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DYNAMIC USABILITY PRINCIPLES IN REHABILITATION, WORK AND COMMUNICATION

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Existing static methods of usability are not effective in application to the dynamic processes like rehabilitation, work safety, implementation of new work and communication technologies including e-business. Joint and independent work of eyes and arms in manual assembly was experimentally studied as a factor of usability and occupational safety. Principles of a dynamic usability are suggested. Application of the principles is demonstrated with invention and usability testing of assembly workstations with indirect observation of operations and negative tilt of work surface.

INTRODUCTION

Application of usability methods to the rehabilitation, work and communication, particularly in e-communication and e-commerce, requires usability methods to be adequate to the dynamic processes. It is not the case for existing usability methods which are based on implicit assumption that a usability tester and a product (hardware or software) are not changing essentially and thus the usability process is a static one.

The static oriented usability methods are not adequate to rehabilitation and to any other dynamic process of human-machine-environment interaction and mutual adaptation. Practice in current dynamic world requires a dynamic usability based on new methodological principles.

Rehabilitation in ergonomics may be defined as a dynamic process directed to restoration of work and communication efficiency handicapped for any reasons. From the point of view of the ergodynamics, rehabilitation is a transformation in human body or/and mind from any kind of a handicapped condition (physical and psychological state, work structure, or cognitive strategy) in relation to the certain work functions into condition which is more adequate to the functions and allows to carry them on with higher safety, efficiency, reliability and comfort (Venda, 1994, Venda and Venda, 1995). Rehabilitation may mean a reverse transformation, return to the previous work structure and strategy. Much often it means transformation to some new structure and strategy equivalent or better than the previous ones. Therefore study of rehabilitation dynamics includes analysis of initial work structure and strategy, their regressive (negative, unwanted) transformation (e.g. occupational disease) and their progressive transformation leading to acceptable work efficiency.

As most transformation processes, rehabilitation requires a multi-disciplinary approach. In many cases rehabilitation of worker who got an occupational disease cannot be achieved using traditional medical therapy, ergonomic re-engineering of the workstation is also needed. We use here the term rehabilitation much wider than usually.

The term includes such various processes studied in ergodynamics as

1) restoration of work functions and return to work after occupational injury or disease, using mutual adaptation between worker and workstation through ergonomic re-engineering of the workstation and professional re-training of the worker;
2) job stress management;
3) restoration of company's psychological climate and business profit;
4) change of operator's cognitive strategy from erroneous to an adequate one;
5) restoring communication and relation in a compact or distributed team (HIS);
6) individual development phase with efficiency increase during transformation in aging
7) micro-transformations in use of a newly upgraded computer software,
8) progressive use of a new or upgraded web site, and any other transformation in work structures and strategies allowing to restore work efficiency criteria. The transformations may be reverse, backward ones as return to previously held work structures and strategies, or they may be direct, forward ones to obtain new work structures and strategies.

USABILITY OF WORKSTATIONS

Why existing rehabilitation methods are ineffective?

Electronic assembly work has a very heavy MSD epidemiology of the repetitive injures (RSI, MSD, CTD).

Analysis of experience of the Workman's Compensation Boards and physio-therapists showed that common practice of healing a repetitive injury with following return to the same workstation often leads to a more serious injury.

We studied the most common repetitive injures of neck and back at electronic assembly lines in telecommunication industry.

After physio-therapy and return to the same workstations many workers got long term disability and stayed with neck injury more than one year.

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The current organization of electronic assembly work requires workers to bend their neck and back, lift their hands and shoulders, and in some cases to maintain a static awkward posture accompanied with high upper trapezius muscle stress and vision strain.

We surveyed and examined many of the current ergonomic design solutions for electronic assembly at electronic assembly companies. All of the surveyed and examined solutions were based on the same methodological approach. The ergonomic designers tried to find a work surface position (for a printed circuit board, PCB, particularly) that might be optimal for the assembler's eyes, neck, wrists, arms, back and shoulders all at the same time. We found that none of those solutions provided work safety and comfort.

As a result of an awkward work posture, many electronic assembly workers sooner or later get disorders, pain or MSD. The existing solutions do not prevent MSD, they do not provide mutual adaptation between worker and workstation and do not allow injured workers to get a full rehabilitation and return to the assembly line.

Injures caused by workstations

The results from an analysis of MSD's and other types of musculoskeletal diseases were presented by Dr. L. Rosenstock, Director NIOSH (1997). The NIOSH review examines relationships among workplace factors and musculoskeletal disorders of the neck, upper extremities, and low back and analyzes the strength of the epidemiologic evidence for causal links between specific workplace factors and musculoskeletal disorders.

Many countries need ergonomic solutions on MSD prevention and the return of injured workers. In 1998 V. Venda organized a network named an International Institute of Ergonomics and Work Safety (InterInErgo). InterInErgo is currently working on the project "MSD Prevention in Electronic Assembly Workers, Particularly Those Workers with Hearing and/or Vision Disabilities and Bound to Wheelchairs". We critically analyzed existing ergonomics design principles and methodology.

Experimental study of workstation usability factors and criteria

The goal of the experiment was to find the optimal PCB angle that provides maximal work comfort. The subjects in the experiments consisted of thirty engineering students at the University of Manitoba. The subjects used standard equipment and were doing typical electronic assembly work similar to that one done at assembly plants.

During the experiments, the angle of PCB was changed between 0° (horizontal position) and 55° (maximal angle where electronic parts start to fall down from the holes).

Every experiment lasted about three hours. Data on work comfort at different PCB angles for the groups of subjects Figure 1. It represents relative work comfort, Qrel, as function of the angle of PCB, F.

Maximum work comfort at the assembly workstation with a direct observation of manual operations, was found at PCB angle of 22°. At smaller angles, the subject's bending of neck and back caused discomfort and caused difficulties in visually finding the holes on the PCB. At larger angles, the subject's lifting of arms and shoulders along with wrist flexion were the major factors of discomfort.

At 22 degrees of PCB angle, neither eyes and neck, from one side, nor wrists, arms and shoulders were in an optimal position, even though work productivity and comfort were maximal for the joint work of eyes and arms.

EMG level remained stable around 20-30%MVC between PCB angles of 15 degrees and 30 degrees. Between angles of 0 degrees and 15 degrees, it was higher because of very large angles of neck and back bending (measured using goniometers of PHY-400). At angles larger than 22 degrees, upper trapezius muscle strain increased very quickly because of arm and shoulder lifting by the subject.

Even though the laboratory subjects assessed work comfort at the angle of 22 degrees as a maximal one in comparison with other angles, they complained that there still was a significant discomfort for eyes, neck, arms, shoulders, back and wrists. EMG measurements of the upper trapezius showed high muscle tension at the level of about 20%MVC.

Our conclusion was that optimization of the PCB angle based on joint work of eyes and arms does not lead to the optimal solution for the assembly workstations. In the next series of experiments we studied a bell-shaped curve for work comfort for eyes+neck, Qe (Figure 1). Its optimum is at about 70°-80°. It is obvious that a worker's arms, wrists and shoulders cannot work so high. Besides, for a PCB where electronic parts are being inserted, the electronic parts cannot be installed at such large angles because the parts fall down due to gravity.

In the next series of experiments, our subjects were asked to keep their head in a straight neutral position, viewing the PCB located in the optimal position found in the previous series. Then we changed height and angle of the workstation surface supporting the worker's hands. The subjects were asked to assess work comfort for arms, shoulders and wrists at different heights and angles. Curve Qa presents results on the angle of the work surface (Figure 1). Maximal comfort for arms, shoulders and wrists, Qa, was found at the angle minus 7 degrees.

It is clear that existing assembly workstations do not allow a negative tilt of work surface, because worker cannot see PCB in that position even if they bend their neck to the maximum angle.

This second series of the experiments confirmed that a new principle must be found in order to allow worker's arms and shoulders to be in the most comfortable position.

Therefore our experiments showed that existing workstations requiring joint work of arms+shoulders+wrists, from one side, and eye+neck, from the other side, strongly compromise work comfort for all of these body parts and organs. EMG of

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level of muscle strain while these body parts and organs are working together, in the interactive mode.
The intersection point of the Qa(F) and Qe(F) curves provides maximal efficiency (work comfort) for the eyes+neck and arms+shoulders working together. This means that using a common work surface for the arms and the eyes leads to a relative maximum work efficiency only at Qae=0.43 when Fae=22 degrees. All other angles decrease the work comfort of eyes+neck to the left from Fae, and of the arms+shoulders on the right from Fae (Figure 1).

PRINCIPLES OF A DYNAMIC USABILITY

Results of the experiments presented in Figure 1 and of many other ones (Venda and Venda, 1995) led us to development of the principles of dynamic usability.

#1. Principle of user-product mutual adaptation: ***Every usability test criterion is a bell-shaped function of every significant usability design factor. The usability test criterion value is maximal when usability design factor value is optimal. This means that the user and the product (machine, environment) are mutually adapted.***
For example, a tempo of study of new software is a bell-shaped function of the length of the user's manual. Too short manual does not provide sufficient information for learning, too long manual slows down learning because presents irrelevant information.
#2. Principle of plurality of user's strategies: ***Each test object may be used by the same subject or by different subjects with application of different strategies. Each strategy is presented as a distinguished bell-shaped function of the usability criterion on the usability design factor.***
Therefore results of the usability test may be presented as a family of the bell shaped curves if the usability design factor was changed in a wide range of its values and subject(s) used several strategies . For example, if the length of the software manual was changed in a wide range and test subjects used different cognitive strategies (e.g. reading by letters, by syllables, by words, etc.), there will be as many functions (curves) as many strategies were used. Summarizing and averaging data obtained while different strategies were used may be considered as a serious methodological mistake.
#3. Principle of interactions and transformations between user's strategies: ***Maximal usability criterion value during interaction and/or transformation between two strategies is presented at intersect point of the respective functions (curves).***
These principles of dynamic usability are based on more general principles ("laws") of ergodynamics (Venda, 1994, Venda and Venda, 1995).

APPLICATION OF THE PRINCIPLES TO DESIGN WORKSTATIONS WITH BETTER USABILITY

The results of the experiments presented in Figure 1 and the rehabilitation requirements: design solution of assembly workstation must allow for the independent work of the arms and of the eyes in order to maximize work comfort for eyes, neck, back, shoulders, arms, and wrists. Using the principles, we invented and designed a new type of workstation meeting the usability and rehabilitation requirements. Our workstation based on indirect observation of manual operations and negative tilt of work surface was recognized by International Patent Offices in London (GB) and Geneva (Switzerland) as invention PCT/CA95/00367.
The workstation is presented in Figure 2. A worker watches the assembly operations on a TV screen, which displays a video-enlarged image of the PCB and parts to be assembled. The PCB TV-image angle and height are optimized based on our experiments (Figure 1). In industry any assembly, material handling or office workstation may allow indirect observation of operations as additional important option. Just a TV block including TV camera and TV monitor is needed.

USABILITY TESTING OF THE WORKSTATIONS

In cooperation with Nortel, we conducted a large series of comparative usability tests of our newly invented V-workstations and traditional T-workstations at Nortel assembly plant.
Twelve assembly workers participated in the experiments. Each of them worked on the first and second days at their workstations in a usual manner with direct observation and then ten days at the same workstations but with our TV block added, using direct and indirect observation of the operations. We registered, measured, and analyzed the workers' productivity, postures, motions, and muscle strain of left and right upper trapezius as EMG, %MVC. We used portable Physiometer-400 by Premed AS connected to a PC or HP palmtop LX-100 with flash card, carried by the worker on a belt to allow mobility. The experiments at the plant lasted two months. They were conducted in three shifts. The workers were involved in the normal technological assembly process.
Comparison of productivity at T and V workstations showed that productivity using the V workstation increases quickly and by third-fourth training day becomes equal and then gets higher by 12-25% than that when using a T workstation. Workers managed to transform all their skills, including soldering, by the fifth-eighth day.
Comparison of the T and V workstations showed a general advantage for V in most criteria: EMG of Right and Left Trapezius, Head (Neck) Flexion and Back Flexion. At V workstation average EMG was 9% MVC for R.T. and 7% for L.T. At T EMG was 32% and 26%. Neck flexion at V was 6°, at T it was 30°. Back flexion was 5° at V and 19° at T.
The twelve workers at Nortel GWS plant who participated in the tests and many more workers there who tried our workstations, highly assessed the improvement in work posture, positions of neck, back, shoulders, arms and wrists, particularly when negative tilt was offered them.
Four assembly workers who had been on disability with neck

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under physicians' supervision. They expressed their opinion that this type of workstation would help them in the rehabilitation and return to work, and that it probably would not had injured them.

CONCLUSION

1. Analysis of MSD epidemiology in electronic assembly industry and usability tests of existing workstations with direct observation of operations, requiring bending neck and body, flexing wrists and vision strain, showed the existing workstations lead to frequent MSD and do not assist in rehabilitation of injured workers and their return to work.
2. Using principles of ergodynamics, a new type of assembly workstations with possible negative tilt, indirect observation of operations and separate optimization of work for eyes, neck, back, shoulders, arms, and wrists was invented, designed, and tested.
3. This invention improves work posture and lower muscle strain and risk of MSD's at electronic assembly plants, as well as in manual material handling and offices.

The workstations allow workers to be seated in a straight, neutral position with relaxed shoulders and arms and wrists supported on the surface with negative tilt.

4. The workstations allow a large magnification of the product assembled or manually handled thereby decreasing visual strain and increasing work productivity.
5. The workstations allows better rehabilitation of those workers who already had developed neck, wrist, back repetitive strain injuries to return to work, but they could not work at the traditional workstations.
6. Principles of dynamic usability were developed, validated and practically used in inventing new workstations with higher usability.

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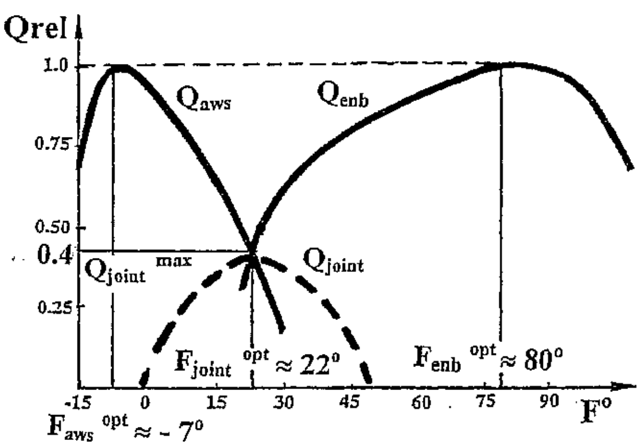

Figure 1. Work comfort for joint (Qjoint) and for independent work of eyes+neck+back (Qenb) and arms+wrists+shoulders (Qaws) as bell-shaped functions of the angle of PCB, F (preliminary experimental data).

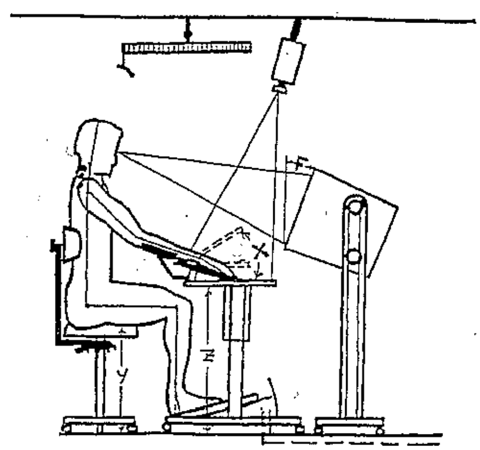

Figure 2. Assembly workstation with indirect observation of operations and negative tilt invented by V. Venda and N. Venda.

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