality and to show the physical therapists the possibility to adjust this parameter on the subject's wishes. Further, even different admittance parameter were tested to show the physical therapists the possibility to customize the device reactivity on the patient's functional ability.

Special attention was paid to the orientation of the end-effector handle, which is crucial for getting a real functional movement both in the case of the hand-to-mouth movement as well as in the case of the reaching movement.

During the hand-to-mouth movement, the handle was free of rotating to allow wrist internal and external rotation as shown in Figure 9. The turning joint allowed even the pronation/supination movement.

Figure 9 Handle starting position (left panel) and ending position (right panel) during the hand-to-mouth movement.

In the case of the reaching movement the handle was positioned horizontally (see Figure 10, left panel) with the idea to facilitate, in the future, patients with supination difficulties.

Next, following the suggestion of some physical therapists, the handle was positioned even vertically (see Figure 10, right panel). In their opinion this position should facilitate patients in pushing the end-effector against gravity.

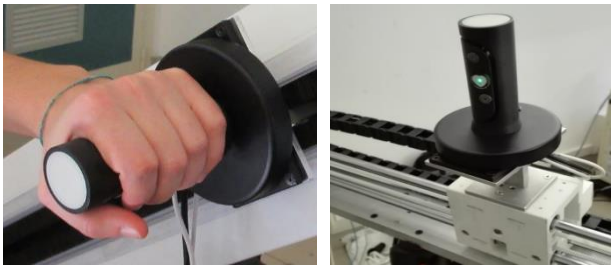

Figure 10: Handle in horizontal position (left panel) and in vertical position (right) panel) to allow reaching movement

In the case of the reaching movement, the system was tested even in the gaming modality using a digital environment especially developed in the framework of the project. Aim of the game was to catch some objects, identified as butterfly (see Figure 11, left panel), trying to avoid catching some others objects, identified as bees (see Figure 11, right panel).

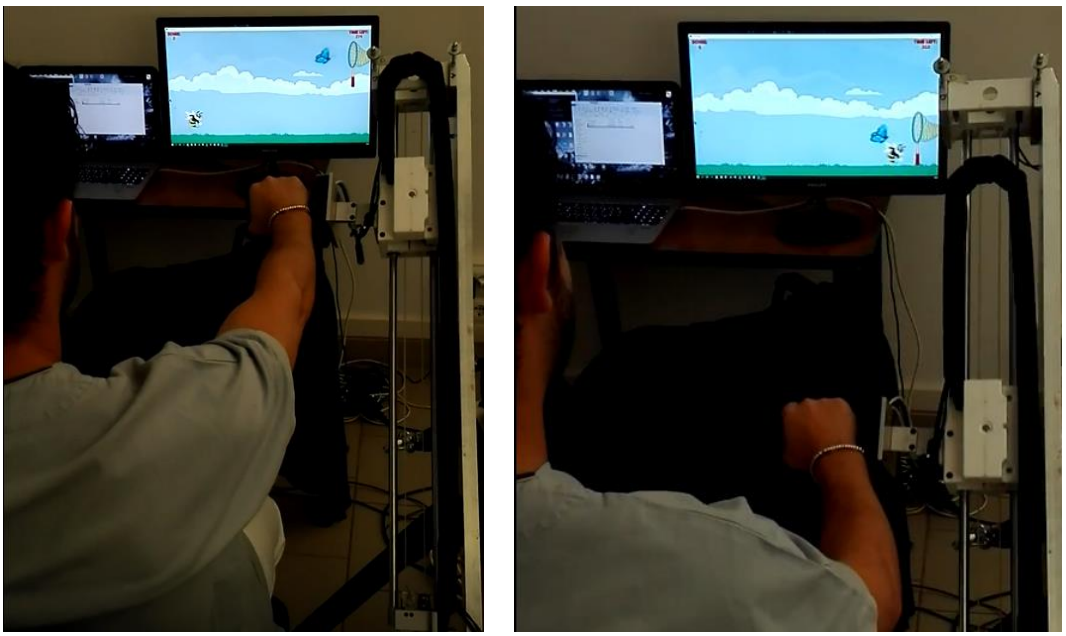

Figure 11. The reaching movement performed in the gaming modality. The subject is flexing the shoulder and extending the elbow trying to catch a butterfly (left panel). The right panel shows the subject controlling shoulder extension and elbow flexion trying to catch a butterfly without getting a bee too.

The level of difficulty of the game was adjusted automatically based on the performance of the subject. Specifically, the number of objects and their speed increased with increasing performance (number of caught objects) or, vice versa, decreased with the number of failings (caught bees). Even the level of assistance was adjusted automatically. The assistance consisted in a kind of force field attracting the end-effector towards the targeted objects, the strength (/speed) of which could be set-up.

The aim of the gaming trials was therefore two folded:

1. to test whether the level of difficulties was adjusted properly during the game;
2. to verify whether the assistance functionality do facilitate catching the butterflies and properly adjusted based on the subject's performance.

4.2 Results

This is a short subsection reporting main results coming from the testing trials. For a detailed technical description of the final prototype functionalities refer to deliverable D1.3. Here below, the results regarding the LINarm++ functionalities tested at RIF will be shortly discussed. The subsection is concluded with some examples regarding the acquired data.

4.2.1 LINarm++ functionalities

The testing trials performed at the RIF aimed at verifying all integrated functionalities did work properly. Recalling LINarm++ is a hybrid assistive system for neurorehabilitation of the upper-limb, main matters to be verified were:

1. All control modalities did function properly;
2. To verify the digital environment did function properly;
3. The FES system and the device worked in perfect synchronization;
4. To test the mechanical structure and transmission of the device;
5. To test the acquisition system.

CONTROL

The LINarm++ can be controlled in different modalities thus enabling a personalized rehabilitation based on the functional residual ability of the patient. During the testing of the device, the reaching against gravity and the hand-to-mouth movements were performed with different levels and types of assistance. The position control (i.*e.* passive mobilization), which is suitable for low-functioning patients, was tested using different movement velocities. In all cases, a quasi-physiological profile, featuring high smoothness, was used. Tests were successful and, particularly, the smoothness of the movement was appreciated by the physical therapists (see Chapter 5, Subsection 5.2).

The admittance control also worked properly. Unfortunately, most of the physical therapists reported, that in their opinion, the handle would be *too heavy* to be driven against gravity by patients of any level of functionality. More reactive and transparent control algorithms will therefore be developed in the near future.

LINarm++ features a variable stiffness mechanism, which allows customizing the end-effector stiffness in addition to admittance control parameters, depending of the control modalities used and the ability of the patient. During trials, the stiffness was changed with the movement type, different control modalities and velocities to make a qualitative test of the effects of the changing stiffness on the subjects' proprioception. The mechanisms to change the stiffness worked properly and the effects were sensed clearly by the testing subjects. Studies will be performed in the near future to define criteria on how to adjust the stiffness.

As previously reported in Subsection 4.1, the assistance modality was tested using LINarm++ in the gaming mode. The first testing subjects reported the assisting movement towards the target to start abruptly; therefore, the resulting movement was uncomfortable. The algorithm was then adjusted to improve the movement smoothness. Consequently, last trials demonstrated a good improvement and the resulting movement was satisfactory.

DIGITAL ENVIRONMENT

The digital environment did function properly during all tests, no freeze, nor crash was reported. The environment was suitable for testing the LINarm++ using the reaching movement against gravity. Particularly, the change in the objects speed due to the automatic adjustment of the level of difficulty, which is based on the Patient Model algorithm, did function properly.

FES SYSTEM

The 2-channel neuromuscular stimulation was perfectly synchronized with performed movement independently of the controlled modality used. Particularly, the combination of FES and admittance control resulted to be very comfortable. In this modality, FES actually help the subject in performing the movement. These are the results reported by the CNR personnel who tested the system before joining at the RIF. Unfortunately, it was not possible to let the physical therapist test the system at the Bioengineering Lab as some electrical issues of the FES system arose and it was not possible to address them during the week spent at the RIF.

MECHANICAL STRUCTURE

All movements, hand-to-mouth included, could be performed without any problem. The reaching movement against gravity was tested with different inclination angles. The hand-to-mouth movement was tested both for the left as well the right hand. The mechanical structure of the system along with the covering shells resulted to be reliable and suitable for the purpose. Some problems regarded the commercial tripod, used to support the device. In fact, it presented some undesired backlashes. A new supporting system, which allows fixing of the device should be developed in the future. Moreover, the cable-based transmission system is still not completely reliable and got stuck once during the week, despite continuous improvements carried out in the last part of the project to improve the overall reliability. Better-performing cables or a redesigned version of the mechanical transmission system should be identified and developed to improve the overall reliability of the system, after the end of the project.

ACQUISITION SYSTEM

The acquisition system allows the recording of some biological signals during the robot-assisted movement. As described in D4.2 the acquisition system is integrated in the end-effector handle.

Some examples of the signals acquired during the tests at the Volterra RIF are shown here below.

4.2.2 Acquired data

This sections deals with the data acquired during the tests performed at the RIF. Data are under elaboration to allow a comprehensive evaluation of the quality of the results and a comparison among subjects and different exercises.

Here below some representative graphs are reported aiming at showing that different movements and control modalities result in a different patient robot biomechanical interaction. LINarm++ kinematics along with the robot-subject interaction forces during the reaching movement performed with position and admittance control are shown in Figure 12 and Figure 13, respectively. Similarly, Figure 14 and Figure 15 show the graphs relative to the hand-to-mouth movement performed in position control (passive) and in admittance control (active), respectively.

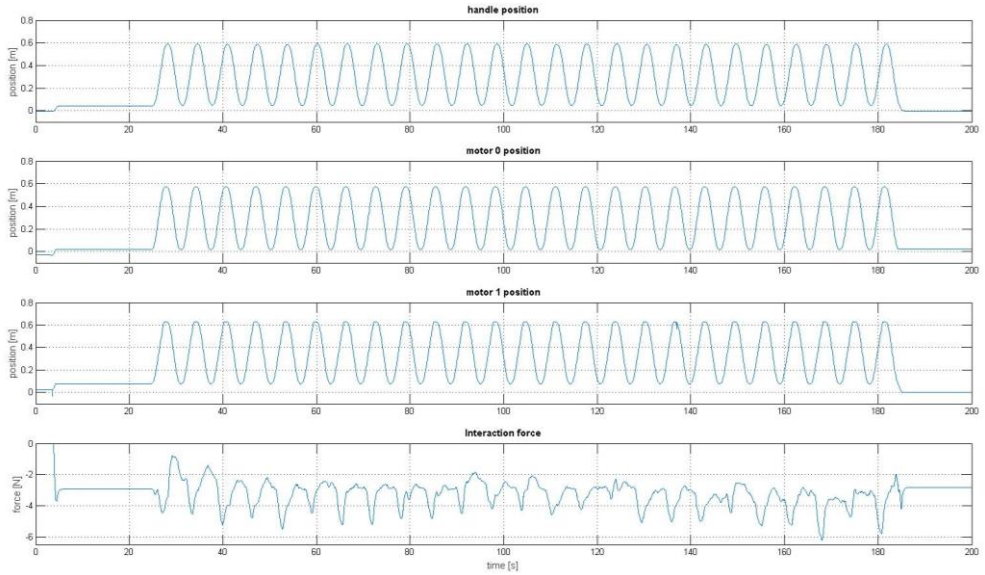

Figure 12. LINarm++ signals acquired during a reaching movement performed in position control

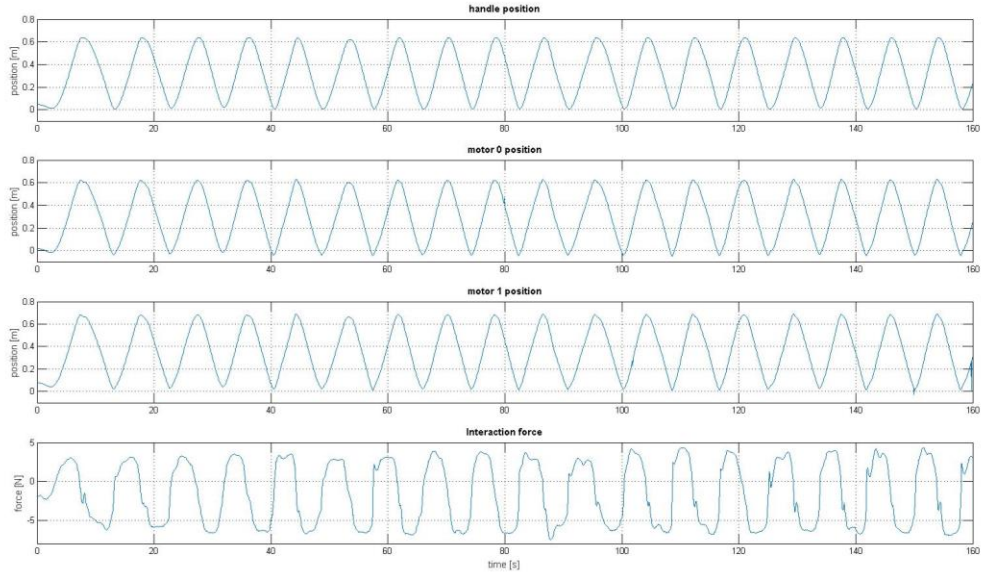

Figure 13. LINarm++ signals acquired during a reaching movement performed in admittance control

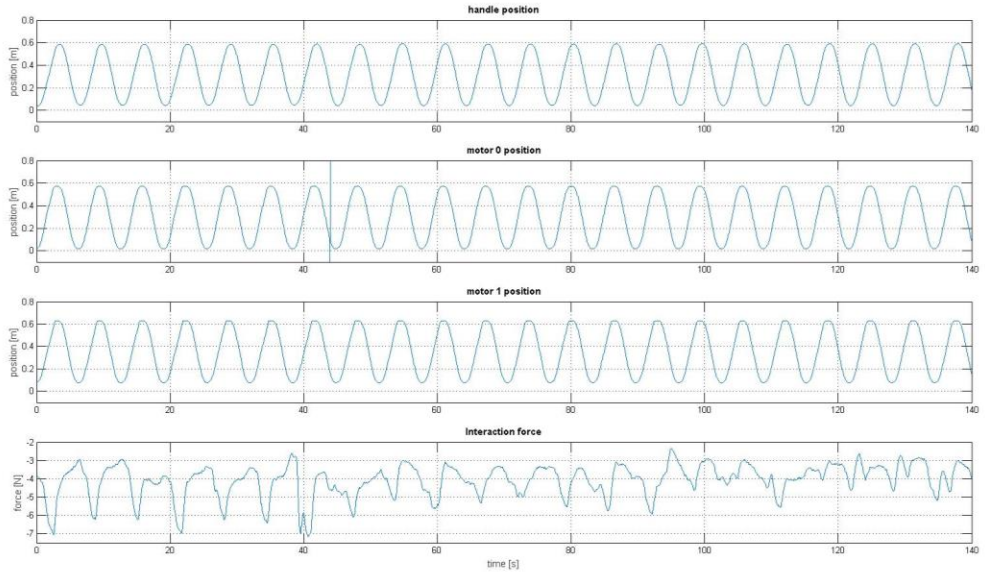

Figure 14 LINarm++ signals acquired during a hand-to-mouth movement performed in position control

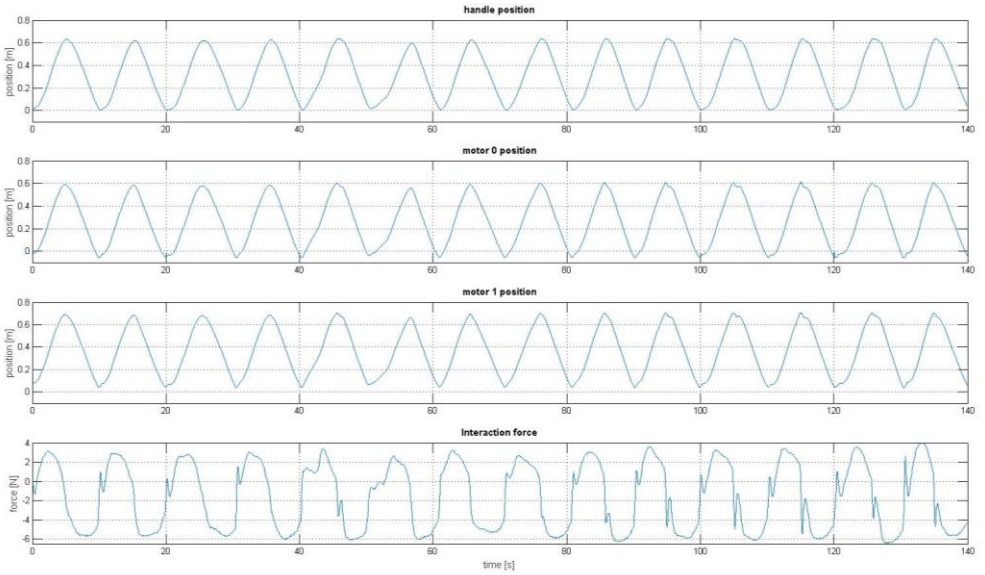

Figure 15 LINarm++ signals acquired during a Hand-to-mouth movement performed in admittance control

Physiological data were collected by the sensorized handle with no special instructions for the subjects, to test the measurement method for robust and unobtrusive monitoring. Since large effect of motion artefacts was expected for all measurement sessions, we decided to include a rest period at the beginning and end of every session, to serve as reference (baseline) period. Figure 16 shows clean physiological data for the duration of the recording session of reaching movement, however in most cases recordings were corrupted by motion artefacts arising from the jerky movements and grasping. Comparing the grasping force signal from Figure 16 to one on Figure 17, we can assume grasping force and jerk can be directly correlated to signal corruption. Similar effect can be observed from Figure 17, where subject was transitioning from task to rest period of the session.

Most significant signal corruption is observed from the photoplethysmogram and skin conductance, where even small changes in pressure can result in different light absorbance by the photo sensor or different electrical contact by the electrodes. In some cases PPG sensor can get saturated (Figure 17) or by increasing the pressure (grasping force) it can also be damped (Figure 18). Skin temperature measurement is found to be very robust to motion artefacts (Figure 17).

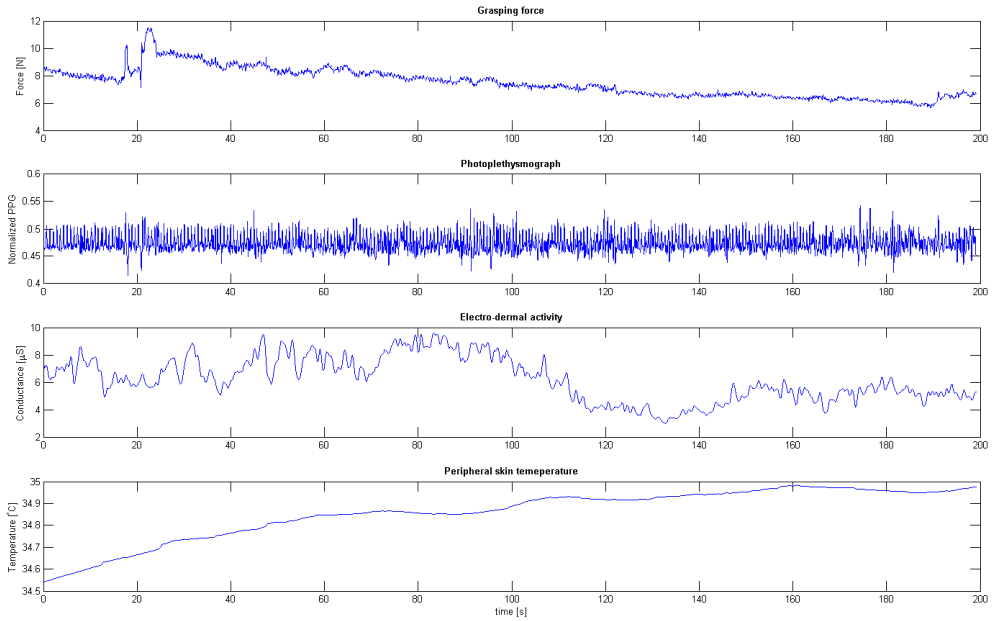

Figure 16: Clean physiological data collected from the handle for the whole duration of the recording session: grasping force, photoplethysmogram, electro-dermal activity, peripheral skin temperature.

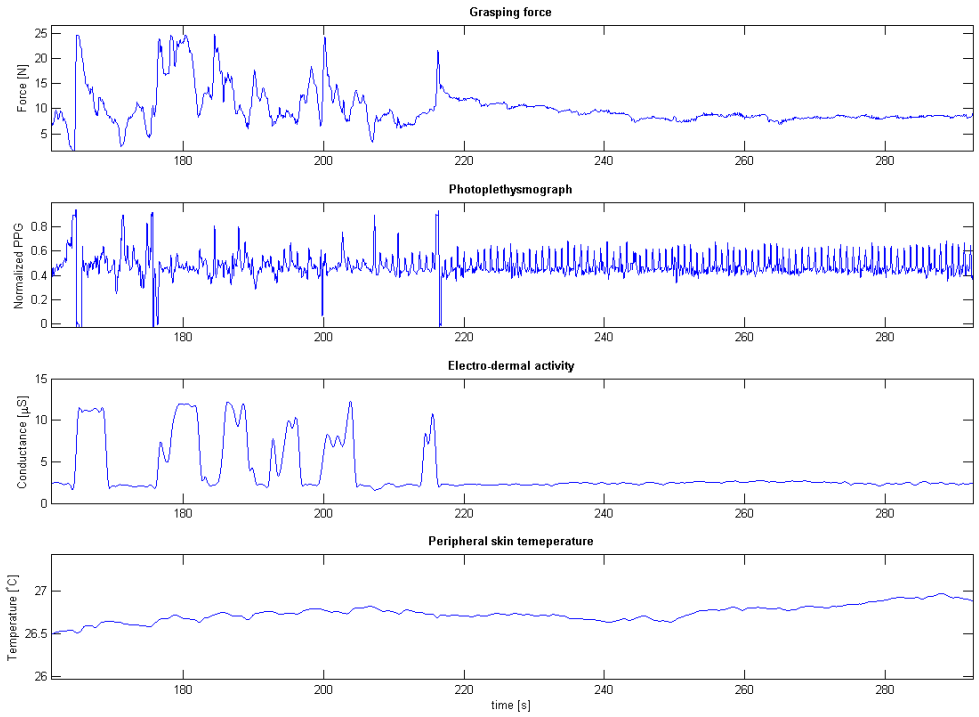

Figure 17: Corrupted physiological data during task, transitioning to improved signal quality in the rest period: grasping force, photoplethysmogram, electro-dermal activity, peripheral skin temperature.

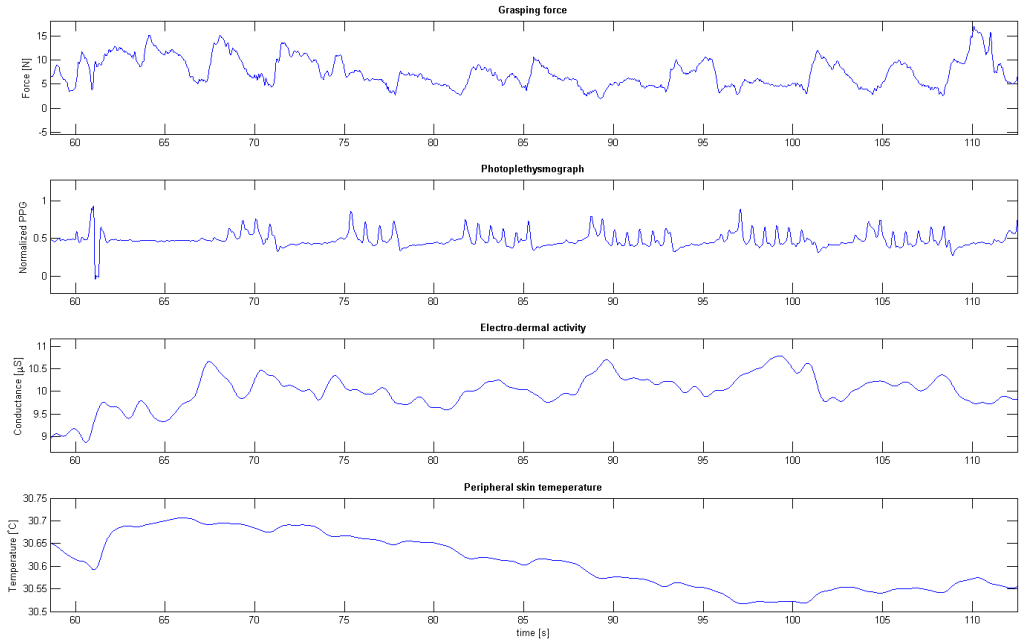

Figure 18: Physiological signal quality changing for the duration of the recording session. Most significant effect found on photoplethysmogram.

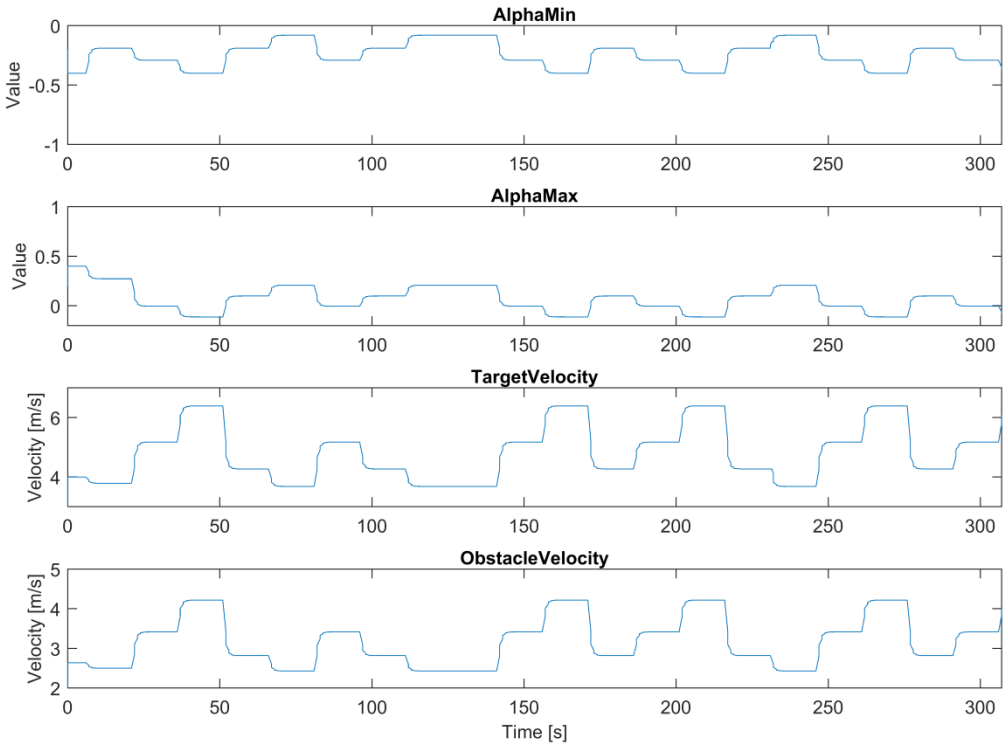

Figure 19: Output of the Patient model during reaching movement: AlphaMin, AlphaMax, TargetVelocity and ObstacleVelocity.

Patient model adaptive behavior can be observed from Figure 19. AlphaMin and AlphaMax parameters are calculated based on success, biomechanical and physiological parameters. Target and obstacle velocities are interpolated so that soft transition between difficulty states is achieved for better user experience in VR.

5 LINarm++ usability evaluation

The LINarm++ usability was evaluated by 12 physical therapists who performed the functional test of the device.

The usability of a system can be measured only by taking into account the context of use of the system — i.e., who is using the system, what they are using it for, and the environment in which they are using it. Furthermore, measurements of usability have several different aspects:

- effectiveness (can users successfully achieve their objectives)
- efficiency (how much effort and resource is expended in achieving those objectives)
- satisfaction (was the experience satisfactory).

However, the precise measures to be used within each of these classes of metric can vary widely. For example, measures of effectiveness are very obviously determined by the types of task that are carried out with the system; a measure of effectiveness of a word processing system might be the number of letters written, and whether the letters produced are free of spelling mistakes. If the system supports the task of controlling an industrial process producing chemicals, on the other hand, the measures of task completion and quality are obviously going to reflect that process.

In the case of the LINarm++, the effectiveness of the system should be assessed by measuring the patients' recovery, which actually needs the running of a clinical trial and, therefore, was out of the scope of these tests. Hence, we decided to let the physical therapists try and test LINarm++ device and its functionalities. Accordingly, starting from the consideration that "usability" is not a quality that exists in any real or absolute sense, we decided to test the system using the "System Usability Scale", a validated questionnaire developed and proposed by John Brooke. SUS has proved to be a valuable evaluation tool, being robust and reliable (Brooke 1996). Further, they were also given the opportunity to express their opinion on the system by answering the following three questions:

1. What did you like most?
2. What didn't you like?
3. Comments, criticisms, suggestions?

5.1 The System Usability Scale

SUS is a simple, ten-item scale giving a global view of subjective assessments of usability. It is a Likert scale where statement are made and the respondent then indicates the degree of agreement or disagreement with the statement on a 5-point scale. The technique used for selecting items for a Likert scale is to identify examples of things, which lead to extreme expressions of the attitude being captured.

SUS was constructed using this technique. A pool of 50 potential questionnaire items was assembled. Two examples of software systems were then selected (one a linguistic tool aimed at end users, the other a tool for systems programmers) on the basis of general agreement that one was "really easy to use" and one was almost impossible to use, even for highly technically skilled users. 20 people from the office systems engineering group, with occupations ranging from secretary through to systems programmer then rated both systems against all 50 potential questionnaire items on a 5-point scale ranging from "strongly agree" to "strongly disagree".

In the next page the template of SUS along with an example is presented.

System Usability Scale

	Strongly disagree				Strongly agree	
1. I think that I would like to use this system frequently					√	4
	1	2	3	4	5	
2. I found the system unnecessarily complex				√		1
	1	2	3	4	5	
3. I thought the system was easy to use		√				1
	1	2	3	4	5	
4. I think that I would need the support of a technical person to be able to use this system	√					4
	1	2	3	4	5	
5. I found the various functions in this system were well integrated		√				1
	1	2	3	4	5	
6. I thought there was too much inconsistency in this system			√			2
	1	2	3	4	5	
7. I would imagine that most people would learn to use this system very quickly		√				1
	1	2	3	4	5	
8. I found the system very cumbersome to use				√		1
	1	2	3	4	5	
9. I felt very confident using the system					√	4
	1	2	3	4	5	
10. I needed to learn a lot of things before I could get going with this system		√				3
	1	2	3	4	5	

Total score = 22

SUS Score = 22 *2.5 = 55

5.1.1 Using SUS

The SU scale is generally used after the respondent has had an opportunity to use the system being evaluated, but before any debriefing or discussion takes place. Respondents should be asked to record their immediate response to each item, rather than thinking about items for a long time.

All items should be checked. If a respondent feels that they cannot respond to a particular item, they should mark the centre point of the scale.

5.1.2 Scoring SUS

SUS yields a single number representing a composite measure of the overall usability of the system being studied. Note that scores for individual items are not meaningful on their own.

To calculate the SUS score, first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1, 3, 5, 7,and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU. The SUS scores have a range of 0 to 100.

5.2 Usability evaluation results

5.2.1 SUS

The SUS was submitted to all twelve physical therapists after they have tested the LINarm++ for almost one hour. They were asked to evaluate the system on its functional and mechanical performance, not on the software (GUI) the CNR personnel used to control the device. In fact, the actual user-interface is not user friendly and has not been tailored yet on the capacities and needs of clinical professionals and patients. The user-interface is at the moment suitable for testing the device on healthy subjects under the supervision of an engineer and is not ready to be used in a clinical environment by physical therapists. It is worth to mention that the development of a user-friendly and user-oriented graphical user-interface was out of the scope of the LINarm++ experiment.

Table 1: The System Usability Scale results of LINarm++ device

	S	A	H	I.1	I.2	I.3	I.4	I.5	I.6	I.7	I.8	I. 9	I.10	Tot
(max)		Years	m	(5)	(1)	(5)	(1)	(5)	(1)	(5)	(1)	(5)	(1)	100
Sbj 01	M	38	1.70	4	2	5	3	3	3	5	2	3	2	70.0
Sbj 02	M	46	1.82	3	1	3	1	3	1	4	1	4	1	80.0
Sbj 03	F	41	1.62	4	1	4	5	3	3	5	1	4	1	72.5
Sbj 04	M	34	1.70	4	2	4	3	3	3	5	2	4	2	70.0
Sbj 05	M	44	1.91	5	2	5	1	4	1	5	1	4	1	92.5
Sbj 06	F	33	1.73	4	1	4	3	4	1	4	1	4	1	82.5
Sbj 07	F	61	1.72	3	1	4	1	4	1	4	1	3	3	77.5
Sbj 08	F	37	1.60	5	3	4	3	4	3	4	3	4	3	65.0
Sbj 09	F	37	1.68	5	1	5	5	5	1	5	1	5	1	90.0
Sbj 10	F	43	1.65	3	2	3	5	2	3	2	4	3	2	42.5
Sbj 11	M	29	1.77	4	2	4	4	3	1	3	2	4	2	67.5
Sbj 12	M	33	1.88	4	2	4	1	4	1	5	1	5	1	90.0

Results of the SUS questionnaire submitted to 12 physical therapists who tested the LINarm++ device. The score of each subject's (rows) for each item (column) is reported along with the total SUS score. The maximum score, calculated as explained in subsection "*Scoring SUS*" is 100 (see second raw).

Average		40		4.0	1.7	4.1	2.9	3.5	1.8	4.3	1.7	3.9	1.7	75.0
St.dev.		8		0.7	0.6	0.7	1.5	0.8	1.0	0.9	1.0	0.6	0.7	13.0

In Table 1 sex, age and height of the tested subject along with the given scores for each of the ten items are reported.

Out of the 12 physical therapists, 6 were female, they were aged between 29 and 61 years (average age 40±8 years) and the average height was 1.73±0.09 m.

The average total score was (75±13)/100.

The questionnaire is made of 5 positive items, which are positively evaluated when they are given a high score (max 5 points), and 5 negative items, which indicate a positive evaluation of the system when they are given a low score (min 1 point).

All positive items but one were averagely scored around 4 points, all negative scores but one were averagely scored lower than 2 points. In fact, item 5 (*I found the various functions in this system were well integrated*) was averagely scored 3.5±0.8 points, and item 4 (*I think that I would need the support of a technical person to be able to use this system*) was averagely scored 2.9±1.5 points.

5.2.2 Open questions

In Table 2 the answers of each subject to the three open questions are reported.

Summarizing, the physical therapists liked the possibility to perform functional movements (2 subjects) especially the hand-to-Mouth movement (4 subjects). They also appreciated the smoothness of the movement (1 subject) or, differently said, the possibility to perform movements at physiological velocity (3 subject). Further, they liked the possibility to work against gravity (1 subject) and to change the level of inclination of the system. Three subjects outlined the ease of use of the system. They even reported the absence of compensatory movements (1 subject) and a positive feeling regarding the shoulder movement (1 subject). Finally, they appreciated the possibility of define the level of difficulty (1 subject) and the degree of assistance (1 subject). One subject liked the idea not to support/constrain the patient's arm/hand although, in some cases, he believes it is needed.

By contrast, the physical therapists outlined that the actual active control of the systems is too heavy and not suitable for patients (5 subjects). Some of them claimed for an arm/wrist support (3 subjects) and did not like the handle ergonomics, which should be improved (3 subjects). They also suggested to consider allow different handle orientations (*e.g.* vertical) during reaching (3 subjects)

Table 2. Subjects' answers to the three open questions

	What did you like most?	***What didn't you like?***	***Comments, criticisms, suggestions?***
Sbj01	• Smoothness of the movement		
Sbj02	• Its ease of use • That movements resembles the physiological ones • Possibility of setting up the degree of assistance	• the resistance is too high, active control is **too heavy** • movement velocities should be better setup (too slow!)	
Sbj03	• The Hand-to-Mouth movement • It's ease of use and convenience	• Lack of assistance NB: this subject could not try the assistance modality because it was implemented the day after.	• Put the **handle** also in **vertical position** • Consider to use a sustain for the arm (for some patients it could be too difficult to hold the handle)
Sbj04	• The are no shoulder compensations (e.g. shoulder shrug)	• The **handle is not ergonomic**; • It is **too heavy**	
Sbj05		• The instability of the tripod, which supports LINarm++.	• Improve **handle ergonomics** • Improve assistance during gaming (should be more smooth) • Block pronation and supination, and internal and external deviation in the Hand-to-Mouth movement
Sbj06	• I like the idea to make functional movements at physiological velocity • I appreciate the possibility to change inclination and orientation of the system enabling different reaching movements • I like the arm is not supported although it can complicate the task	• It is **too heavy**, even for an healthy subject; • I believe the handle in the horizontal position could lead to shoulder intra-rotation • Assistance in gaming should be better setup	• Put the **handle** also in **vertical position** • Think to functional movements combined with manipulation tasks; connect the wrist to the system thus letting the hand free.
Sbj07	• Movements against gravity • Possibility to define level of difficulty of the task thus progressively increasing motor recruitment • Hand-to-Mouth		• Monitoring stretch reflex through EMG • Improve visual feedback
Sbj08	• Functional movements • Hand-to-Mouth		• Probably it would be **too heavy** for a patient to actively control the system against gravity
Sbj09	• Hand-to-Mouth • Possibility to work in standing position		• Improve **ergonomics of the handle** • Make a **support** for the wrist
Sbj10	• I liked the feeling of the shoulder compactness (during reaching) • The movement of the humerus and scapula (during reaching)	• Movement is **too heavy** • **Lack of support** of the forearm • Position of the handle	• Put the **handle** also in **vertical position** • Provide a **support** of the forearm • Simplify the preparation of the exercise
Sbj11			• Improve the Hand-to-Mouth movement, especially the degrees of hand movement.
Sbj12	• Its ease of use		• Improve the Hand-to-Mouth movement, especially the degrees of hand movement

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6 Conclusions

Summarizing, both the integration work and the testing phase were positively completed. All functionalities were successfully integrated and tested. The LINarm++ prototype at the actual state works properly allowing even the acquisition of the physiological signals. Although physiological signals are influenced by motion invoked by exercise, there are several solutions that could be implemented to improve signal quality, by providing more detailed instructions to the subject prior exercise, and by using an adaptive/predictive filter to reduce the effect of motion, based on the integrated grasping force measurement, which is found to be directly correlated to the signal corruption. Such filter should be implemented in the near future Main concern regards the mechanical transmission which is still not enough reliable for a continuous and heavy use. It will require to be improved in order to allow an intensive use of the device. The overall feedback of the medical personnel was positive, especially because of some features considered innovative in the robotic rehabilitation field, such as the movements against gravity or towards the body. The main criticisms are a starting point to redesign some parts of the prototype to be even more tailored on patients' characteristics to guarantee an exhaustive rehabilitation training.

To conclude, the visit to RIF was positive in our opinion considering the results achieved. Special acknowledgments go to Eng. Stefano Mazzoleni, the director of the Bioengineering Lab at the Auxilium Vitae, who help the LINarm++ partners in designing the trials and to the whole team of physiotherapists who fantastically collaborated in performing the trials.

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