Ergonomic solutions in designing workstations for operators of cranes on harbours

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Abstract

By nature of their work, container crane operators using cranes over 30 metres high have to hold awkward postures of the cervical, dorsal and lumbo- sacral spine for long periods of time.
That is because the visual field is located under the operator's feet. The floor of the crane cabin is in fact made of glass: during the hooking and transport of the container the crane operator is obliged to keep his back and cervical spine bent and his legs wide apart, while he moves the control levers.
The aim of this research is to study and re- design ergonomic adaptations that reduce the risk in these work- stations. The risk evaluation for these workplaces was carried out through the inspection of three major European ports and through biomechanical analysis.
In the prototype development stage, use was made of surface EMG studies (at % of MCV) of the muscles of the upper limbs and trunk with an innovative completely wireless EMG system. The objective comparison of the measurements obtained in the different work- stations examined, lead to the design of an ergonomic work- place capable of causing the lowest level of muscular activation while meeting the constraints of job performance.

Keywords: crane cabin operator, surface electromyography, work- place re- design, biomechanical evalutation.

1. Introduction and aims

Shipping container crane operators work in crane cabins that are 35 to 40 meters above the ground.

During loading and unloading operations the cabins run along the arm of the crane, taking them from the yard to the docked ship.

The cabin structure is particular, given that the visual field is beneath the feet of the operator: the floor is therefore made of glass.

The main characteristic of the working posture is therefore conditioned by the position imposed by the visual field: back and head bent forward, legs wide apart with feet on 2 separate foot- rests (see Fig. 1).

To move the cabin long the crane arm the operator uses a main stick and other levers.

Given the position of the visual field, the spinal column assumes a particular flexed position accompanied by cyphosis.

Given the height of the cabin (35- 40 m) the work requires high levels of concentration: the crane operator talks on the radio with the workers in the ship's hold or on the dock.

Depending on the type of cabin, work- station and crane, the following risks can all be present: vibration, acceleration, inadequate microclimate and glare.

The aim of this work is to reach a re- design of this workspace, bearing in mind the most up- to- date international ergonomic technical rules.

Fig.: 1 Working posture of shipping container crane operators.

2. Methods

In order to find new ergonomic solutions, the following operative steps were necessary:

a) Inspections of some big European harbours to examine and evaluate operator activity.

b) Application of the following investigation protocol, including:

- operator interviews (multiple choice questions about: problem reported during the use of the different components (push buttons, joysticks…) and work- place regulations (seat, footrest, armrest regulation), level of strength required (BORG's scale application), report of any suggestions for improvement.
- evaluation of upper limb biomechanical overload (by filming the operative phases).
- evaluation of static awkward postures of the entire spine and upper limbs: this study targets the flexion angle of the trunk and cervical spine during the operative phases.
- electromyographical analysis in the design field to assess physical exposure in ergonomic studies [1]; where the comparison of the measurements obtained in the workspaces under examination provided objective values (reference) with which to redesign the workspace in a way that reduces the subject's muscular activity to a minimum.

c) The processing of results and the invention of preliminary ergonomic solutions, taking into account the most recent international technical ergonomic rules [2, 3] about:

- seat shape, measurements and regulation; also in order to improve the visual field.
- shape, measurements and regulation of the armrest.
- positioning, force level, dimension and form of the control levers.

2.1 Biomechanical analysis methods

A biomechanical analysis was carried out on the principle joints and muscles used in the job and therefore subject to possible risk of overload.

Then a rough estimate of cervical discal (C7) and lumbo sacral (C4-C5) loads was made, imposing a static equilibrium of the moments.given by the part of the body above those joints [4].

2.2 Methods used for the electromyographic study

Surface EMG signals were recorded (*ZeroWire* EMG system and acquisition software*, Aurion, Italy)* (see Fig. 2) from 5 pairs of bipolar electrodes equipped with a miniaturized unit for signal processing trasmission directly in the mechanical workshop that produces the Brieda firm's cabins.

Fig.2: *ZeroWire* EMG: completely wireless system for surface EMG.

The electrodes were placed above 5 muscles of the right upper limb: upper Trapezium, Cervical erectors, Lumbar erectors, Triceps, Biceps.

MCV (Maximum Voluntary Concentration) signals were achieved for each muscle.

Then the signals simultaneously coming from the 5 channels were recorded in different postures regarding 11 different possible design solutions.

Such solutions were compared with muscular activity recording of a subject in seated position with supported back and limbs (named reference posture).

The EMG signals were elaborated to find out % of MCV activations in each posture and for each muscle (*Myoresearch XP Master Edition* software, *Noraxon-USA inc, Arizona):* MCV signals were rectified to get then the average value out of the values found in 2000 ms containing the highest values (in µV) of each muscles [5].

The signals recorded during the other postures were rectified, filtered (RMS every 300ms) and normalized in width with respect to related MCV average value.

3. Results

A new workstation solution was designed including chair, adjustable footrest and armrest, accounting for the several "technical constraints" associated with this particular workstation. National and international regulations in force were taken in due account as well as results of electromyographic tests that proved to be essential for research of solutions requiring the least muscular effort.

For existing workstations where no change in workplace is envisaged in the short term, a special sling was designed, adjustable to the subject and adaptable to all kinds of seat allowing (without producing compression or nuisance) to unload trunk weight.

This section summarizes in subsequent steps the results of biomechanical and electromyographic study risk assessment and solutions are discussed.

3.1 Results of risk assessment and biomechanical analysis

Given the position of the visual field and the required degree of attention, the spinal column assumes a particular flexed position accompanied by cyphosis.
Head, neck and trunk muscles (head extensors, spine extensors, upper trapezius extensors) are in isometric contraction: this means a low muscular activity (low value of Borg's scale) but borne over long periods of time. Actually the scientific literature reports that even for MCV 20% values, adequate recovery times are needed in proportion to static contraction duration [6, 7].
An interview to several workers in different harbours revealed that articular segments more affected by diseases are exactly cervical and lumbo sacral zones.

For rough estimate of cervical discal (C7) and lumbo sacral (C4-C5)) loads; the static equilibrium of the moments.given by the part of the body above those joints was imposed [4]: the moments (Table 1) are represented by the force of different body segments located above invertebral discs multiplied by respective lever arms according to the following formula:

$$Ce=((\sum (pi* xi))/ be) * \cos\alpha) +\sum pi;$$

where

h=175cm
w=70Kg
be= lumbar extensor arm= 4,5cm / cervical= 2cm
pi= weight of body zones
Xi=arm of body zones

Values of approx 13 Kg for cervical- dorsal area and 205 Kg for lumbar area were obtained.

Table 1 Lever arms and weights of body areas.

AREA	ARM (cm) Xi	% BODY WEIGHT pi
Head	35.2	6,9
Neck	26.4	1
Trunk	17.6	39.3
Arm	13.2	2.7
Forearm	4.,4	1.6
Hand	24.2	0.6

3.2. Results of electromyographic analysis

The results of electromyographic analysis expressed in MCV % of analyzed muscles (identified by biomechanical analysis) are reported. First the results of reference posture (0) (seated position with supported back and limbs) were compared with classical posture (1) of crane operator (seated position with trunk front flexion without supporting on back: extended arms and hand on stick).

3.2.1.Comparison between reference postures (0) and classical posture (1).

Comparison of reference posture (0) with classical posture (1), highlights a remarkable increase of upper trapezius activity (3.5% to 14% of MCV: 76% increase), cervical erectors (5.7% to 10% of MCV: 44% increase), lumbar spinal erectors (14.5.% to 20.4% of MCV: 28% increase) due to visual field being at floor level conditioning posture with trunk and head in flexion (see Fig.3)

3.2.2 Comparison of classical postures (1) and with sling (2)

Effectiveness of a specially designed sling was tested, being easily adaptable to all work- places already in use and likely not to be replaceable in the short term.

Passing from Posture 1 to Posture 2 (seated position with abdomen supporting sling: arms still extended and hand on stick), evidences only a slight diminution of muscular work of muscles trapezius and cervical erectors (the head remains fixed and the arms semisupported) but a significant reduction at lumbar level (-79%) with MCV % values passing from 20.1 to 4. Use of sling allows an excellent trunk weight unloading leading MCV % values to levels even lower than obtained in reference posture(see Fig.4).

3.2.3.Comparison of different supporting modalities of forearms

Passing from Posture 1 to seated Posture (10), without abdomen supporting sling, with forearm horizontally supported on armrest, evidences a remarkable diminution of trapezius muscle work (67% reduction, 14% of MCV to 4% of MCV), and lumbar (64% reduction, 20.4% of MCV to 7.2.% of MCV), due to trunk and limb weight unloading on armrests (see Fig.5). The trend of muscle force levels for different kinds of forearm supports (fore and back inclinations) was then investigated in order to find optimal adjustment ranges. Figure 6 shows the results of MCV % for all the 11 hypothesized design solutions.

In short, passing from Posture 1 to Posture 11 evidences an ever increasing reduction of average muscle activity.

The devised prototype was tested by a number of crane operators (always in the company shop): reduction of muscle effort (evidenced by EMG) proved to be coherent with the increased comfort perceived by subjects.

3.3 The main characteristics of the seat

A seat model with high back and head rest was adopted as workplace completion (see Fig. 6).

The back has a wide and deep lumbar support and its inclination can be adjusted up to a nearly horizontal position: these characteristics were added to give some rest during breaks specially in night shifts.

The seat plan is shaped so as to provide an adequate support to wide apart legs and fore inclination is adjustable in addition to height.

It is also possible to change springing system properties.

Fig.6: The seat model

4. Conclusion and discussion

Workstations of crane operators were analyzed in three major European harbours.

The visual field being on the floor, the operator, in the classical work posture is obliged to keep the head and trunk flexed and the lower limbs wide apart for long periods of time, with consequent troubles and possible MSD onset.

Ergonomically-based knowledge, biomechanical and electromyographic studies provided workplace redesign solutions aimed at minimizing the biomechanical overload from that particular posture.

Being not possible for the time being to change the visual field position (technical constraint), the biomechanical overload could be mainly reduced at trunk and upper limb levels.

The cervical tract being still overloaded, adequate breaks have to be introduced in the shift.

For existing workstations, where short- term changes are not possible, the use of a special adjustable sling , adaptable to all kinds of seat becomes extremely useful. It unloads trunk weight without compression or nuisance.

Electromyographic study proved to be extremely useful to find and objectify ergonomic solutions in order to reduce biomechanical load. This equipment proved to be even more useful being used in shop in real time during design stages.

It has already been stressed that given the persistence of visual field on the floor, the biomechanical overload of cervical tract is still high and is further enhanced by the great attention required by container handling at 30- 40m height.

In the future the visual field could be moved in the fore and top part of the cabin through a large plasma screen connected with a TVcamera under the cabin in correspondence with the real visual field.

Advantages would be:

- The subject works with supported back neck and limbs (definite solution for the cervical problem)
- The visual field can be improved by the use of TVcamera zoom in topical moments such as container hooking. Actually given the large distance of work station from collection areas, a further outcome is increased safety and reduction of loading operation times.
- At any time use of classical real visual field can be resumed.

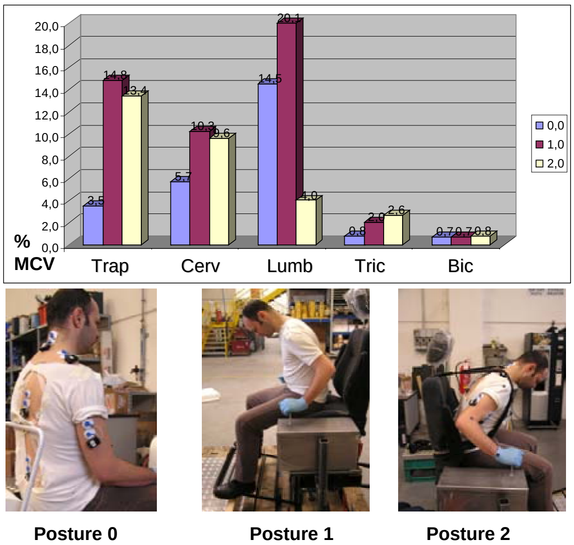


Fig.3: mean value of muscles activation (at % MCV) in postures 0, 1 and 2 were Trap= upper trapezius, Cerv= cervical erector spinae, Lumb= lumbar erector spinae, Tric= triceps, Bic= biceps.

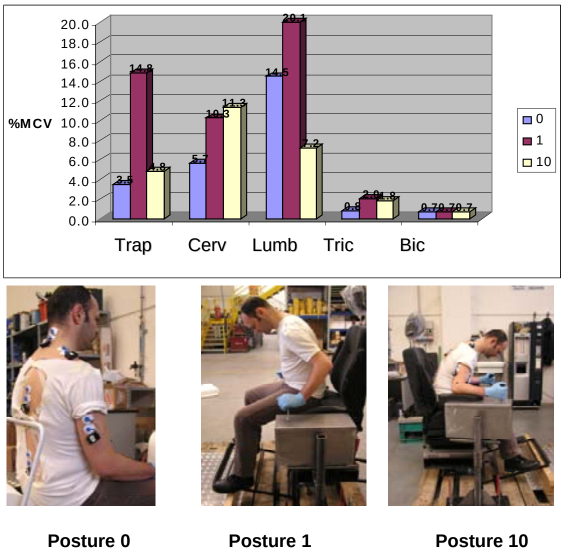
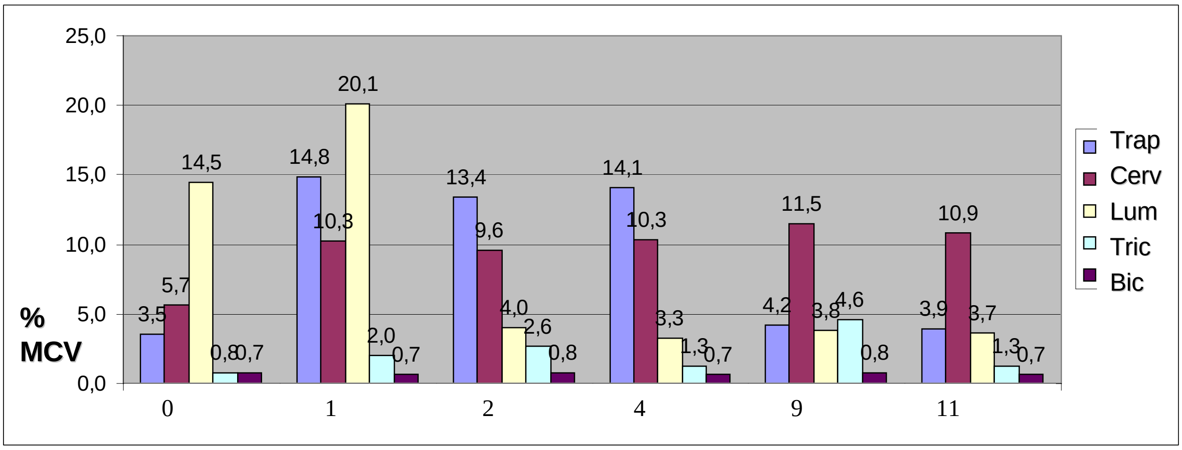
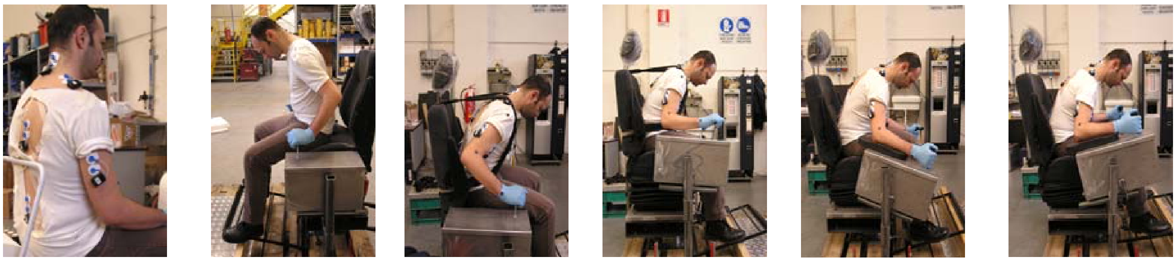


Fig.4: mean value of muscles activation (at % MCV) in postures 0, 1 and 10.





Posture 0 **Posture 1** **Posture 2** **Posture 4** **Posture 9** **Posture 11**

Fig.5: mean value of muscles activation (at % MCV) in postures 0, 1, 2, 9 and 11.

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