Disable Workstation Development: A Multicompetence Approach to Human Behaviour Analysis

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Abstract. The aim of this paper is to report the analysis process adopted by an interdisciplinary team to understand human-product physical interaction in order to develop a PC workstation 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: ethnography, biomechanics, user centered design, disabled worker.

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 to obtain 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

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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 Process Description

The methodological process consists in 3 main steps (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 was divided in a virtual study and a laboratory test. The first one was based on a biomechanical 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.

The second one comprehending real movement acquisition and evaluation was performed on healthy subjects in a first stage to define the strength associated to reaching objects in different positions in the extracorporeal space. A stereophotogrammetric 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.

c. 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].

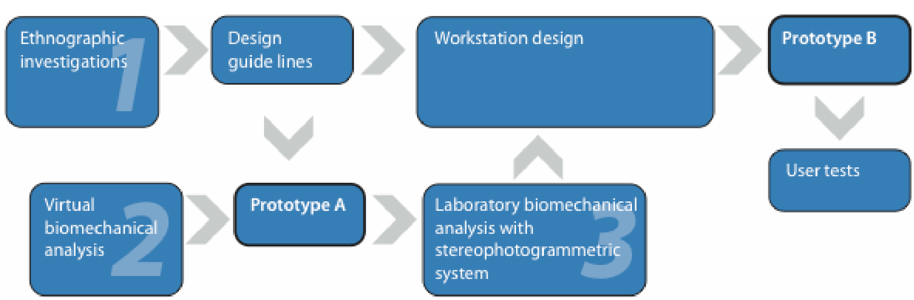

Fig. 1. General research process with 3 main steps and integration

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.

3 Method

3.1 On-Site User Analysis and Target Group Definition

The ethnographic investigation has been structured in four steps: warm-up, general questions, static analysis of the work environment, user observation during their work activity. 16 workstations placed in home and office environment has been evaluated regarding qualitative issues.

The acquired data have been compared and the real situations have been grouped in 3 different categories:

– user with high spinal cord lesion, working with an assistant, without moving from their workstation, at home;
– user with middle-high spinal cord lesion, working without moving from their workstation, at home or in the office;
– user with middle-low spinal cord lesion, working moving from a workstation to another, in the office in team with colleagues or with patients.

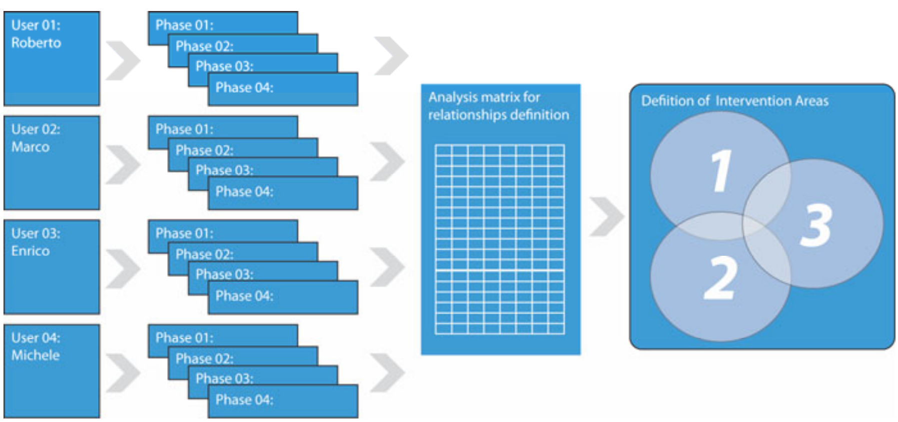

Fig. 2. Ethnographic investigation process (on the figure are represented only 4 users has example)

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 a 40cm high, which are more frequent in home workplaces. A careful study of those adaptations could suggest useful solutions to be transferred also in office environment.

A great number of object are dislocated in both situations 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 this object according to user habits.

Table dimensions vary from 100cm to 300cm length, 70cm to 90cm depth, 67cm to 85cm high. Their configuration appears to be affected by working modalities: the desks are predominantly rectangular if interaction with colleagues or patient is needed and "L" formed 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 office for further development since it is the more statistically frequent situation and it permits the development of a solution suitable also for tele-work.

The most important needs detected through on site user 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.

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.

3.2 Virtual Human Model and Workspace Definition

In order to identify the portion of the workplace space that can be reached with a certain level of muscular effort, a dynamical model was developed which allowed 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 designed 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 can be adjusted to test different relative positions between subject and table. The table itself can be risen or lowered and rotated around a horizontal transversal axis to reproduce different slopes. Each point of the extracorporeal space can be reached by changing the angles of the different joints. A limit however was defined by the total limb length. Additional space can be added by changing the inclination of the trunk. For each position in space of the hand, the corresponding joint angles and joint moments are computed, so that the whole reachable space can be mapped.

In the example presented here, the right hand movement was analyzed (but the procedures here described are also valid for a left-hander) and a unimanual task

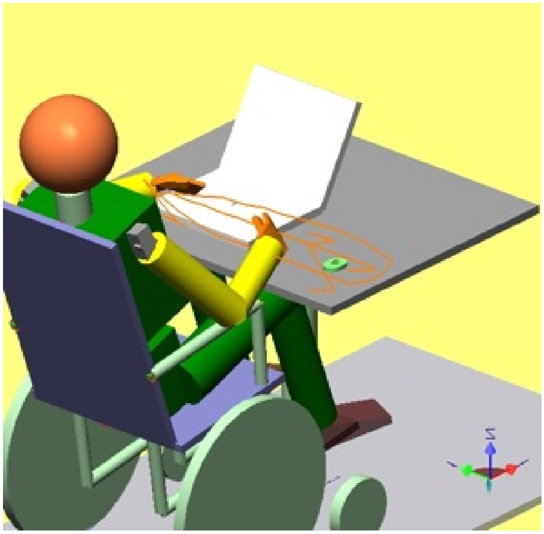

Fig. 3a. The anthropomorphic dynamic model represented in one specific position (see text). The track of the hand centre of mass during systematic analysis of the reaching is reported on the table by a orange line.

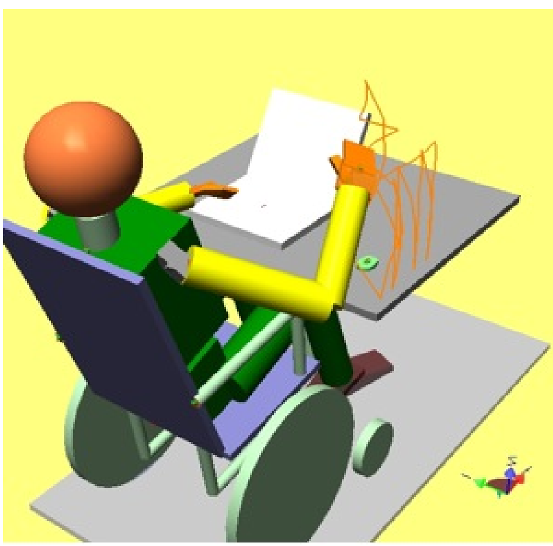

Fig. 3b. The same model while scanning the right-hand space on a vertical plane (see the hand track)

(i.e. without using the contralateral arm) was simulated in which the hand was positioned in different point of the deskwork plane. The seat height was 0.466 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).

Since the same point of 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

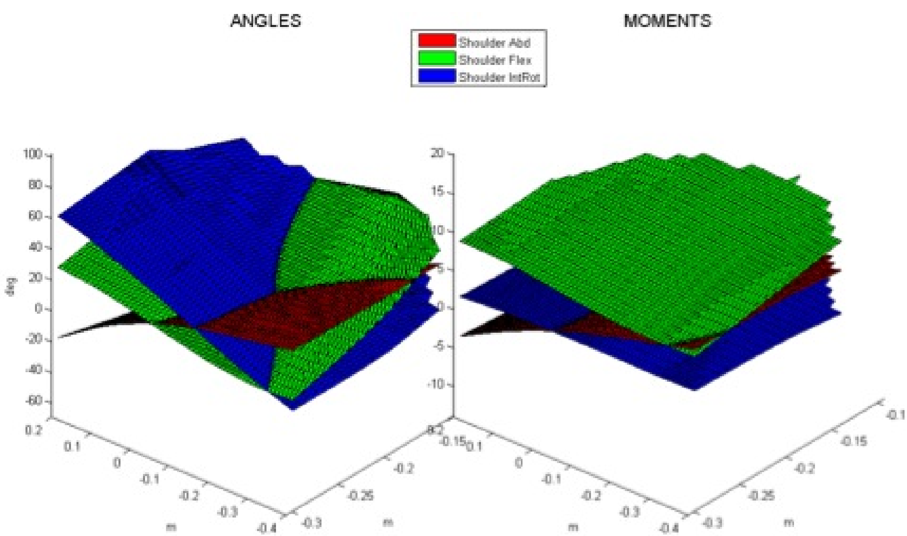

Fig. 4. Systematic analysis of the shoulder angles and moments associated to maintaining a given position of the hand on the work plane, supposed horizontal, 5 cm above the table surface. The three intersecting surfaces refer to shoulder flexion (green), abduction (red), internal rotation (blue). The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

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 contribution which is less than the maximum moment the subject can develop. A similar result was obtained for the angular rotations.

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

4 Discussion of Results

In previous researches [10] we faced some problems with the analysis of data acquired from natural users movements because of the excessive variability in behaviors that made inter-subject comparison very difficult. On the other hand a to strictly definition of movements risks to make them unnatural. In this experience we consequently decided to consider different conditions: the relative positions of wheelchair and table were changed as well as the location and orientation of different objects like: monitor of the computer, keyboards, mouses, joysticks, electrical plugs, electrical switches, other communication devices (switches activated by head, blow, eyes).

From methodological point of view, we found a positive conciliation to integrate ethnographic qualitative data and physical modeling movement quantitative data to support product development defining a 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 analysis while its extension to the design phase and to other application fields 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].

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