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VIRTUAL ERGONOMIC ANALYSIS AND REDESIGN OF A DENTIST'S WORKCYCLE

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ABSTRACT

The application of ergonomic principles to the design of processes, workplace and organization, is not only a way to respond to legal requirements, but also an indispensable premise for any company that wants to pursue a business logic. One of the most stressful works, in terms of prolonged wrong postures and psych-cognitive effort, is the dentist's one. This paper shows a cheap and effective method to acquire workplaces, work-cycles and workers-postures, in a work-environment (Dental clinic), in order to analyze how dentists (workers) move themselves into the work environment around the workstations (Dental clinic seat), with their own tools and devices, and do their jobs. The aim of the analysis is to determine the best way to plan the movement of the workers and their work-cycle in order to optimize the productivity and to obtain the best ergonomic rating for the workers. For those purposes, authors used Virtual Prototyping techniques and OCRA Analysis for making the biomechanical risk assessment; time acquisition and video acquisition has been made to analyze the work cycle. DELMIA® software was used to model the workstation and for modelling activities and postures associated with various repetitive actions; pictures taken by cameras have been processed through the KINOVEA® software and simulations have been made for the own worker percentile. An ergonomic/comfort driven redesign of the work-cycle has been suggested in order to optimize the work cycle in terms of risk minimization. The application has been made on the typical working day of an Italian dentist.

Keywords: comfort evaluation, digital human modeling, ergonomics, not-invasive postural analysis, dentist's work.

1. INTRODUCTION

Ergonomic studies are able to identify design evaluation parameters that help designers, buyers and users to choose product and process solutions. In working environments, ergonomic factors are taken into account in product and process development because they are a key component of the human-machine interface.

The most used method for in-process ergonomic analysis is based on the following three steps: 1) Direct and indirect (videotaped) observations of users and workplaces [1,2]; 2) information collection about work-environment and work-cycles [3,4,5]; 3) Data analysis and ergonomics-rating synthesis. Digital human models allow engineers to simulate the workers and the work environment during the work [6]. Digital Human Models allowverifying the appropriate use of the tools, by the workers, and their ability to support these efforts according to their anthropometric characteristics. These models allow making efficient the ergonomic analyses both in terms of design efforts and in development times.

During the last two decades, the market has been impacted by several laws like EN ISO 14738, 2002 [7], ISO 11226/2000 [8] and EN 1005-3/2009 [9] that set several geometric parameters to be met in machine design in order to improve the workers safety. In the meanwhile, ISO Normative series 11228, in its three parts [10,11,12] deals with ergonomics in the manual handling of objects. In work-environment layout and work-cycle design, ISO 11228-3 is the most used because it deals with evaluation of risk in cases that require repetitive movements. Risk evaluation is based on two procedures: first, an initial screening of the check list proposed by ISO Standards; second, a detailed evaluation procedure based on International standard methods of Ergonomic analysis like RULA [13], REBA [14], LUBA [15], STRAIN INDEX [16]; OCRA [17], OREGE [18], and others, with a preference given to the OCRA [6,19]. These standards have been taken as reference point for developing an ergonomic-driven design/redesign method for work-tasks and work-environment layouts. This paper focuses its interest about a dentist's postures (types and times) because their direct involvement in the rise of musculoskeletal disorders in humans. A posture is defined to the human joints' positions and movements. In literature several studies like [20,21] cites the needs to understand the behavior of human joints in terms of Range of Motion (ROM) [21,22], neutral (zero) positions (defined as the one that allow the maximum state of comfort [21]) and Comfort Range Of Motion (CROM) [23,24].

In our work, the postural analysis has been made in a way that does not affect the efficiency of the Job/Task, i.e. the cheap and effective method based on photogrammetry 4D as suggested in [2,25] and to preventively analyze comfort and ergonomics performances as suggested in [26,27]. The test case has been developed in a dental clinic in Salerno, by analyzing the work environment and the work cycle of two dentists in a dental clinic of Salerno (Italy).

2. TEST CASE AND METHODS

The work shift analyzed is 7,5 hours long in duration, from 9:00am to 6:00 p.m. with 1,5 hours break during the shift.In one day, a dentist has an average of 15 patients. The active work-shift has a duration of about 280 minutes because there are about 170 minutes of stops, interruptions or pauses; in 280 minutes of work, there are

240 minutes of repetitive activities and 40 minutes of not-repetitive activities. The duration of each of these activities has been measured, based on an analysis of their video recordings.

The work-environment being analyzed is the operating room of the dental clinic, in which the worker can work seated or in standing position. The workstation is composed by:

- a sort of desk on which the dentist can place his instrument and notebooks;
- a normal seat with a height-setting system, for the dentist;
- another normal seat with height-adjustable system that can be used by the dentist's assistant;
- the dental clinic seat, that is composed by a fully-adjustable seat for the patient, a big swinging lamp, a tray-table for instruments and drills' set, a rinse and flush system for the patient;
- a small drawers with other instruments and tools.

The analysis of the duration of activities' times allows us to calculate an average net time of 960 sec. for the total repetitive cycle with an average number of actions equal to 59.

The result of 960 sec. has been reached by averaging the working time for the following kind of main activities:

- dental care;
- extraction of teeth;
- conservative dentistry;
- checkup visit.

Each of the previous activities is composed by several sub-activities that have been analyzed and timed in every detail. The analysis of the entire cycle of work shows that several activities seem to be critical and repetitive ones.

3. MODELING OF WORKSTATION AND WORKER

CATIA® V5R16 was used for virtual-modelling of the work environment of the dentist with all his own furniture and tools. Several elements were modeled individually and then combined.

In the following Figure1-2,the real and the faithful modeling of the workstation are shown.

Figure-1. Real workstation.

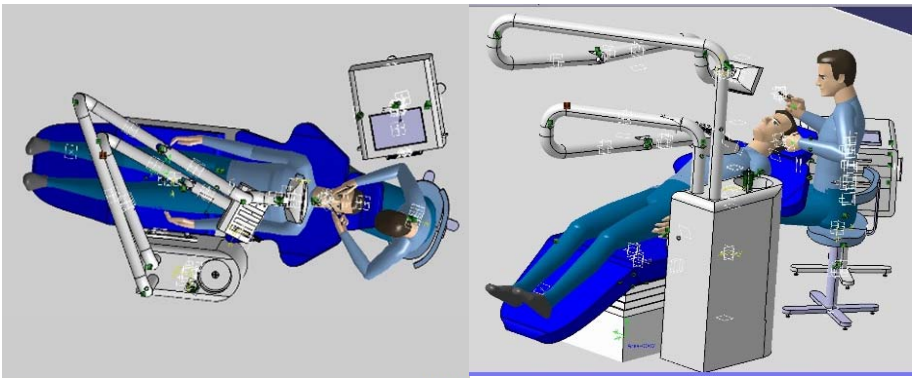

Figure-2. Virtual workstation.

A "dummy" based on a real worker's anthropometric measures has been used to model the worker. Because of two dentists, having the 50° percentile and the 93° percentile have been analyzed, the workers' measurements have been based on the two real percentiles.

Several pictures were taken of each posture to be analyzed. These snapshots were subjected to angular detection using Kinovea® software rel. 0.8.7.

The reference position for detection and measurement of joint angles was the geometric-zero position. This position is defined as the one that allows the maximum state of comfort among the values in the "Comfort Range of Motion" (CROM) [21].Some of the critical postures have been shown in the following figures:

Figure-3. Torsion and lateral flexion of dentist's trunk.

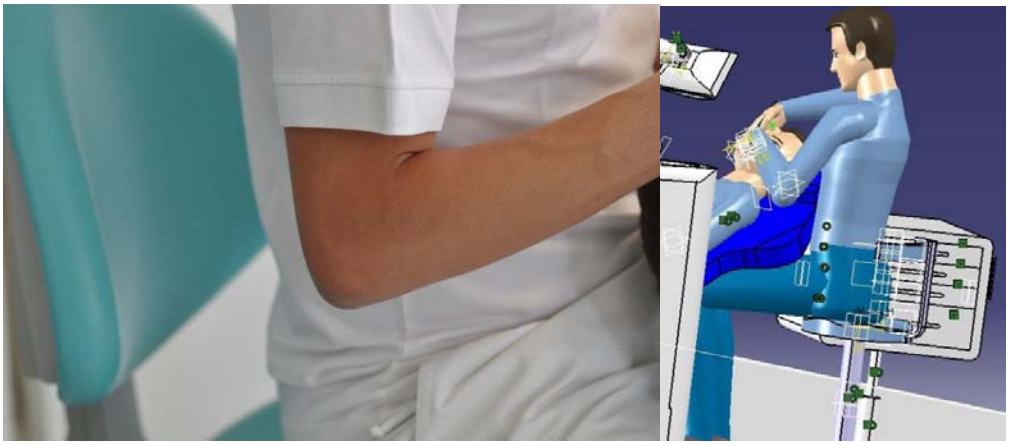

Figure-4. Virtual and real analysis of the dentist's posture on the seat.

Figure-5. Example of wrong postures during dentist's work.

In the virtual environment, the dummy was placed inside the virtual work-environment in order to carry several checks. The "reach position" function allows the manikin to move itself into the desired position. The photographic acquisition method has been checked and validated by comparing the output angles calculated by the software with those obtained from analysis of the pictures (see Figures from 2 to 5).

Photographic data acquisition may cause some detection errors that were analyzed and controlled in order to ensure that all values were in an acceptable range [2]. Taking pictures from only two points of view when the work was not in progress (a steady-state picture) was very useful as a way to avoid errors. Some of the acquired angles were slightly modified to correct for inadequacies of the photographic acquisition method.

An extra "visibility" analysis was made; this demonstrated that some acquired angles showed errors due to acquisition methods. Some angles, for this reason, were modified in order to remain as faithful as possible to workplace reality. In all cases, the angles' evaluation error was under the 5%.

After angles detection, all worker positions were modeled through the "edit posture" and saved into an Excel® tableto be analyzed through the OCRA Method [17,28].

Finally, the simulation of the movements of the manikin, in the studied activities, has been performed in order to compare the simulated movements with the video-recorded actions.

4. ERGONOMIC AND COMFORT EVALUATION

The repetition of work activities is a factor to consider very carefully. Repetition can lead to biomechanical overload of the upper limbs (SBAS) that results in trauma and injuries from stress, and micro-traumas that are repeated over time and have a cumulative effect.

In order to evaluate the possibility of biomechanical overload, risk factors associated with repetitive movements of upper limbs have been considered in connection with the total time duration of repetitive movements.

ISO 11228-3 strongly recommends the use of the OCRA analysis as the risk assessment method. The extended OCRA method is the tool to use for mapping the risk.

The OCRA index is calculated as the ratio between ATA (Overall number of technical actions carried out in the work shift) and RTA (Overall number of technical actions recommended in the work shift). It allows risk levels to be assessed for each task and assigned to one of three risk level bands: green band, between 0 and 2,2 (no risk), yellow band, between 2,3 and 3,5 (possible or slight risk) and a red risk band, more than 3,6 (high risk).

In the studied case, we had the several values for calculating the OCRA Index (see following Tables1and 2)

Table-1. OCRA score evaluation: calculation of ATA

	Cycle
NTC (Total number of actions in the cycle)	59
CT [s] (cycle time)	960
F=(NTC*60)/CT (technical actions' frequency)	3,7
D [min] (net duration of the repetitive work)	240
ATA=F*D	888

Table-2. OCRA score evaluation: calculation of RTA.

30 *	**30**
FOm*	0,65
POm*	0,07
REm*	0,7
ADm*	0,8
D=	240
RPA*	183
DUm*	1,3
RCm=	1
RTA	238

In the Table-2,we have:

30 = number of repetitive actions performed during the work shift
FOm = Force multiplier
POm = Posture multiplier
REm = Repetitiveness multiplier
ADm = Additional factors multiplier
D = Net duration in minutes of the repetitive action
RPA = Partial number of technical actions for each task
DUm = Duration factor
RCm = Recovery period factor.

In this study, the analysis was also based on videos that were recorded during the work activity.

The final values of the OCRA index was 3,7, so that an high risk situation has been detected in the dentist's work shift, both for 50° and for the 95° percentile.This result does not agree with the risk-limits imposed by Italian Law.

The risk for both right and left upper limbs is high because the worker uses both limbs to perform the activities; also the spine, in the lower part, and the trunk show critical postures during the work shift. The whole cycle is definitively critical because most part of movements are "free-hand" ones, without any kind of support.

Due to the high risk detected, a serious evaluation of improvement actions is needed; furthermore, the Comfort questionnaire given to the workers suggested us to improve and completely change the work methods in order to increase the general comfort of the workplace.

Multiple assessment methods must be applied and risk factors must be analyzed on the basis of information from the different evaluated elements, in order to avoid serious errors of interpretation.It was essential, therefore, to undertake a postural analysis of all the activities, but with a particular attention paid to those activities that were proven critical by the previous analysis.The postural analysis consists of several phases:

- The measurement of the joints' angles for each posture;
- The attribution of a comfort score for each joint;
- The selection of criteria for the combination of the comfort scores.

Each posture can be defined by several anthropometric parameters. These parameters represent the angles of each joint.

Once the parameters are determined, it is necessary to associate to each parameter with a comfort score. The comfort scores, which have been obtained using CaMAN®software [26], have to be combined according to criteria that allow evaluating the postural comfort index. The postural comfort analyses showed Comfort results going from 2.5 to 4.5 in a scale 0-10: several modificationsare needed in order to reach a minimal value of 6/10 in all studied postures.

5. ERGONOMIC/COMFORT DRIVEN RE-DESIGN

In order to solve the problems with the activities revealed by the analysis results presented above, it was necessary to make changes to the work-shift and to teach to the dentistsa new way for making the operation.

The guidelines that have to be followed by the dentists provide several suggestions and modifications both for assumed postures and for used furniture.The most important can be read below:

- Design and realization of a new lamp for a different kind and direction of lighting;

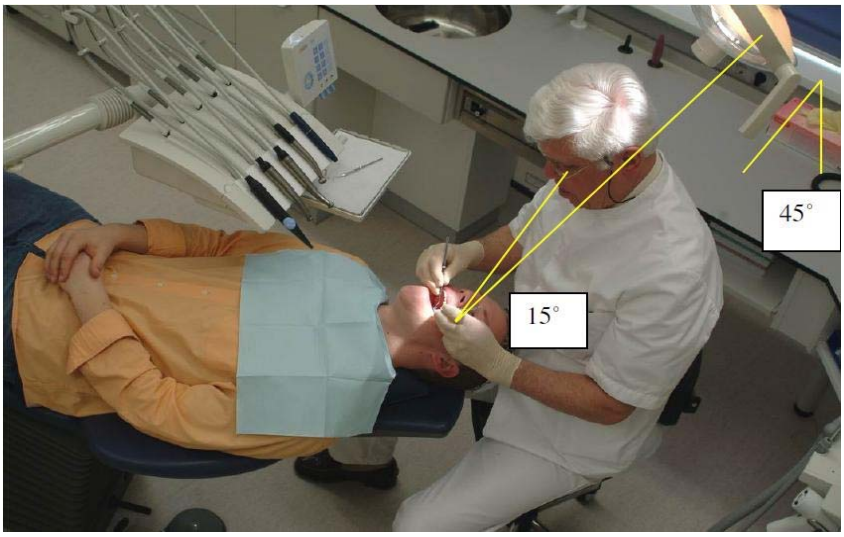

Figure-6. Analysis of lamp positioning and lighting.

- The main support for operative instruments has to be positioned higher and closer to the dentists;
- The position of the main instruments' support has to be between 30° and 60° on the side (left or right) of the dentists;
- Some instruments need a support for the elbow in order to be correctly used;
- Some pauses are needed during the long-time operation; in these pauses the dentists has to perform a little stretching activity in order to cool down muscles and ligaments;
- The seat has to be changed because a good lumbar support is always needed (see Figure-7);

Figure-7. Simulated right postures.

- The position of the seat, towards the operative bed, has to allow a symmetric posture of the trunk;
- The relative position between head and trunk has never to go out of the optimal range (not more than 25/30°);
- The angle between forearms and trunk has to go not more than 25°;
- The alternation between "leaning back" position and "hanging back" position has to be respected in order to move the spine;
- The torsions of the trunk have to be avoided or limited.

Figure-8. Right postures, studied and applied in new work cycle.

Figure-9. Right postures, studied and applied in new work cycle.

All these changes have been implemented in the Virtual model in order to check the new work-cycle.

After the redesign of the furniture, a virtual postural analysis, using DELMIA® software, has been made in order to calculate the new postural configuration.

The OCRA index has been calculated again; the results are summarized in the following tables:

Table-3.

	Example of new work shift
Cf	30
FOm	0,65
POm	0,6
REm	0,7
ADm	0,8
D	240
RPA	1572

Table-4.

	Example of new work shift
RPA	1572
RCm	1
DUm	1,3
RTA	2044

Table-5.

	Example of new work shift
ATA	888
RTA	2044
OCRA	0,43

The OCRA score has been improved, reaching a value of 0,43, going to values that are always in the green band (no risks).The resultant joints' angles have been used for calculating, by CaMAN® software, the new values of Postural Comfort.

The results show an improvement of all Comfort scores, that, in the new configuration, go from 6,1 to 7,2. In new simulation, nonew activities were introduced.

6. CONCLUSIONS

The focus of the ergonomic-postural analysis was the work environment of dentists. The goal of the analysis was to redesign the workstation and to optimize the work shift's timing in a way that would allow dentists to perform their activities with less incongruous and incorrect postures. The proposed redesign that resulted from the analysis of ergonomics parameters and the evaluation of the perceived postural comfort was aimed at improving dentists' health and safety.

Severalstressful actions were finally targeted for redesign. In addition, furniture and instruments have been redesigned.

Analyses and evaluations were performed using the very popular ergonomics analysis method, OCRA Index and through the novel comfort evaluation method proposed by University of Salerno (Italy): the CaMAN® method/software.

Regarding the other activities analyzed, comfort and ergonomics indexes suggested major modifications to some angles of the dentists' posture in order to improve workers' perceived comfort. These changes need to be combined with training for workerson how to move and use the equipment properly.

This study shows how a process optimized and redesigned in terms of ergonomics and comfort led to a higher quality working environment and an increase in workers' productivity. Additionally, simulating the entire work cycle with modeling software combined with an analysis of the activities' flow allowed for the identification of critical processes and for a virtual study (with shorter times and lower costs) of new possibilities for dentists' equipment.

Lastly, it is important to emphasize that the method used to perform the ergonomic and comfort

analysis is very cheap (photographic and video-graphic acquisition of human postures) and can be used during the work-shift, without affecting the workers performance in terms of productivity and of quality of the given service. These methods can be easily joined with the FEM/BEM simulation [29] in order to virtualize all the operation in dentist's activity.

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