Participatory Workplace Development for Disabled Workers Reintegration

Andreoni G.[5], Costa F.[1], Dall'Amico M.[2], Frigo C.[3], Gruppioni E.[4], Muschiato S.[1], Pavan E.[3], Piccoli, M.[2], Romero M.[6], Saldutto B.G.[4], Standoli C.E.[5], Verni G.[4] and Vignati G.[6]

[1]Health Care Design SkillPoint, Design Department
Politecnico di Milano, Italy

[2] Prototyping and modelling Lab, Design Department,
Politecnico di Milano, Italy

[3]MBMC Lab, Electronics, Information and Bioengineering Department,
Politecnico di Milano, Italy

[4]INAIL (Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro), Italy

[5]LyPhe, Design Department
Politecnico di Milano, Italy

[6]PhyCo Lab, Design Department
Politecnico di Milano, Italy

ABSTRACT

The aim of this paper is to report the process conducted by an interdisciplinary team to develop an accessible and satisfactory PC workstation to be used by physically impaired people for their professional reintegration. A biomechanical, ethnographic and participatory approach has been applied to occupational ergonomics in order to integrate qualitative and quantitative analysis methods. On the basis of these results an iterative process of prototype development and user testing has been conducted which led to the refinement of an adjustable workstation as adaptable as possible to different users pathologies and office activities. The experimented multicompetence approach has been able to integrate different research methods into a research strategy providing a more comprehensive understanding of the analyzed phenomena and increasing the quality of final results.

Keywords: User Centred Design, Physically Impaired Worker, PC Workplace, Ethnographic Observations, Biomechanics, Participatory Ergonomics

INTRODUCTION

A physical disability should not be an obstacle to participate in the work world, however, some workplaces are not conceived in order to admit disabled workers or to be appreciated by their user. Generally disabled workers reintegration is usually faced through ad hoc adaptation of workstation and work environment for each subject (e.g. Andrich, Bucciarelli, Liverani, Occhipinti and Pigini, 2009). This approach allows obtaining high-customized solutions that are very efficient form the functional point of view, but involve a great effort and cannot be applied on a large scale. For this reason we decided to focus our research on the development of a standardized adjustable solution as adaptable as possible to different users pathologies and office activities.

As Human Machine Interaction (HMI) and participatory ergonomics are multifaceted issues it is important to address them from different perspectives and to combine data coming from different methods. For this reason a biomechanical, ethnographic and co-design approach has been applied to occupational ergonomics in order to integrate qualitative and quantitative methods. Interesting studies (e.g. Aubry, Julliard and Gibet, 2007) have been conducted to develop specific virtual reality approaches for supporting the Design for All strategies since occupational ergonomic analysis on virtual mock-up is today not possible due to the fact that the human models within existing applications do not include impaired persons. Learning from adaptation experiences and virtual reality approaches we based our research on ethnographic observation (e.g. Lifchez and Winslow, 1979) and combined it with the development of a proprietary virtual model and its validation through laboratory test. The outputs regarding user behavior and movement strategies were used to define the first design proposals which have been the basis for an active involvement of users in testing and prototypes development. Iterative prototype processes have already been applied in the occupational ergonomic field for industrial product development (e.g. Parimalam, Premalatha, Padmini, Ganguli, 2012) and to involve users with cognitive impairments in computer therapy tools design (e.g. Galliers, Wilson, Roper, Cocks, Marshall, Muscroft and Pring, 2012). In our case we applied the iterative prototype process to a product for physical disabled workers in order to achieve usability and acceptability goals.

METHODS

Human Systems Integration

The methodological process applied in the research project consists in 4 main steps (fig.1):

a. An ethnographic investigations on subjects affected by spinal cord lesion at different levels to identify their user habits (e.g. Amit, 2000) and self-made solutions and strategies. Observations accompanied by contextual interview were carried out in the real user environment and involved 7 paraplegic and 3 quadriplegic subjects. On this basis we defined a test setting and a series of motor tasks to be investigated from the biomechanical point of view.

b. A virtual biomechanical (e.g. Helin, Viitaniemi, Montonen, Aromaa, 2007) analysis based on a model with six degrees of freedom (dof) for the upper trunk, three dof for each shoulder, two dof for the elbows, two dof for the wrist was implemented in order to compute the joint moments required to perform the different tasks. The outputs regarding user behavior and movement simulation were used to define a functional mock-up of the workstation.

c. A laboratory biomechanical analysis, which includes real movement acquisition and assessment, was performed on healthy and spinal cord lesioned subjects to define the strength associated to reaching objects in different positions in the extracorporeal space. A stereophotogrammetric system with eight infrared TV cameras was used to detect the movement of the upper limbs in relation to the trunk, and the movement of the trunk in relation to an absolute reference system fixed within the laboratory. Retro-reflective markers were attached to the head, shoulders (acromions), elbows, wrists, and metacarpal area and dorsal surface of the trunk.

d. The outputs regarding user behavior and movement strategies were used to define the first design proposal which has been the basis for an active involvement of users in virtual and real prototypes development (e.g. Sanders and Stappers, 2008). The virtual prototype had been developed with the involvement of expert users and the workstation has been tested regarding usability and acceptability by 4 end users in subsequent phases and fine tuned.

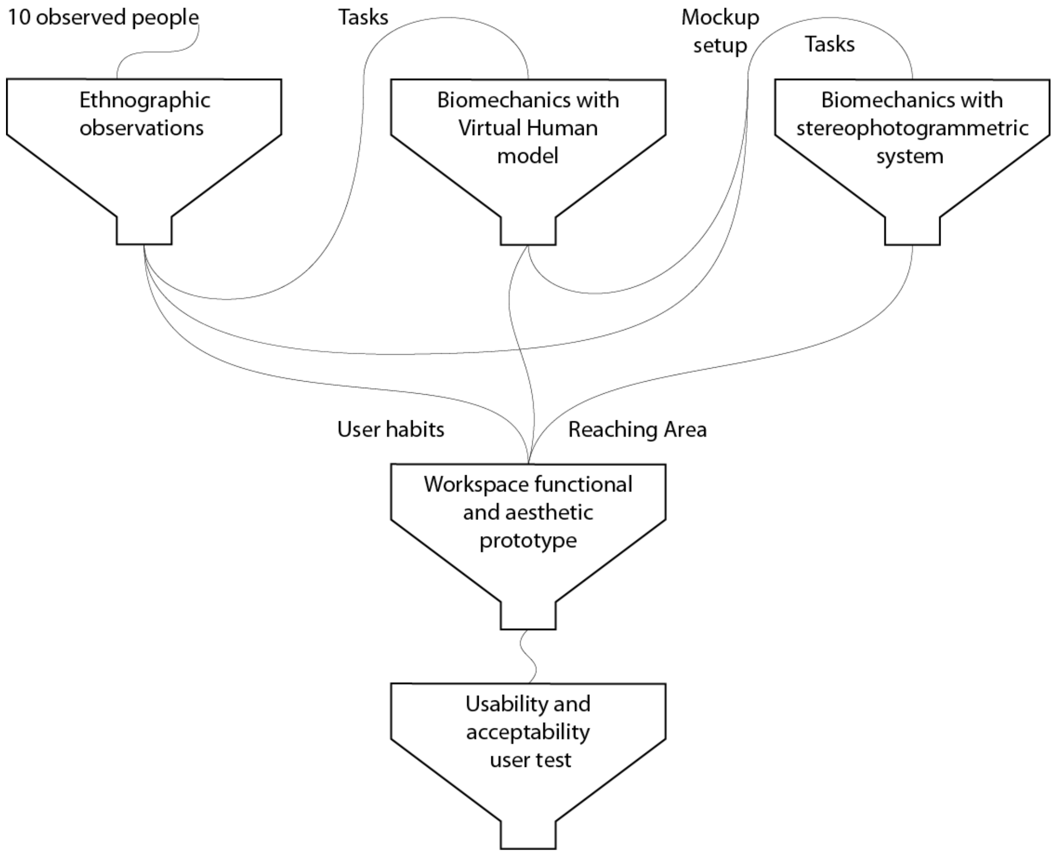

Fig.1. General research process with 4 main steps and integration

Ethnographic Investigation

In order to define the needs of the specific target group of users, an ethnographic investigation has been performed which was structured in four steps:

- warm-up,
- general questions,
- static analysis of the work environment,
- observation of the users during their work activity.

Sixteen workstations, placed in home and office environment, have been evaluated regarding qualitative issues. We began with 10 ethnographic investigations on subjects affected by spinal cord lesion at different neurological levels to detect their habits and solution strategies during PC-workplace use. Observations together with contextual interview were carried out in the real user environment (6 homes and 4 offices) and involved 7 paraplegic subjects and 3 quadriplegic.

The acquired data have been compared and the real situations have been grouped in 3 different categories related with the level of spinal cord lesion:

- users with high spinal cord lesion, that work with an assistant without moving from their workstation, at home;
- users with middle-high spinal cord lesion, that work without moving from their workstation, at home or office;
- users with middle-low spinal cord lesion, that work moving from one workstation to another, in the office, in team with colleagues or with patients.

Fig. 2. Two different users observed during their work.

In all situations, a great number of object are located on or around the workplaces including obvious and less obvious ones ranging from PC, paper, pencils to mobile phone, pictures and medicaments. A new workstation has to face the problem of organizing all these objects according to user habits. Size of the work table vary from 100cm to 300cm of width, 70cm to 90cm of depth, 67cm to 85cm of high. Their configurations appear to be affected by working modalities: the desks are predominantly rectangular if interaction with colleagues or patient is needed and "L" shaped in several cases were people work alone and place is available.

The three identified categories were evaluated and we choose the one regarding people with middle/high spinal cord lesion working alone at home or in the office for further development since it is the more statistically frequent situation and it permits to develop solutions that could be also suitable for tele-work. Deeper analysis of this users group and their needs has been performed through a questionnaire to the users and interviews to experts like occupational ergonomists and disabled worker's reintegration specialists.

On field analysis revealed interesting differences between home and office workstations regarding for example self adaptation solutions, like the placement of the printer under the table at 40cm from the floor, which are more frequent in home workplaces. A careful study of those adaptations could suggest useful solutions to be transferred also in the office environment.

The most important needs detected through on site users analysis regarding the selected category concern:

- avoiding the necessity to shift from wheelchair to operating chair;
- maintaining distances and adjustments in relation with the working area;
- increasing trunk mobility and stretching possibilities;
- increasing trunk balance and facilitating the achievement of an upright posture when it happens to lose it;
- reducing the falling of objects or facilitating their recovery;
- positioning of an easy to reach case for personal items;
- reaching all devices and commands;
- avoiding cable hindrance.

On this basis we defined a test setting and a series of motor tasks to be investigated from the biomechanical point of view on the next step.

In previous researches (e.g. Romero, Mazzola, Costa and Andreoni, 2008) we encountered some problems with the analysis of data acquired from users in free condition of use because of a large variability in movement behavior that made inter-subject comparison very difficult. On the other hand a too constrained definition of the movements would risk to make them unnatural. In this experience we consequently decided to consider two separate data source: qualitative information from natural movement observed in the first step (ethnographic observations) and quantitative information from third step (motion capture), using first step to define which movements to analyze on the third step.

Biomechanical Analysis with Virtual Human Model

In previous experiences (e.g. Occhipinti, Colombini, Frigo, Pedotti, and Grieco, 1985) simple biomechanical measurements and electromyographic analysis were used to evaluate the physical stress connected to different workplace situations.

In order to identify the portion of the workplace that can be reached with a certain level of muscular effort, a dynamical model was developed which allowed us to quantify, by simulating several load conditions, the force necessary for completing the task. The model (Figure 3) is composed of a number of rigid bodies corresponding to head, trunk, pelvis and lower limbs, upper arm, forearm, and hand for both sides. The parameters like segments' length and mass, were obtained from anthropometric tables (e.g. Clauser, McConville, Young and Weight, 1969) Location of centers of mass and moments of inertia derived directly from the geometry of the rigid bodies. The focus here was the upper limb movement, and so the following constrains were defined among the segments: three rotational axes at the shoulder representing adduction/abduction, flexion/extension, internal/external rotation, one rotational axis at the elbow, representing flexion/extension, one rotational axis at the wrist, representing pronation/supination of the hand. The trunk was fixed to the backrest of the wheelchair, and the pelvis to the seat. Both inclination of backrest and seat height could be adjusted to test different relative positions between subject and table. The table itself could be raised or lowered and rotated around a horizontal transversal axis to reproduce different slopes. Each point of the extracorporeal space could be reached by changing the angles of the different joints. A limit however was implicit in the total limb length. Additional space could be added by changing the inclination of the trunk. For each position in space of the hand, the corresponding joint angles and joint moments were computed, so that the whole reachable space could be mapped.

In the example presented here, the right hand movement was analyzed, although the procedure could be applied to left-handed subjects as well. The task analyzed was a unimanual task (i.e. without the use of the contralateral arm) and was simulated by leading the hand to reach different points of the desk work plane. The seat height was 0.47 m (forward edge with respect to the ground); the table height was 0.7 m from the ground and the surface was horizontal. The backrest was inclined by 20° on rear, and the relative position between subject and table was such that the lower edge of the trunk (corresponding approximately to the extremity of the rib cage) was at 0.19 m from the edge of the table. A grid of points was defined on the table surface sufficiently close each other as to have a good spatial resolution, within the reaching-area border (namely the limits of the full area where an object can be placed that can be reached by only extending the arm, without moving the trunk).

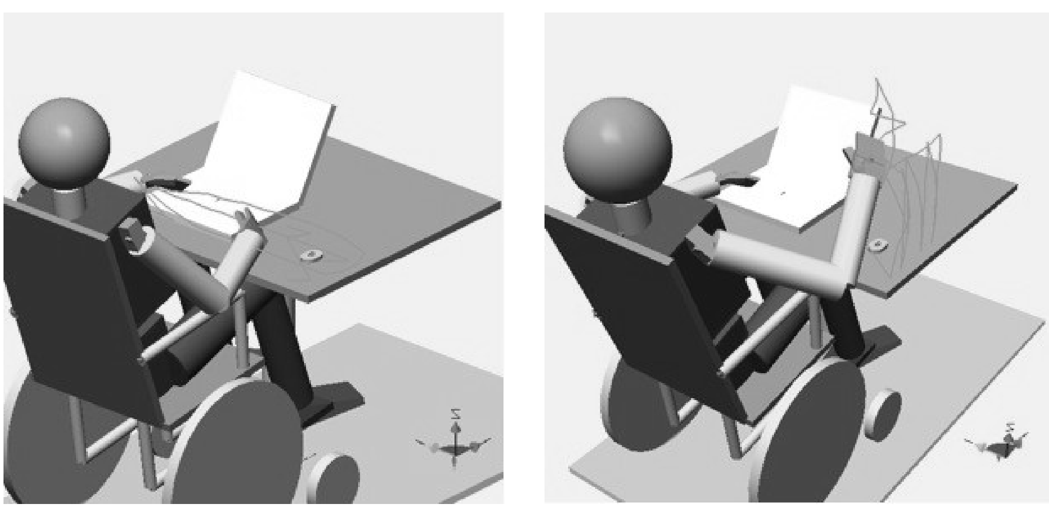

Fig. 3. A) The anthropomorphic dynamic model represented in one specific position (see text). The track of the hand centre of mass during systematic analysis of the reaching is reported on the table by a line. B) The same model while scanning the right-hand space on a vertical plane (see the hand track)

Since the same point in the space could be reached in different manners, each representing a diverse combination of rotations about the different axis of the joints, a particular condition was imposed that was a fixed orientation of the hand palm in relation to the horizontal plane. The wrist angle also was kept at a fixed degree. In this way the hand, which originally had six degrees of freedom, is constrained so that only four degrees of freedom are active. These, in our choice, are the three shoulder rotations and the elbow rotation. The goal was thus to associate to each position of the hand, the joint angle and the joint moment obtained from the dynamical simulations, for each of the following movements: shoulder ab-/adduction, flexion/extension, internal/external rotation of arm, elbow flexion/extension.

The results are shown in Figure 4. Here the joint angles and moments associated to each position of the hand in the reachable plane are reported with reference to the shoulder joint. They are represented by three surfaces corresponding respectively to the flexion/extension, abduction/adduction, internal/external rotation degrees of freedom. It appears that the whole positioning of the arm segments has a direct influence on the increase or decrease of any considered moment necessary for reaching a particular point in the space. If a particular joint moment or joint angle cannot be overcome because of limitations in the strength or mobility of the hypothetical subject, different portions of the original space could be identified, which can be reached by applying a moment which is less than the maximum moment the subject can develop. A similar result was obtained for the angular rotations.

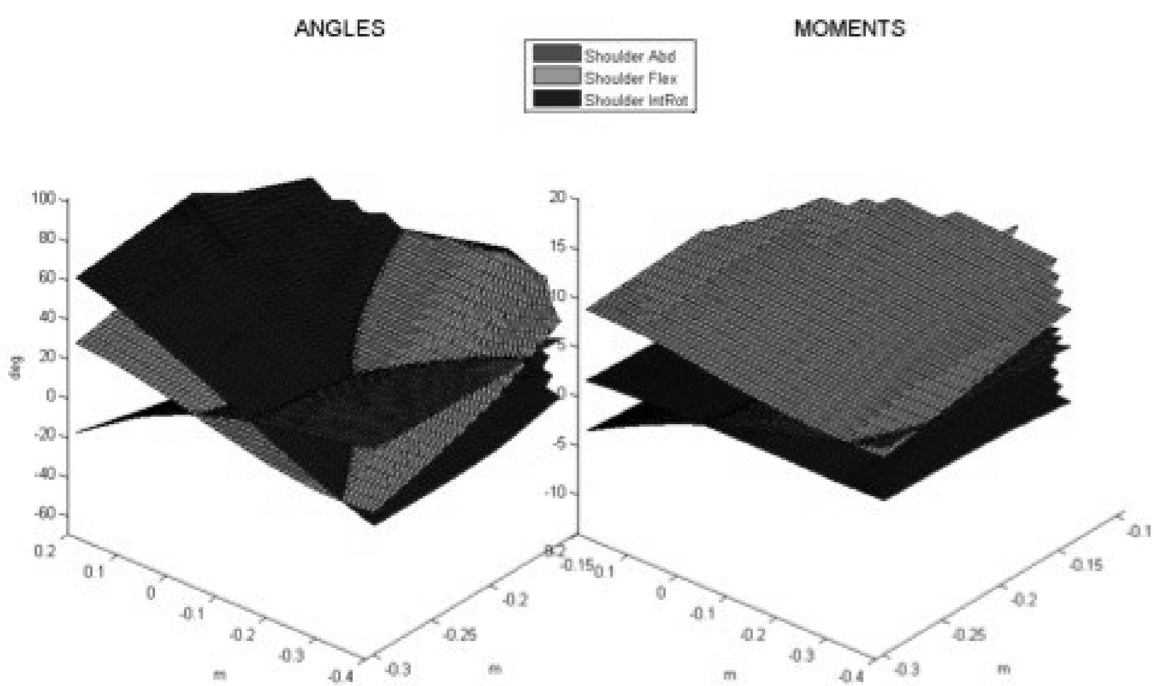

Fig.4. Systematic analysis of the shoulder angles and moments associated to maintaining a given position of the hand on the work plane, supposed horizontal, 5 cm above the table surface. The three intersecting surfaces refer to shoulder flexion (green), abduction (red), internal rotation (blue). The point (-0.4, -0.35) corresponds to the right-rearmost corner of the table surface.

In this way, alterations due to pathology, which imposes limitations in both the range of movement and the moments produced, may be considered in order to identify those parts of the space that could be reached more easily than others and, consequently, in order to consider these limitations during the design process.

This virtual analysis, based on a biomechanical model, was implemented in order to compute the joint moments required to perform the different tasks. The outputs regarding user behaviour and movement simulation were used to define the first design proposals and a functional mock-up of the workstation.

Biomechanical Analysis with a Motion Capture System

A Workspace mockup was then built to perform movement acquisition and evaluation on healthy and spinal cord lesioned subjects in order to quantify the strength required to reach objects with individual motor strategies in different positions in the extracorporeal space. A motion capture system with eight infrared TVcameras was used to detect the movement of the upper limbs in relation to the trunk, and the movement of the trunk in relation to an absolute reference system fixed within the laboratory. Retro-reflective markers were attached to the head, shoulders (acromions), elbows, wrists, and metacarpal area and dorsal surface of the trunk. (Fig. 5-B)

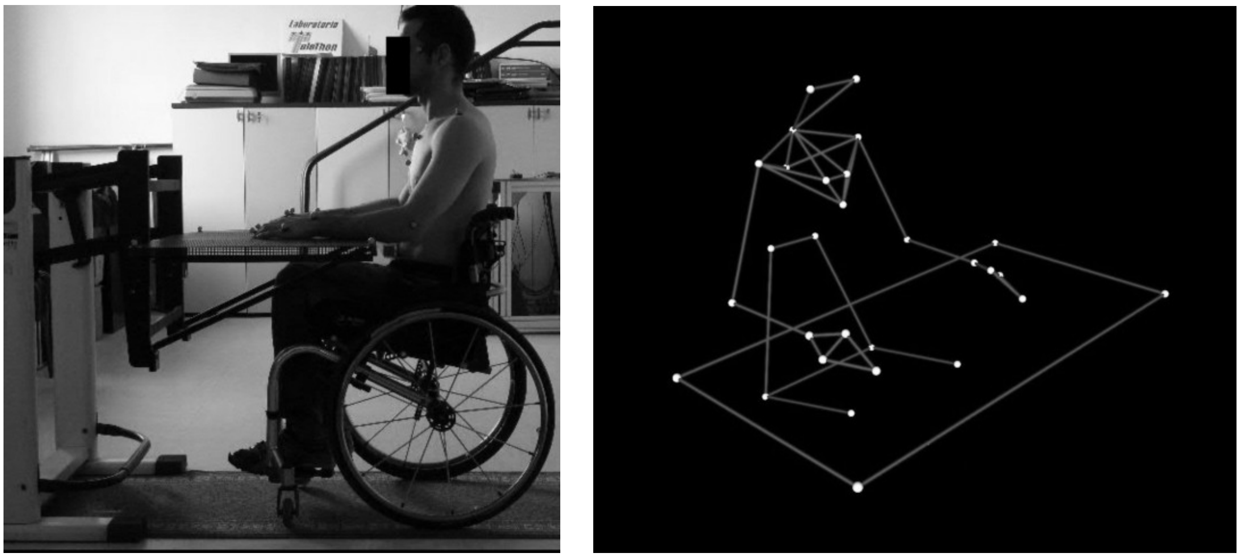

Fig.5. A) Lateral view of a subject placed on the mockup B) with retroreflective markers.

As to the different tests performed, particular attention was paid to the different modes of positioning the trunk. The following conditions were considered:

1) trunk supported by the wheelchair backrest;
2) trunk unsupported, with possibility of supporting the contralateral arm on the table, with slight force in order to help for stability;
3) trunk unsupported, with possibility to apply a relevant support force on the table by the contralateral limb to the purpose of reaching farther positions without falling down;
4) simulation of opening the drawers located laterally under the table surface, as if the subject was picking up objects.

As to the task of reaching positions in the space over the work plane, another test was added consisting in simulating the reaching of objects located on shelves or support planes at a give height above the work plane.

Work Station Design and Prototypes Iterative Development with Users

Building on the outputs of ethnographic observation and biomechanical trials it was possible to define the concept and realize virtual and physical prototypes to be tested iteratively by users. The iterative prototyping process initially developed in the field of computer interfaces (e.g. Bury, 1984) is here applied to physical product design. The different phases of prototype development concerned the solution of technical problems, the improvement of functional performances required for an easy use of the product and the refinement of aesthetics characteristics needed for product's acceptability (e.g. Norman, 2004). An important experimental solution suggested by observed user behaviors was the introduction of a motorized platform with a variable angle in order to allow the variation of the trunk's position. This was a requirement to provide greater comfort to the users regarding posture.

Fig.6 Final product concept

In order to realize a satisfactory system we evaluated different virtual solutions, all responding to the ethnographic and biomechanical research results, with expert users (occupational ergonomists and disabled worker's reintegration specialists) and began the physical prototype development on the basis of these results. The final product concept has thus been achieved through an iterative design process (e.g. Karat C., 1990) involving a working prototype. Several tests have been performed with end users, each of them determinated changes in the prototype which evolved step by step thanks to users comments and preferences regarding usability and acceptability issues. Each iteration produces deliverables for evaluation with an emphasis on enabling users to experience and provide feedback on working examples.

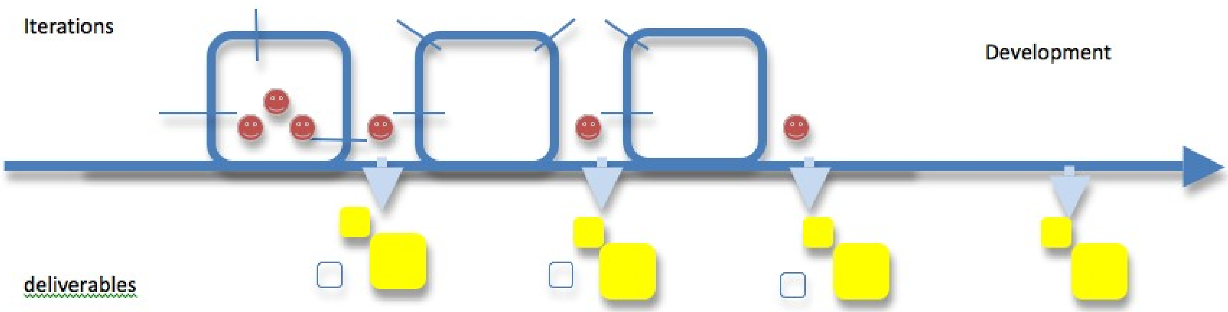

Fig.7. Iterative process phases

In this process prototypes are used as "boundary objects" in new product development (e.g. Carlile, 2002) both to interact and support innovation within the research group - which involves different stakeholder like INAIL (Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro), Spinal Unit of the Ospedale Cà Granda di Niguarda, Design Department and Bioengineering Department of Politecnico di Milano - and to facilitate user participation. "Prototypes, in the best cases, can become so-called boundary objects between different domains and stakeholders and may deliver positive effects within the innovation process" (e.g. Rhinow, Koeppen, Meinel, 2011)

As required by the iterative process of design qualitative tests with users were carried out some during the implementation of the prototype. The different phases of evaluation and product development allowed the implementation of requirements assumed by virtual simulations. Different positions of the trunk to obtain a posture shift and comfort perception have been specifically tested and verified.

The tests were performed in working environment where the subsequent prototypes has been placed with the aim to put users in a real contest. This approach made it possible to let people feel ease to describe their sensation in the specific work conditions. The same conditions considered in the biomechanical analysis were evaluated also from the users subjective point of view in real environment.

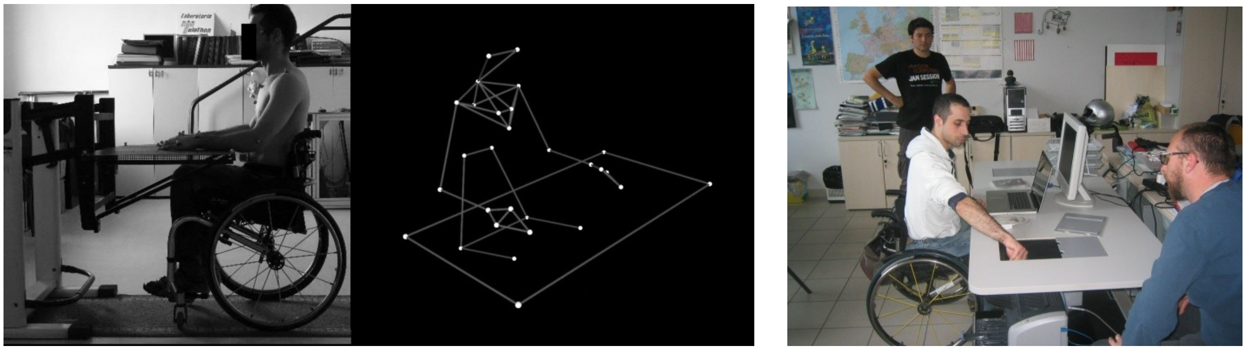

Fig.8. A) Lateral view of a subject placed on the first mockup environment during the biomechanical tests

B) View of a user in real office

The structure of the tests has been organized in 4 steps:

1) warm up: familiarization between user and researcher;
2) perceptual phase: the user is asked to make comments on the object without touching it;
3) use phase: the user is asked to perform some tasks on the object and express aloud his or her comments;
4) structured debriefing: the researcher re-inquires the user opinions expressed in the first phase of the test.

A first beta test was organized at INAIL with a disabled user working in the institute's offices also because he had both a specific comprehension about the project and the knowledge of the possible expectations of the other users. He tested the three main components of the project: liftable plan, adjustable platform and accessories on the work plan and below.

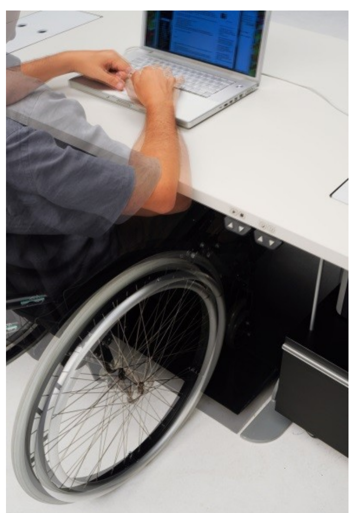

Fig.8. Adjustable platform detail

The main comments were related to the platform's speed regulation in relation to a general sensation of "loss of balance" and instability experienced by the user. The functionality and usability requirement ware satisfactory and the prototype was evaluated very easy to use. Also regarding acceptability requirement the project was perceived as a "normal work place". The interaction with the user permitted to co-design a new layout of accessories on the work plan and locating of data and energy connections.

Subsequent qualitative tests carried out with three more users brought to improvements on adjusting the speed of the platform but have not resolved the acceptance element regarding the feeling of insecurity already noted in the beta test, although the angle and the platform speed has been further tuned. Through the interaction with different a major need of modularity emerged regarding for example table dimensions, colour and printer availability, depending on the implementation of the workplace in different working environment i.e. office and home

The analysis of users' physical abilities in the different phases of interaction with the prototype permitted to define the adjustability range of the table's height, the right place for cabinets containing small business accessories and the horizontal accessibility of everyday objects used in the workplace.

After the tests the final prototype is the results of different technical and esthetical changes originated in the different iterative phases of project development. The workplace is composed by: a table at adjustable height with remote control, a platform that allows a rotation angle, boxes for the containment of medium and small objects, cabinets for small objecys such as battery chargers, telephones, paper etc. supporting accessories as scanner and printer.

CONCLUSIONS

From a methodological point of view, we found a positive conciliation integrating ethnographic qualitative data and physical modeling movement quantitative data in product development. Physical prototypes were very useful as "boundary objects" in the participatory ergonomic process (e.g. Broberg, Andersen, Seim, 2011) to perform usability and acceptability tests as well as to involve all the the stakeholders in the collaborative design process.

The iterative design process together with other centered design methodologies permitted to integrate the real needs of people who suffered from a heavy trauma in a work environment they share with other colleagues. From the psychological point of view it is very important to be able to carry on a professional activity after an disabling event using objects and tools aimed at facilitating working tasks without stigmatization of users. The involvement of experts and disabled people permitted to integrate technical and esthetical components to achieve a positive affective response of users. Further the formal continuity of the final prototype with the office environment makes it's adjustability a quality for all. Although the final tests were conducted with a limited number of users, due to inevitable time constrains in product development (e.g. Dow, Heddleston, Klemmer, 2009), we believe that they they gave a considerable qualitative added value to the whole process.

Finally we can state that the experimented multicompetence approach has been able to integrate different research methods into a research strategy (e.g. Brannen, 2005) providing a more comprehensive understanding of the analyzed phenomena and increasing the quality of final results.

AKNOWLEDGEMENTS

This work was supported by INAIL (Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro). The highly professional assistance of occupational therapists of the Spinal Unit of the Ospedale Cà Granda di Niguarda, in particular Mr. Davide Mangiacapra, is warmly acknowledged.

REFERENCES

Amit, V., *Constructing the Field: Ethnographic Fieldwork in the Contemporary World*, Routledge, 2000

Andrich, R, Bucciarelli P, Liverani G, Occhipinti E, Pigini L, *Disabilità e lavoro: un binomio possibile*, Fondazione Don Carlo Gnocchi –ONLUS, Milano, 2009.

Aubry, M., F. Julliard F., S. Gibet, *Interactive ergonomic analysis of a physically disabled person's workplace*, European Center for Virtual Reality, Brest, 2007.

Brannen, J., “Mixing Methods: The Entry of Qualitative and Quantitative Approaches into the Research Process”, International Journal of Social Research Methodology, Volume 8, Issue 3, pp. 173–184, July 2005.

Broberg, O., V. Andersen, R. Seim, “Participatory ergonomics in design processes: The role of boundary objects”, Applied Ergonomics 42, pp. 464-472, 2011.

Bury, K.F. “The iterative development of usable computer interfaces”, Proceedings of IFIP INTERACT'84 International Conference on Human-Computer Interaction, London, U.K., 4-7 September 1984.

Carlile, P.R., “A pragmatic view of knowledge and boundaries: boundary objects in new product development”, Organization Science 13, pp.442-455, 2002.

Clauser, C.E., J.T. McConville, J.W Young Weight, *Volume, and centre of mass of segments of the human body, AMRL Technical Report (TR-69-70).* Wright-Patterson Air Force Base, OH, 1969.

Dow, S. P., K. Heddleston, and S. R. Klemmer, “The efficacy of prototyping under time constraints”, Proceeding of the seventh ACM conference on creativity and cognition CC 09, 165. ACM Press, 2009.

Galliers, J., S. Wilson, A. Roper, N. Cocks, J. Marshall2, S. Muscroft and T. Pring, “Words Are Not Enough: Empowering People With Aphasia In The Design Process”, ACM International Conference Proceeding Series, Volume 1, pp. 51-60, 2012.

Helin, K., J. Viitaniemi, J. Montonen, S.T. Aromaa , “Digital Human Model Based Participatory Design Method to Improve Work Tasks and Workplaces”, Lecture Notes, Computer Science, Volume 4561/2007, pp.847-855, 2007.

Karat, C.-M., “Cost-benefit analysis of iterative usability testing”. Proceedings of IFIP INTERACT'90 Third International Conference on Human-Computer Interaction, pp. 351-356, Cambridge, U.K., 27-31 August 1990.

Lifchez, R, and Winslow B., *Design for independent living: The environment and physically disabled people*, Architectural Press, Boston, 1979.

Norman, D.A., *Emotional Design. Why We Love (or Hate) Everyday Things*, Basic Books, 2004

Occhipinti, E., D. Colombini, C. Frigo, A. Pedotti, A. Grieco, "Sitting posture: analysis of lumbar stresses with upper limbs supported", Ergonomics, vol. 28, n. 9, pp. 1333-1346, 1985

Parimalam, P. , Premalatha, M.R., Padmini, D.S., Ganguli, A.K., “Participatory ergonomics in redesigning a dyeing tub for fabric dyers”, Work, Volume 43, Issue 4, pp., 453-458, 2012.

Romero, M., M. Mazzola, F. Costa, and G. Andreoni, “An Integrated method for a qualitative and quantitative analysis for an ergonomic evaluation of home appliances”, Proceedings of Measuring Behavior 2008

Rhinow, H., E. Koeppen, C. Meinel, “Design Prototypes as Boundary Objects in Innovation Processes”, DRS 2012 Bangkok, Chulalongkorn University, Bangkok, Thailand, 1–4 July 2011

Sanders, E.B. and Stappers P.J., “Co-creation and the new landscapes of design, CoDesign”, International Journal of CoCreation in Design and the Arts, 4:1, pp.5-18, 2008.