CHAPTER XX

The integration of ethnography and movement analysis in disabled workplace development

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ABSTRACT

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. The aim of this paper is to present the process conducted by an interdisciplinary team to analyze human-product physical interaction and develop an accessible workplace. We focused our research in a PC-workplace to be used by physically impaired people for their professional reintegration. In previous experiences [1] simple biomechanical measurements and electromyographic analysis were used to evaluate the physical stress connected to different workplace situations. In the present context we have chosen to apply to occupational ergonomics both a biomechanical and ethnographic approach and then correlate them in an integrated approach. The idea of merging qualitative and quantitative methods has become increasingly appealing in areas of applied research. As Human Machine Interfaces (HMI) and ergonomics are multifaceted issues it is important to approach them from different perspectives and to combine data coming from different methods.

Multicompetence approach integrates different research methods into a research strategy [2] increasing the quality of final results and providing a more comprehensive understanding of the analyzed phenomena.

Keywords: User Centred Design, physically impaired worker, PC workplace, Ethnographic Observations, Biomechanics.

1 INTRODUCTION

Ergonomic evaluation and physical disabled people's workplace development are very difficult issues because standard methods are not applicable: risk analysis is not reliable because tasks are often performed in an unusual way and functional anthropometrical data are difficult to retrieve.

Interesting studies [3] are in progress to develop specific virtual reality approaches for supporting the Design for All approach 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.

Generally disabled workers reintegration is usually faced through ad hoc adaptation of workstation and work environment for each subject [4]. This approach allows obtaining high-customized solutions that are very efficient 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.

Learning from adaptation experiences and virtual reality approaches we based our research on participatory observation [5] and combined it with the development of a proprietary virtual model and its validation through laboratory test.

A participatory phase was planned to directly involve users in product development and evaluation [6].

2 METHODS

The methodological process consists in 3 main steps before a final integration trough product development (Fig.1.).

a. At the beginning we performed ethnographic investigations on subjects affected by spinal cord lesion at different levels to detect their user habits [7] and self made solutions and strategies. Observations accompanied by contextual interview were carried out in the real user environment and involved paraplegic and quadriplegic subjects. Evaluating the collected data we also defined a test setting and a series of motor tasks to be investigated from the biomechanical point of view.

b. The biomechanical analysis based on a model which includes 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.

c. The second biomechanical analysis, comprehending real movement acquisition and evaluation, 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.

The outputs regarding user behavior and movement strategies were used to define the first design proposals which are the basis for an active involvement of expert users in virtual and real prototypes development. [8].

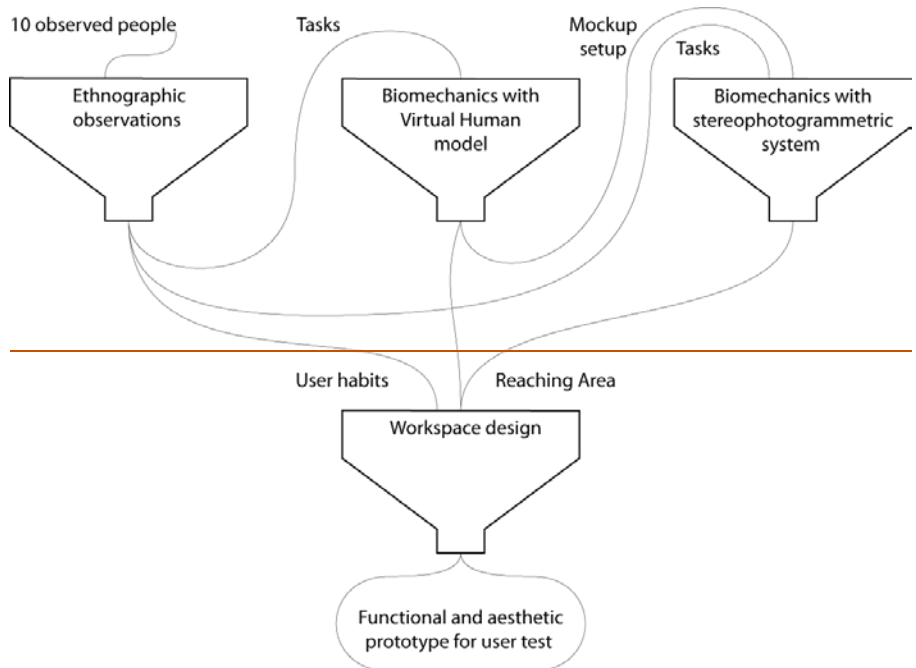

Fig.1. General research process with 3 main steps and integration

The subsequent evolution of the project will include the tests to be performed with the involvement of disabled people and an inquiry about the level of acceptance of the proposed solutions.

Ethnographic investigations

In order to define a 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 in the 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.

Biomechanical analysis with virtual human model

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 [9]. 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).

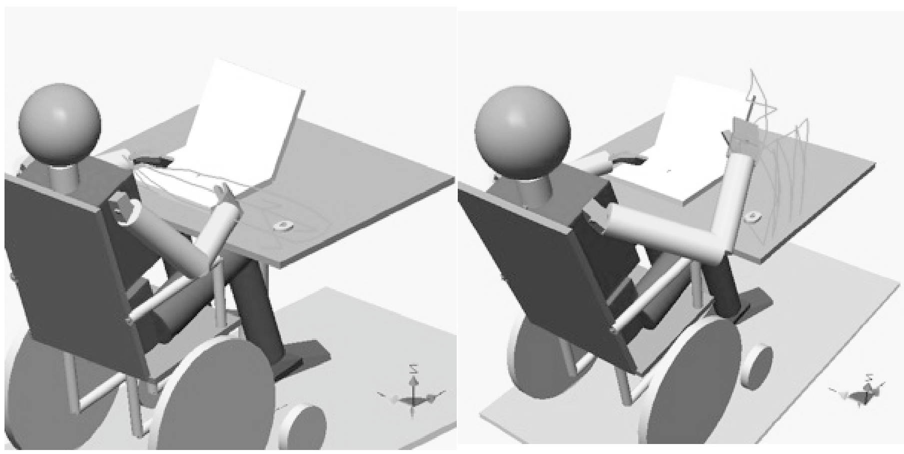

Figure 3-A) The anthropomorphic dynamic model represented in one specific position (see text). The track of the hand centre of mass during systematic analysis of the reaching is reported on the table by a line. B) The same model while scanning the right-hand space on a vertical plane (see the hand track)

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.

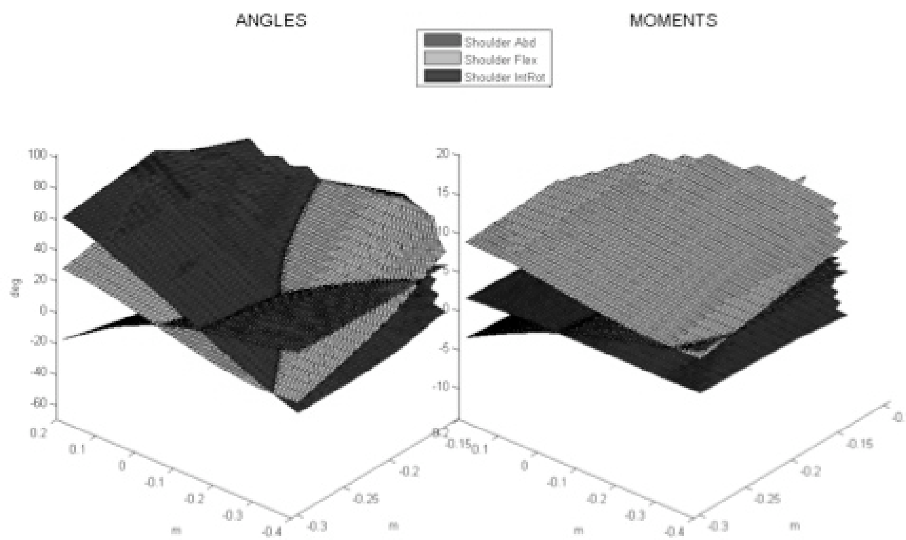

Fig.4) Systematic analysis of the shoulder angles and moments associated to maintaining a given position of the hand on the work plane, supposed horizontal, 5 cm above the table surface. The three intersecting surfaces refer to shoulder flexion (green), abduction (red), internal rotation (blue). The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

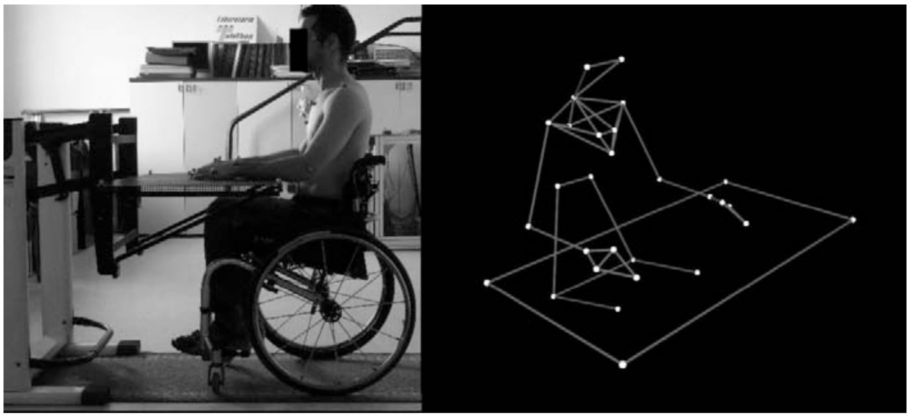

Fig.5- A) Lateral view of a subject placed on the mockup with retroreflective markers. B)

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.

In previous researches [10] we encountered some problems with the analysis of data acquired from natural users 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.

The outputs of the biomechanical tests permitted to fine tune the concept and realize a prototype workstation to be tested regarding usability and acceptability by the end user.

3 RESULTS

Some interesting elements in the reaching strategies have been highlighted by both the observational analysis and the biomechanical analysis with the stereophotogrammetric system. A relevant one was the use of the contralateral limb as a support to help achieving farther objects and balancing the body. In all cases in which the subject adopts this technique, there is a need to provide a strong supporting surface and an area of the table relatively free from objects, in order to allow the limb support. An alternative solution could be to provide special handles directly on the table, where the subject could hang or pull him/herself forward or laterally, consistently with his/her specific needs.

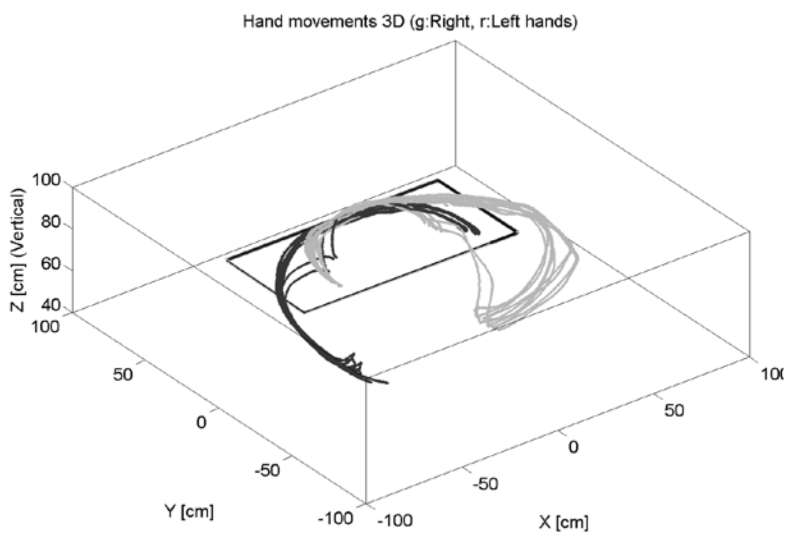

Fig. 6 Positions Tracks of both hands on the space, related with a 70cm height worktop (left hand in darkest line)

In such a way the table surface could be more efficiently used as a work surface. From another point of view the edge of table could provide an accessory support function to improve the trunk stability, for example in the case of an excessive forward bending, when the chest can rest against the table. In this case the border of the table has to be without sharp edges, or even covered by soft material. In some cases a recess tailored on the chest size could help improving his/her medio-lateral stability. The integrated result of this three-steps process was an innovative PC-workplace. Final project has been produced with final aesthetic characteristic and is ready for user tests in a real context of use.

4 DISCUSSION

From methodological point of view, we found a positive compromise to integrate ethnographic qualitative data and physical modeling movement quantitative data in product development defining an proactive approach to ergonomics based on data related to physical interaction between the human and new or existing products. The method was applied to disabled worker PC station development while its extension to other aspects and other concepts is under development. Further developments should also take into account the integration of functional supports needed by persons with spinal cord lesions who sometimes make use of assistive devices and functional electrical stimulation to perform basic functions. [11].

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

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