DELIVERABLE REPORT

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WP3, Task 3.5, Providing test platform setup
Lead: OBHP

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1 DESCRIPTION OF THE TASK

In order to enable rapid interface conformity testing on the spot for all partners, OBHP will provide each partner, as far as needed, with a device to allow testing from an early stage on. To this end, either full arm prostheses, hardware emulators or software emulators thereof will be developed if needed and distributed to the partners requiring such a device for testing prototype systems of signal acquisition and processing. The goal of this task is to facilitate easy transition from local developing to controlling a physical arm for clinical testing for each partner. OBHP will:

- Assess the feasibility and practicability of providing each partner with a physical Otto Bock arm prosthesis or a physical emulator
    - In case of decision for full arm prostheses, OBHP will distribute these among the partners as loan devices.
    - In case of decision for a physical emulator, the device will be designed, manufactured and distributed to the partners by OBHP
    - In case of decision against a physical test device, a virtual arm software that emulates a physical arm prosthesis will be developed and provided
- Provide each partner with an abstraction layer software that receives abstract prosthetic movement commands and translates them into direct control commands for the prosthesis or emulator

2 DESCRIPTION OF DELIVERABLE

It will be decided, which kind of prosthesis test system (physical prosthesis or prosthesis emulator or software) will be made available to each partner requiring such a device for testing purposes.

3 IMPLEMENTATION & RESULT

3.1 COST-RELEVANCE-ANALYSIS

In order to determine whether a physical prosthesis setup, a physical emulator or a virtual prosthesis should be provided for all partners, a cost-relevance estimation was carried out among the options set out in Annex I of the Grant Agreement 687795.

i. *Prosthesis & Components:*
A physical Michelangelo hand prosthesis from Ottobock, plus its components such as active wrists, a controller, battery pack and electrodes

ii. *Emulator*:
A small hardware device, emulating a prosthesis with the same command interface, but no active joints. Instead, for example a display or LED lights could be used to indicate the recognized movements. Since the interface is identical to that of the physical prosthesis, the emulator can be used for development and later be easily replaced by a real prosthesis for clinical tests with no or limited software adaptations.

iii. *Virtual prosthesis:*
An animated 3D model of the hand prosthesis from i., which behaves like the physical model but in a virtual environment. Such a model is already available from previous projects (see Annex) but without interaction capabilities with other virtual objects.

3.1.1 METHOD

A literature study has been carried out in order to assess the clinical effectiveness of the three options set out in Annex I of the Grant Agreement.

In [1], [2] it has recently been shown that offline analysis of prosthetic control alone can lead to misinterpretations. Offline and online control are only loosely correlated. It is therefore important to carry out experiments where users actually act on and interact with the control in a live situation. This is thought to be the case because users can adapt to their movement strategies in real time when they are presented with the live estimation results given by the controller, which is the case in classification tasks but even more so in regression based control [3]. In INPUT, regression based control will be pursued.

In most studies presented in literature which employ real time testing, virtual control was used, since physical prostheses are expensive and difficult to obtain by research institutions. A large number of studies made use of the Fitt's law test, where a virtual cursor has to be placed in a virtual target [4]–[10]. This test allows for directly assessing controlling qualities such as information throughput, control accuracy, control optimality and precision. However, the presented feedback (cursors and target circles) is quite abstract and still does not necessarily translate directly to the controllability in real life of a prosthesis. For example, in a Fitt's law test, overshooting by a few degrees of rotation may result in bad statistical values, but might be easily compensated by a user in real life when grasping an object by slightly changing the body position. On the other hand, physical interactions of the user with the prosthesis such as weight bearing, prosthesis inertia or socket related problems are left out in a Fitt's law test. A detailed study on the transferability of Fitt's law test results to controllability of a physical prosthesis is not known to the authors of this deliverable.

Another virtual real time assessment method often used in literature is the target achievement control (TAC) test [1], [5], [11]–[15]. In this test a virtual 3D model of a hand is presented on a screen to the user. A second hand, usually in a different color (e.g. red) is presented as an overlay to the first hand and in a different position (e.g. the original hand is in a neutral position with the fingers opened and the overlaid hand is rotated, with the fingers closed). The task of the user is now to control the first hand in such a way that it reaches the given position prompted by the overlaid hand (e.g, close the hand, then rotate it). When a satisfying match is achieved, the user receives a feedback on the success of his control efforts (usually by coloring the initially red overlay hand green). Similar measures as in the Fitt's law test can be assessed. The main limitation of this test is that it is often quite difficult for the user to judge on a 2D display whether the 3D hands are overlapping already or not, or which movement is needed to achieve the match. 3D displays and virtual reality goggles to overcome this limitation are currently investigated but have not been published with conclusive results yet.

The most realistic scenario to evaluate prosthetic control is thus with physical prostheses worn by amputees. This kind of study setup however requires large efforts for acquiring prostheses, fitting them to the user by means of a prosthetic socket and performing appropriate tests. Usually only rather small sample sizes can be recruited for these studies [16] whilst having innate large variability (amputee sex, age, time since amputation, stump length, fatigue, experience, socket fit, non-prosthesis related motor skills, etc.). Therefore, literature of such studies investigating improved control schemes is quite scarce. Some examples are found in [16]–[18].

In INPUT, many of these limitations can be overcome due to the constitution of the consortium. As manufacturer, Ottobock has the possibility to provide hand prosthesis components to its partners for

testing. OBHP (in Austria) and UMCG (in the Netherlands) have longstanding experience in fitting amputees with sockets for wearing experimental arm prostheses. Since all clinical tests will be carried out in Austria (OSS) and the Netherlands (UMCG), prosthetic fitting for test subjects is facilitated. Furthermore, five of the six partners in INPUT have longstanding experience in performing tests with amputees. Therefore, a relatively large number of amputees can be obtained for studies. It can hence be concluded that in INPUT hurdles, which are usually present when attempting to verify prosthetic research outcomes with amputees using physical experimental prostheses, will be overcome by employing the resources and experiences of the consortium.

A dedicated working group for Upper Limb Prosthetic Outcome Measures (ULPOM) was founded in 2008 [19], advising tests to be conducted with physical prostheses. Arguably, despite their complexity, studies involving amputees wearing physical prostheses performing activities of the daily living provide the most valuable insights into prosthetic and prosthetic control development [3]. Tests with physical prostheses are closest to the clinical application; however they are not very flexible. E.g. making a certain joint stiff or movable or changing the grasping pattern in the prosthesis is relatively easy in a virtual prosthesis but very difficult in a physical prosthesis.

Physical prosthesis emulators to replace real prostheses in tests have not been described in literature so far to the knowledge of the authors. They would certainly be useful during the software development process but not for clinical evaluations, which might explain the lack of research papers on that topic.

3.1.2 ANALYSIS OF OPTIONS

Based on the above described literature and the experiences of the consortium, the most relevant factors for describing the value of virtual or physical prostheses or emulators thereof for INPUT have been extracted and summarized in Table 1. The effectiveness for clinical tests as planned in the second half of INPUT is opposed to the estimated relative costs in the project per solution. Points were given to judge each element from 0 (not relevant/cost effective at all) to 10 (highly relevant/cost effective). The sum of points is calculated to assess the best option for INPUT.

Table 1: Cost Relevance Analysis

	Prostheses & components	**Emulator**	**Virtual prosthesis**
Relevance			
Relevance for clinical tests	10	1	2
Close to final product	10	3	1
Familiarty of end-user with device	8	1	5
Ease of commissioning	9	5	9
Certainty of non-change requests	10	3	2
Flexibility	1	8	8
Useful for development (debugging,…)	7	5	7
SUM	**55**	**26**	**34**
Cost effectiveness			
Short development time	10	1	6
Cheap development (personnel)	10	2	3
Cheap development (material)	9	2	10
Cheap production	1	4	10
SUM	**30**	**9**	**29**

From Table 1 it is apparent that the advantages of a **physical prosthesis** + components outweigh the higher costs of such a device in INPUT. In particular, a physical prosthesis will be by far the most relevant medium for all clinical tests and closest to the final product targeted in INPUT. Note that as manufacturer, Ottobock has good access to prosthetic hardware by its own manufacture. However, the high production costs for physical prosthesis still have to be considered. Further development is not required, since off-the-shelf components from Ottobock can be used.

The **virtual prosthesis**, which is already available from previous projects, would require adaptation which is difficult to estimate (based on the needs that will develop in the project such as TAC tests or other virtual objects, accounted for in point "Certainty of non-change requests"). As of now, only a simple virtual hand prosthesis is available (see Annex for example screenshots). For clinical tests however, physical interactions with virtual objects might be needed ("place ball into box", etc.), or a TAC test implementation required, which would be time consuming to implement. Due to the low costs but also low relevance and higher uncertainty, the virtual prosthesis is therefore ranked second in this cost-relevance estimation. The virtual prosthesis *as is* however might still be a useful tool during software development, since it can be used in its current development status.

A prosthesis **emulator** has the lowest relevance and highest costs and is therefore not considered an option for the project at this point.

3.2 Conclusion and Decision

Based on the results of the literature review and the cost and effect analysis (Section 3.1) it is concluded that physical prostheses and their components are the best choice to be used as test devices in INPUT.

The resulting ranking is as follows:

1. Physical prosthesis
2. Virtual prosthesis
3. Emulator

Each partner receives the required amount of test devices from Ottobock in form of loaner devices as set out in Annex I of the Grant Agreement, description of Task 3.5. According loaner agreements are set up, detailing the terms of use and return of the devices. In particular, the devices' loan periods will last until the end of the INPUT project. This way, all partners have the testing components available at their disposal for the entire project duration.

3.2.1 Financial Coverage

During project preparation time, the decision made here in this deliverable had intentionally been left open to be decided at project runtime. Therefore, no clear budget allocation was possible at the drafting stage of the project proposal. In particular, it had either been possible to allocate budget to a person working on the virtual prosthesis or emulator, or on material costs for the physical prosthetic devices.

Since during the projects application phase, the extension of the virtual prosthesis or the development of an emulator had seemed more likely, personnel costs for an engineer had been planned in the budget for OBHP. Since such an engineer is now not required anymore or only to a limited amount, the budget allocated for the engineer may be shifted from personnel costs (cost category A) to other direct costs (cost category D), at the end of the project. The budget plan had been made accordingly to fit both of these options once decided during project runtime.

According to the Grant Agreement, Chapter 2, Article 4, Paragraph 4.2, no amendment to the Grant Agreement for such a change is required:

> *„The estimated budget breakdown indicated in Annex 2 may be adjusted by transfers of amounts between beneficiaries or between budget categories (or both). This does not require an amendment according to Article 55, if the action is implemented as described in Annex 1.“*

As detailed above, the action is still implemented as described in the Annex I of the Grant Agreement, where the decision (and thus financial coverage of providing loaner devices) has been described in Task 3.5:

> *“…In case of decision for full arm prostheses, OBHP will distribute these among the partners as loan devices.”*

and in this deliverable itself, which had been foreseen to make this decision at project runtime (see also Sections 1 and 2 of this deliverable). Therefore, although a budget shift from cost category A to D will be required, the scope and goal of the project as set out in Annex I of the Grant Agreement are unchanged.

The recommendation obtained in this deliverable will therefore be communicated to the EU Project Officer of the INPUT project. Subject to the approval of the EU Project Officer (pending at submission time of this deliverable) regarding the financial provisions, the recommendations found in this deliverable will be executed in INPUT.

4 SUBCONTRACTING

No subcontracting was needed – all work was done by OBHP.

5 REFERENCES

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ANNEX

Screenshots of the virtual hand developed in previous projects, displaying 4 DOF. It does not yet support a TAC test or interaction with other virtual objects.

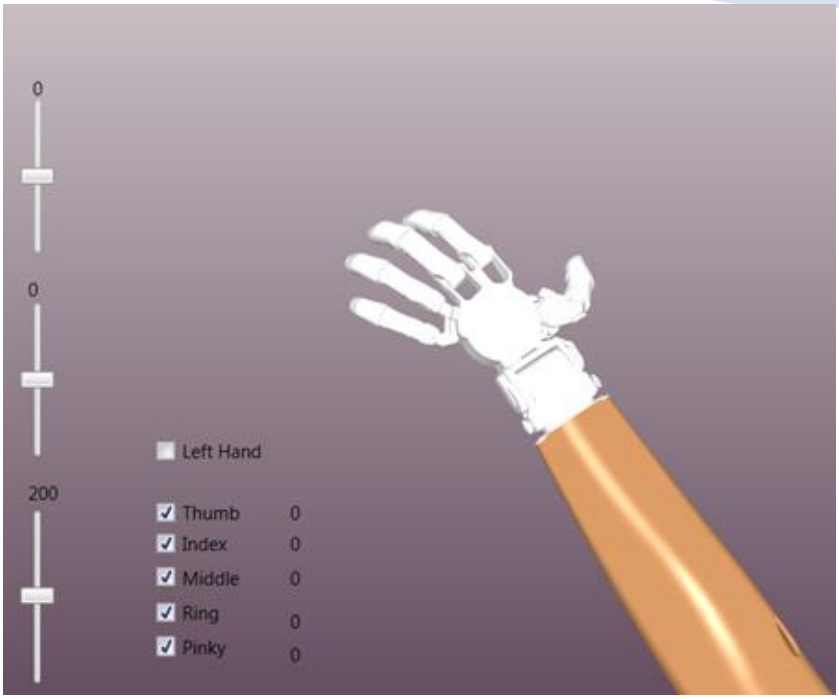

Figure 1: Neutral position

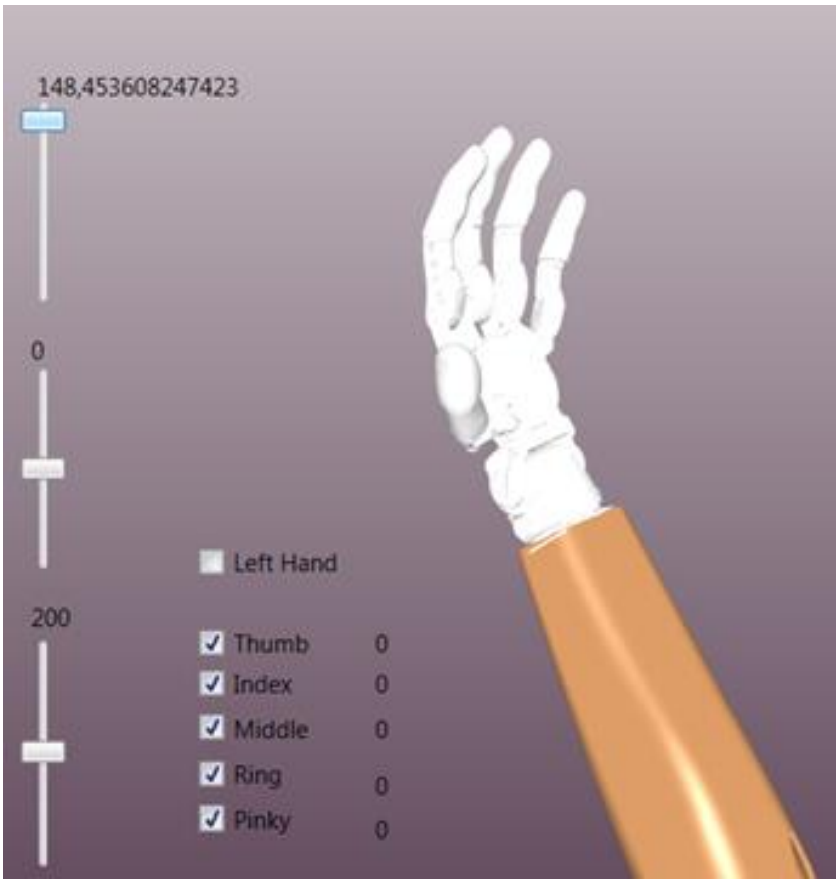

Figure 2: Supination

Figure 3: Supination + Extension

Figure 4: Supintation + Extension + Fine Pinch

Figure 5: Supination + Extension + Lateral Grip

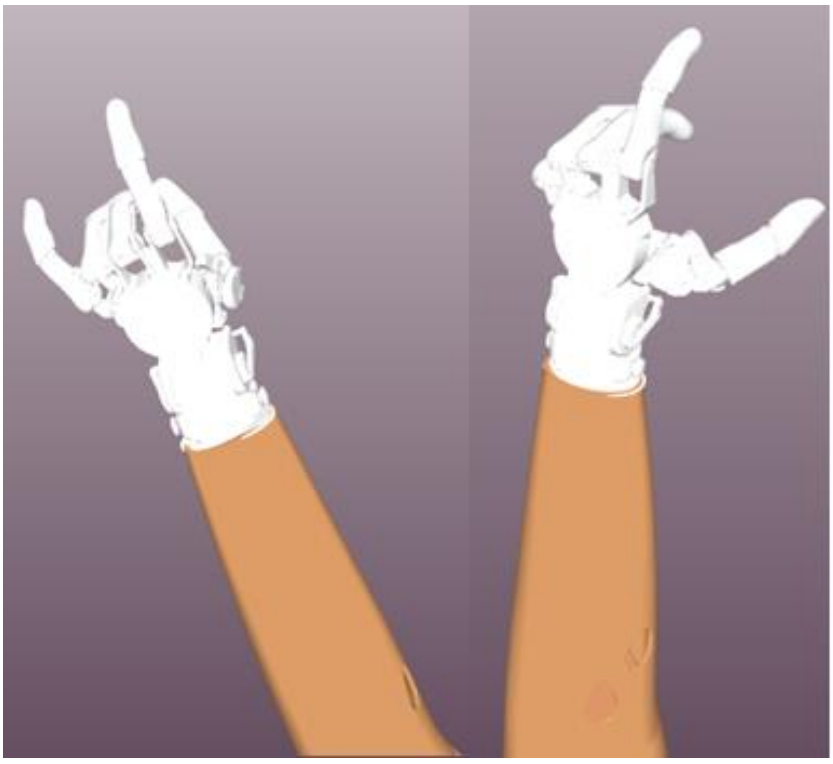

Figure 6: Unlike the real prosthesis, the virtual can also move individual fingers only