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Postural analysis in HMI design: an extension of OCRA standard to evaluate discomfort level

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Analysis and modelling

ABSTRACT

Purpose: The aim of this work consists in developing a design methodology for preventive ergonomics and comfort analyses of Human-Machine-Interface (HMI).

Design/methodology/approach: Our method is based on the simulation of the main posture that a digital human model (a manikin representing, for example, a car's driver) takes while using a machine (in this work, driving a car), in order to judge human safety and comfort during interaction with dashboard, instruments' panel, levers and other commands. The ergonomic analyses are made using an appropriately modified OCRA (Occupational Repetitive Actions Index) protocol, in order to evaluate different involvement degrees of upper limb segments in comfort action range.

Findings: The three-F principle -Human fit, form and function- is becoming the most addressed guideline for improvement and appeal-increasing of product in the current demanding global marketplace. Our work uses modern technologies and new design methods, developed by our research team, and allows to manage and optimize Human Machine Interface under "comfort" point of view.

Research limitations/implications: Today, designers attempt to elaborate product development methodologies that conform itself towards best comfort performance; our work helps them to override several problems that a product development plan shows. Future developments can be made using biomechanical parameters and studies in order to better quantify and evaluate the comfort parameters.

Practical implications: Using our approach and methods, comfort analysis can be made in the earliest part of the design development of a product so that designers can appreciably reduce time to market and improve and innovate comfort performances.

Originality/value: First paper on this matter has been presented by one of the authors in 2008 in a World Automotive Congress; it has been the first paper on this specific matter. All over the world, new research frontier, on these topics, is going towards HMI evaluation under physical comfort and cognitive ergonomics point of view. Our paper represents, today, the newest and more specific development method, especially in automotive field of research.

Keywords: Engineering design; Safety and health management; Comfort analysis; Design methods; Digital human modelling

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1. Introduction

Machine ergonomic studies are able to develop design evaluation parameters in order to provide a help to designers, buyers and users in choosing design and/or product solutions. In industrial environment and mainly in transport systems (like automotive, train, operator machines) and in industrial plants one (like tooling machines, assembly lines and so on…), ergonomic factor is taken into account in product and process development because it represents the first contact between product/machine and user.

During the last decade, because of the importance of the matter, several researchers and designers have been involved in increasing the ergonomic comfort of their product and work-cells (process). In fact, during the last year we have seen an improvement of comfort and usability of product, because of the new ergonomic approach, but we haven't seen the evolution of common guidelines for designers in order to minimize this "time-consuming" activity. Today a typical ergonomic analysis is made during an entire working day.

The most used method is based on the following steps:

Direct and not-direct observation (using videotapes) of user workplace;

Information collection about work-cell and work-cycle

During the last decade the market has been subjected to several National and International laws like:

- EN ISO 14738, September 2002 "Safety of machinery – anthropometric requirements for the design of workstations at machinery"[1];
- ISO 11226/2000 – "Ergonomics – Evaluation of static working posture"[2];
- EN 1005-3/2002 "Safety of machinery – Human physical performance – part3: Recommended force limits for machinery operation"[3].

These standards fix several geometric-parameters in a machine design process in every using condition (from the guidance system of a train to the supermarket cashier box).

In all imposed standards we can underline the lack of guidelines about the evaluation of the ergonomic factor during human-machine interaction. An operator generally uses a machine (product or in process) for a time in which he repeats actions several times per hour/per day. The stress due to repeated action often depends on position of commands in a dashboard (for example) and the ergonomic factor is evaluable considering which kind of interaction exists between user and machine.

This work presents a new method for dynamic ergonomic evaluation that can support designers during product development process; it helps designer to give him an easy and fast instrument to verify the comfort performance in designing a machine command dashboard.

2. Developing a new methodological approach

Since the advent of Computer Aided Design, the product development process passes through the virtual design and evaluation of required performances of product and process (i.e. CAD modelling, FEM Analysis, Product Lifecycle Management, Virtual Reality Visualization, and more....) in order to significantly reduce the time-to-market and to increase the ability to create, develop and prototype the product/process [4].

In this design loop our methodology can be placed in product virtual development and uses some software to verify the Human-machine Interface: CATIA like CAD (computer aided design) and DELMIA [5] like DHM (Digital Human Modelling) one, both produced by Dassault-Systemes.

The method we want to introduce is based on the following steps:

- First Step: CAD modelling, in a virtual environment, of the machine we want to study [6];
- Second Step: Configuration of Anthropometric parameters for our users that have been simulated using a manikin;
- Third Step: definition of the tasks we want the manikin to do and validation of the sequence of operations: the actions made by manikin will be described like a sequence of operations in „normal" working condition [7];
- Fourth Step: Evaluation of working-place ergonomics: software market offers several standards to evaluate ergonomic factors of a sequence of operations basically using two parameters: an „Applied Force Factor" and a „High Frequency Factor";

ISO Normative (International Organization for Standardization), series 11228, deals with ergonomics in manual handling of objects (extended meaning) and is composed of three parts:

- ISO 11228-1 (Ergonomics - Manual handling - Part 1: Lifting and carrying) [8];
- ISO 11228-2 (Ergonomics -- Manual handling -- Part 2: Pushing and pulling) [9];
- ISO 11228-3 (Ergonomics -- Manual handling -- Part 3: Handling of low loads at high frequency) [10].

ISO 11228-3 deals with evaluation of risk in case of repeated movements. Risk evaluation is primarily based on two procedures: the first one makes an initial screening about the check list proposed by ISO Standards; the second one is a detailed procedure based on International standards of Ergonomic analysis like RULA, REBA, STRAIN INDEX; OCRA[10], HAL, OREGE, and others, with a preference for OCRA one.

The best evaluation standard to be chosen for our application is the ISO 11228-3 one, because in our paper we analyze the comfort level while using a machine, in which repeated operations are the most involved. OCRA method has been chosen because it allows to make a detailed analysis of stress due to the continuous use of upper limbs. OCRA method takes into account the following factors:

- force
- posture
- operation frequency
- environment characteristics that can affect the ergonomics of operations
- duration and position of breaks during working periods

Machines are generally designed using methods that exclude critical working position for operators.

OCRA index was born as a method for ergonomic evaluation of repetitive operations; it takes into account only critical postures; postures are defined "critical" when they cause a work-related disease for workers.

So OCRA index doesn't work when used, for example, in the comfort evaluation for a driver in a car-interior and cannot discriminate about the best dashboard to be used in order to increase the comfort level of the driver because, in car-interior, a driver never takes critical postures!! The aim of this work is to modify the OCRA index in order to discriminate different comfort levels in not-critical working/using conditions.

3. Comfort factor

The first step to understand which posture is better than another is the creation of an instrument that allows to associate the comfort level to the geometric parameters that describe a posture of a manikin (joint angle values): in paper [12] in 2009 our research group has developed a procedure to do that!

In this paper we have defined several comfort curves that allow to judge the comfort level of each joint of upper part of human body. These curves have been modified in order to be used in the OCRA evaluation standard. The main aim of this paper is the development of a method to objectify the judgment on postures that a worker can take, a method that can be applied both in comfort and in ergonomic analysis, as recent technical standards suggest [13].

3.1. Comfort curves and posture factor: a comparison with bound values of OCRA scale

Shoulder movements: in the following figures you can see comfort curve of shoulder flexion (Fig. 1): the first one shows the trend in load-free extremities condition, and the second one the trend, for example in case of abutted on steering-wheel arm [10, 12].

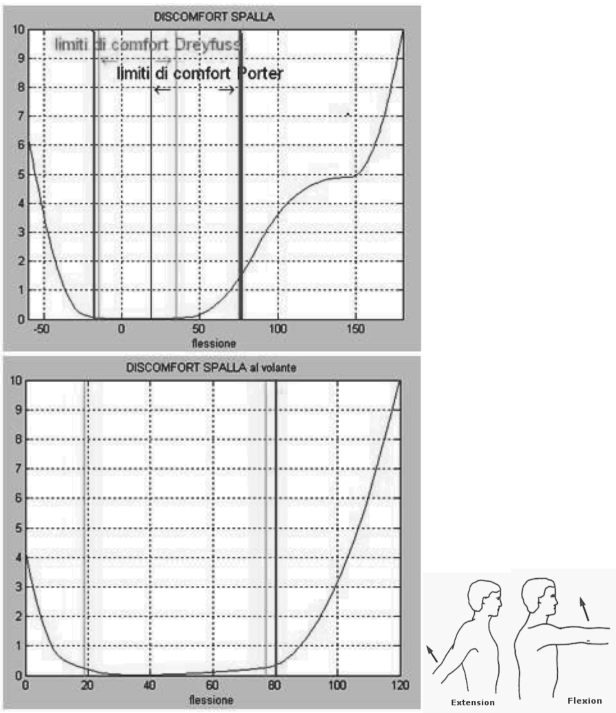

Fig. 1. Discomfort curves for shoulder flexion movement for load-free arm and for abutted hand.

We can underline that OCRA bounds are wider than physical comfort bounds: it demonstrates that OCRA method is not useful to discriminate the comfort level within the comfort bounds. In these figures you can also see the OCRA bounds over which we have to consider several decreasing coefficients called "Pom".

We have found the same curves behaviour for shoulder abduction and extension; in the following figures OCRA bounds are highlighted in orange (Fig. 2).

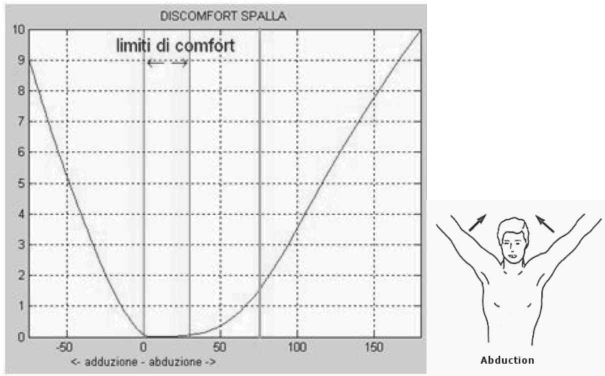

Fig. 2. Discomfort curves for shoulder abduction movement

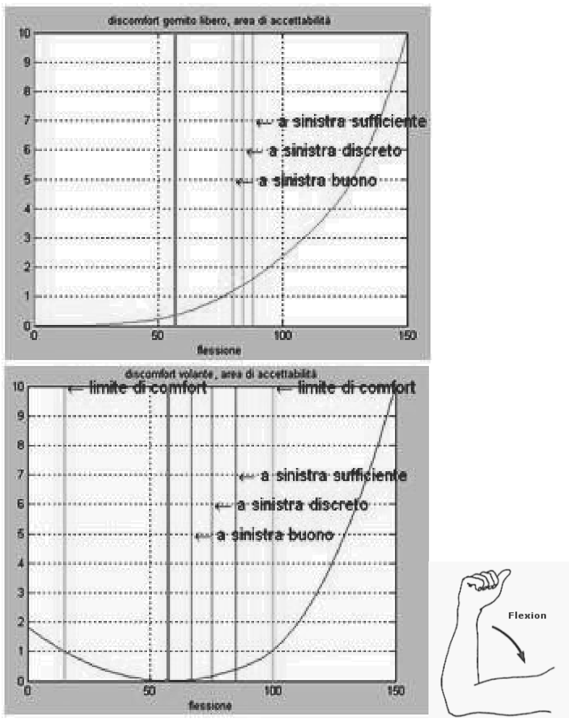

Fig. 3. Discomfort curves for elbow flexion movement

Elbow movement: in this case the proposed method for comfort evaluation is more accurate than the OCRA one (whose bounds are highlighted with orange lines). For elbow flexion our standard can give a judgment about discomfort also for little flexion-angles both in load-free and in abutted hand conditions (Fig. 3) [10, 12].

As you can see from images (Figs. 3 - 4), the integration between OCRA methods and our comfort method, for elbow flexion, appears more difficult. It happens because it seems very difficult to evaluate Pom values around 0° elbow angle when your arms are positioned on steering-wheel; in fact, the position corresponds to a position near neutral angle (on the left) when the measurement of discomfort creates several problems.

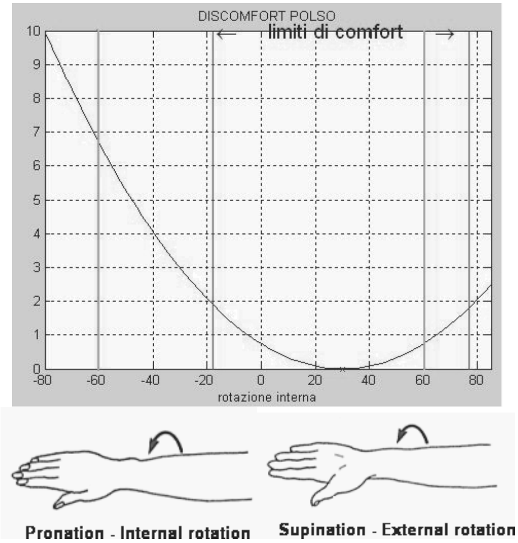

Fig. 4. Discomfort curves for elbow pronation-supination

Our research suggested to translate (changing them) the OCRA bounds in order to better take into account the values around neutral angle that correspond to a "stress to be checked" in OCRA method. Comfort limit is over the ISO bounds also for pronation-supination of the elbow that we also will take into account. It is normal, in OCRA simulation, to ignore this kind of postures because OCRA normally gives a value of "critical" only to postures that causes work-related disease.

For our work, we've considered the value of 60° like comfort limit, for elbow pronation-supination.

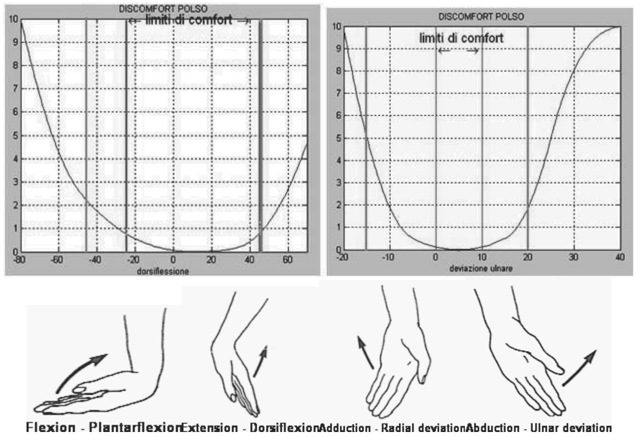

Fig. 5. Discomfort curves for wrist flexion-extension and radio-ulnar deviation

Wrist movement: as for shoulders, we can underline that OCRA bounds are wider than physical comfort bounds: it demonstrates that OCRA method is not useful for discriminating comfort level within the comfort bounds (Fig. 5). In these figures you can also see the OCRA bounds [10, 12] over which we have to consider several decreasing coefficients called "Pom".

4. Method description

We start from curves described in the last paragraph and we calculate the posture factor "Pom" for all human joints taken into account: shoulders, elbows and wrists; our new evaluation has to be based on new parameters that discriminate different positions that in the OCRA evaluation lie always in the "green field" for postures because OCRA is not so fine to evaluate them. The Pom factor is evaluated using the Table 1.

Table 1.
Posture factor (Pom) values for different degrees of freedom of upper limbs

Portion of the cycle time				
Main Awkward posture [10]	Less than 1/3 (from 1% to 24%)	1/3 (from 25% to 50%)	2/3 (from 51%)	3/3 (more than
SHOULDER: abduction between 45˚ and 80˚ and /or extension more than 20˚				
ELBOW: supination (^{3}60˚)	1	0.7	0.6	0.5
WRIST:extension (^{3}45˚)or flexion (^{3}45˚)				
HAND: hood grip or palmar grip (wide span)				
ELBOW: protion (^{3}60˚) or flexion/extension (^{3}60˚)				
WRIST: radio/ulnar deviation (^{3}20˚)	1	1	0.7	0.6
HAND:pinch				
SHOULDER: flexion/abduction more than 80˚				

% time	10	20	30	40	≥50
Multiplier	0.7	0.6	0.5	0.33	0.03

It is important, for reader, to explain how we can use the comfort data developed in [12] in order to increase sensibility of modified OCRA index. As you can see in the figure s, there is a wide range of angle value for shoulder, elbow and wrist, in which OCRA index doesn't give us a value because they lose their importance in ISO standards (that evaluates risks in repetitive movements).

Our idea for increasing OCRA index sensibility [11] is based on modification of bounds using "physiologic" values around neutral position of joints (see [12]).

New values are described as following:

1) New upper bound for shoulder flexion: 80°
2) New upper bound for shoulder abduction: 80°
3) New upper bound for shoulder extension: 20°
4) New upper bound for elbow flexion-extension: 60°
5) New upper bound for elbow pronation-supination: 60°
6) New upper bound for wrist flexion-extension: 80°
7) New bounds for wrist radio-ulnar deviation: from -15° to 20°

Our research group has focused its attention on those articular posture range in which the OCRA method doesn't give an information about work-related disease but that can be evaluated as more or less comfortable than the best posture that we have hypothesized to be in the physiologic neutral position [12]; so we have opportunely scaled the values of Pom factor starting from OCRA postures curves. Pom values go with inverse proportional trend compared to the comfort curves, so that a perfect comfort posture reaches a Pom value equal to 1 (one). Once we have optimized and standardized the judgment scale we can use both methods on the same graph (OCRA and our new method). We always have to remember that OCRA analysis gives us different values for the same operation if we use a different Cycle-timing (CT) because of its link with technical action duration.

In the first analysis we have adopted a time-independent analysis, in order to convert the ergonomic analysis into a comfort analysis[7].

In the following figures are shown Pom factor values towards posture angles for different joints of our postural analysis; the joints we have taken into account are the same used for the OCRA evaluation [12].

4.1. Pom factor for shoulder movements

As you can see from Figure 6 flexion-extension movements are evaluated around their neutral angle (that is the same of OCRA posture) but their evaluation is extended also to the angle range in which OCRA analysis doesn't give us a comfort value because those movements are not dangerous for repetitive actions. The curves come from the fusion of our curves with OCRA curves and allow to take into account all the angular range of movement for each joint: this fusion is practically obtained from the study published in [13].

The Figures 6 and 7 show the same graph described before, with a posture that takes into account the position of hands on steering-wheel.

This condition increases the comfort value for drivers because the hands on steering-wheel lighten the skeletal-muscle structure of arms and shoulders; in addition, it is easier to reach some comfortably postures for shoulder flexion; in this condition the value of neutral angle for shoulder flexion-extension obviously changes.

The approach for shoulder abduction movement is the same for extension/flexion works: the only visible difference is a discontinuous section of the curve around 80° of abduction angle because the Pom factor uses different weights for postures with angle more than 80° and postures with angles less than 80°.

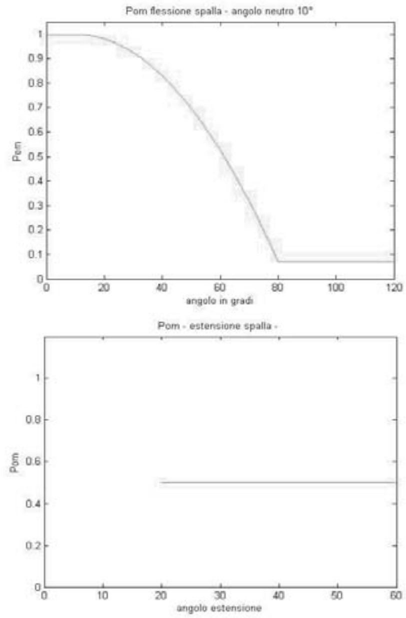

Fig. 6. Graphs of Pom factor vs. joints 'angle for shoulder flexion (the first one) and extension (the second one)

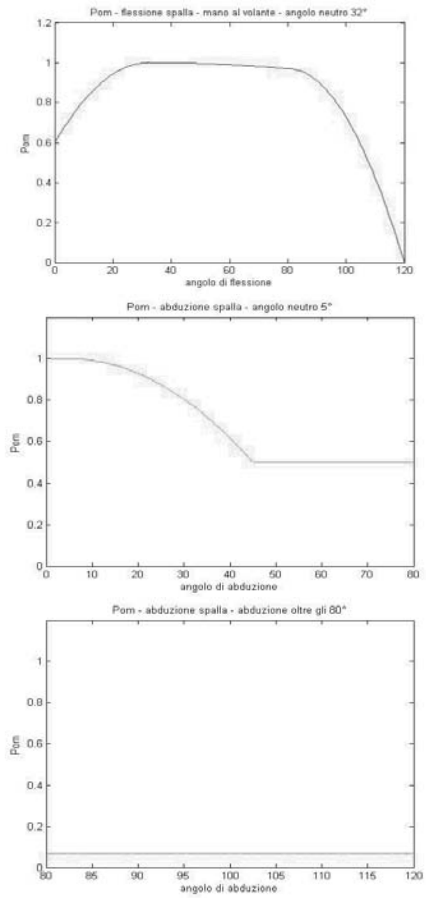

Fig. 7. Graphs of Pom factor vs. joint angle for shoulder flexion (the first one) and extension (the second one)

4.2. Pom factor for elbow movements

The following figures show Pom factor values towards elbow postures described by pronation-supination and flexion-extension angles; also in this case we have analyzed two different postures for elbow flexion-extension: the first one involves free hands and the second one involves hands on steering-wheel. The approach is the same used for shoulder flexion in the same cases. The comfort curve obtained is a modified ergonomic curve, after a scaling and a value changing operation in order to give us an evaluation agreeing with original Pom ones (Fig. 8).

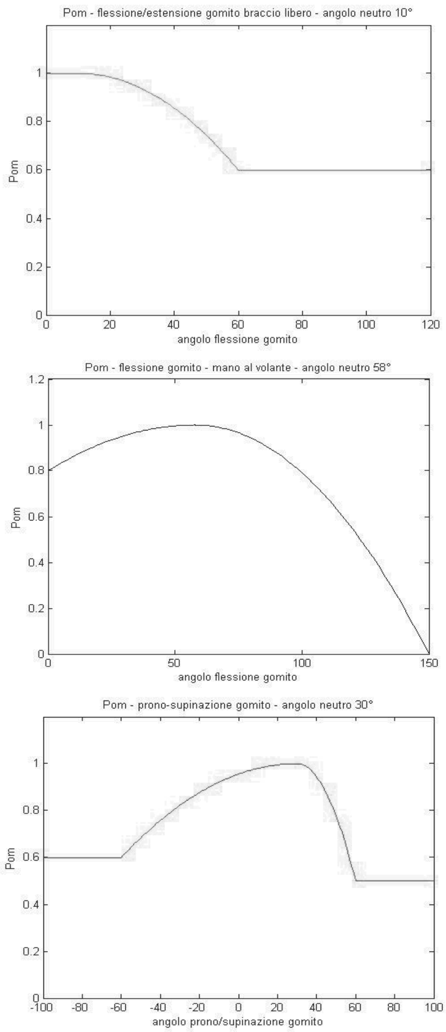

Fig. 8. Graphs of Pom factor vs. joint angle for elbow flexion (the first and second ones) and pronation-supination (the third one)

In order to have a good accordance with statistical and experimental results (generally based on jury tests), also pronation-supination movements are treated and evaluated using the OCRA Pom graph, opportunely scaled, in the worst working condition (the one that corresponds to the longest time of operation duration in the OCRA analysis).

4.3. Pom factor for wrist movements

The wrist movement has been analyzed with the same method and in the same condition of elbow pronation-supination, obtaining the following Pom factor curves (Fig. 9).

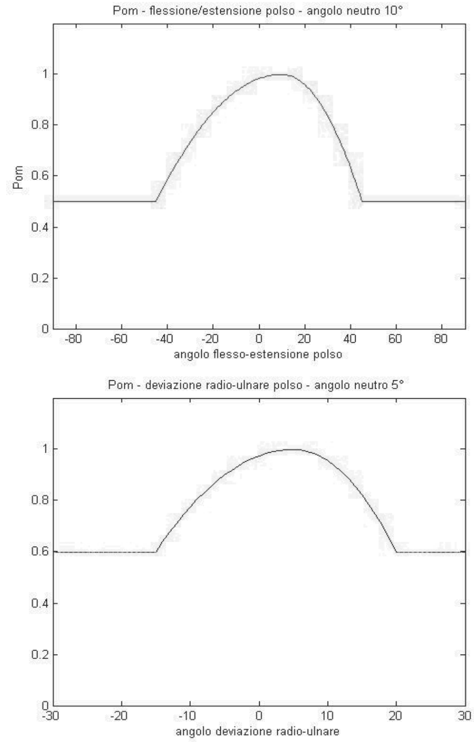

Fig. 9. Graphs of Pom factor vs. joints angle for wrist flexion/extension (the first one) and radio-ulnar deviation (the second one)

5. Applied method and results analysis

The method described in the fourth paragraph has been implemented using several virtual prototyping instruments and tested on several configurations of "driver in a car during a ride" that can be defined "homogeneous" in terms of comfort, and for which we want to check and discriminate the comfort level.

The approach used and the instruments applied are the following:

- Driver and environment modelling defined and developed using CATIA CAD (Computer Aided Design) systems by "Dassault Systemes"[4, 5];
- Driver interaction and movements defined and implemented using DELMIA DHM (Digital Human Modelling) systems by "Dassault Systemes";
- Posture configuration and joints' angles analysis using DELMIA and an automatic routine of posture parameters extraction, defined in MATLAB by ourselves [7, 11];
- Comfort evaluation made by a MATLAB routine developed by our research group and based on criteria explained in the fourth paragraph.

Table 2.
Calculated postural data

Ungeared "N"	Gearshift in Reverse	Actuation of air-conditioner	Leverage movement to first gear	Leverage movement to second gear	Leverage movement to third gear	Leverage movement to fourth gear
% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)
CN_dx(1)=15.71;	CR_dx(1)=7.67;	A_dx(1)=25.33;	C1_dx(1)=43.22;	C2_dx(1)=2.13;	C3_dx(1)=42.50;	C4_dx(1)=0;
CN_dx(2)=18.97;	CR_dx(2)=12.66;	A_dx(2)=10.50;	C1_dx(2)=15.37;	C2_dx(2)=4;	C3_dx(2)=19.18;	C4_dx(2)=5.65;
CN_dx(3)=0;	CR_dx(3)=0;	A_dx(3)=0;	C1_dx(3)=0;	C2_dx(3)=0;	C3_dx(3)=0;	C4_dx(3)=0;
CN_dx(4)=51.77;	CR_dx(4)=45.95;	A_dx(4)=62.12;	C1_dx(4)=5.78;	C2_dx(4)=65.92;	C3_dx(4)=4.96;	C4_dx(4)=74.05;
CN_dx(5)=60.30;	CR_dx(5)=77.0;	A_dx(5)=43.27;	C1_dx(5)=77.0;	C2_dx(5)=77.0;	C3_dx(5)=77.00;	C4_dx(5)=77.0;
CN_dx(6)=12.70;	CR_dx(6)=41.56;	A_dx(6)=8.36;	C1_dx(6)=17.47;	C2_dx(6)=21.80;	C3_dx(6)=24.34;	C4_dx(6)=39.67;
CN_dx(7)=15.16;	CR_dx(7)=20.02;	A_dx(7)=13.90;	C1_dx(7)=29.74;	C2_dx(7)=14.11;	C3_dx(7)=29.21;	C4_dx(7)=10.74;
% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)
CN_sx(1)=45.60;	CR_sx(1)=45.54;	A_sx(1)=45.55;	C1_sx(1)=45.6;	C2_sx(1)=45.54;	C3_sx(1)=45.54;	C4_sx(1)=45.54;
CN_sx(2)=10.93;	CR_sx(2)=11.61;	A_sx(2)=12.44;	C1_sx(2)=10.93;	C2_sx(2)=11.61;	C3_sx(2)=11.61;	C4_sx(2)=11.61;
CN_sx(3)=0;	CR_sx(3)=0;	A_sx(3)=0;	C1_sx(3)=0;	C2_sx(3)=0;	C3_sx(3)=0;	C4_sx(3)=0;
CN_sx(4)=48.85;	CR_sx(4)=48.87;	A_sx(4)=49.11;	C1_sx(4)=48.85;	C2_sx(4)=48.87;	C3_sx(4)=48.87;	C4_sx(4)=48.87;
CN_sx(5)=32.42;	CR_sx(5)=30.30;	A_sx(5)=27.86;	C1_sx(5)=32.42;	C2_sx(5)=30.30;	C3_sx(5)=30.30;	C4_sx(5)=30.30;
CN_sx(6)=11.53;	CR_sx(6)=10.77;	A_sx(6)=9.71;	C1_sx(6)=11.53;	C2_sx(6)=10.77;	C3_sx(6)=10.77;	C4_sx(6)=10.77;
CN_sx(7)=18.44;	CR_sx(7)=18.93;	A_sx(7)=19.88;	C1_sx(7)=18.44;	C2_sx(7)=18.93;	C3_sx(7)=18.93;	C4_sx(7)=18.93;
Leverage movement to fifth gear	Turning 30° Left	Turning 30° Right	Turning 20° Left	Turning 20° Right	Hands on steering-wheel	
% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)	% right arm (joint degree)	
C5_dx(1)=40.96;	SX30_dx(1)=65.34;	DX30_dx(1)=29.26;	SX20_dx(1)=57.64;	DX20_dx(1)=33.39;	R_dx(1)=43.86;	
C5_dx(2)=22.17;	SX30_dx(2)=11.51;	DX30_dx(2)=1.19;	SX20_dx(2)=12.41;	DX20_dx(2)=4.15;	R_dx(2)=10.41;	
C5_dx(3)=0;	SX30_dx(3)=0;	DX30_dx(3)=0;	SX20_dx(3)=0;	DX20_dx(3)=0;	R_dx(3)=0;	
C5_dx(4)=4.82;	SX30_dx(4)=22.83;	DX30_dx(4)=70.26;	SX20_dx(4)=33.68;	DX20_dx(4)=65.06;	R_dx(4)=51.16;	
C5_dx(5)=77.0;	SX30_dx(5)=36.46;	DX30_dx(5)=34.79;	SX20_dx(5)=36.17;	DX20_dx(5)=37.14;	R_dx(5)=36.38;	
C5_dx(6)=28.35;	SX30_dx(6)=26.73;	DX30_dx(6)=10.71;	SX20_dx(6)=21.00;	DX20_dx(6)=10.26;	R_dx(6)=13.02;	
C5_dx(7)=27.44;	SX30_dx(7)=10.97;	DX30_dx(7)=24.70;	SX20_dx(7)=13.08;	DX20_dx(7)=21.67;	R_dx(7)=17.09;	
% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)	% left arm (joint degree)	
C5_sx(1)=45.54;	SX30_sx(1)=28.26;	DX30_sx(1)=66.34;	SX20_sx(1)=33.95;	DX20_sx(1)=60.48;	R_sx(1)=45.6;	
C5_sx(2)=11.61;	SX30_sx(2)=4.58;	DX30_sx(2)=10.06;	SX20_sx(2)=8.33;	DX20_sx(2)=12.39;	R_sx(2)=10.93;	
C5_sx(3)=0;	SX30_sx(3)=0;	DX30_sx(3)=0;	SX20_sx(3)=0;	DX20_sx(3)=0;	R_sx(3)=0;	
C5_sx(4)=48.87;	SX30_sx(4)=67.53;	DX30_sx(4)=22.77;	SX20_sx(4)=59.52;	DX20_sx(4)=30.42;	R_sx(4)=48.85;	
C5_sx(5)=30.30;	SX30_sx(5)=26.88;	DX30_sx(5)=37.50;	SX20_sx(5)=25.14;	DX20_sx(5)=28.91;	R_sx(5)=32.42;	
C5_sx(6)=10.77;	SX30_sx(6)=6.07;	DX30_sx(6)=25.63;	SX20_sx(6)=8.80;	DX20_sx(6)=20.48;	R_sx(6)=11.53;	
C5_sx(7)=18.93;	SX30_sx(7)=29.74;	DX30_sx(7)=9.00;	SX20_sx(7)=27.61;	DX20_sx(7)=14.04;	R_sx(7)=18.44;	

Postures configuration (Table 2) made by using DELMIA is based on the OCRA analysis tool that takes into account several technical actions (in sequence) that the human performs interacting with his environment and with each "mechanism" that can be actuated. In this paper it is not explained the whole sequence of actions that we have taken into account; it is only important to remember that the OCRA ISO (International Standardization Organization) standards allow to characterize a movement using parameters that describe the ergonomic of a posture like the "numbers and duration of repetitive movements of the upper part of the body" [13].Those parameters are the ones described in the fourth paragraph and, obviously, are the same used in this paper to evaluate posture comfort.

In this paper we have applied our new method in the analysis of the "cycle" made by a car-driver during a city-ride.

The analysis has been conducted on postures of the upper part of the body (shoulder-elbow-wrist) during the following kind of operations: We have so configured several kinds of postures using the described table. We need to remember that OCRA method is not able to select the best posture among the proposed ones; anyway it can be used for judging the following grasps made by hand-fingers apparatus:

- Pinch with fingers
- Handbreadth pinch, with opened wide hand
- Hooked pinch

OCRA method gives an evaluation based on duration of pinch in the examined posture so the first evaluation step is the analysis of the type of pinch the driver uses. In our test-case there are only few pinches with fingers (like the movement of air-conditioning command) [15, 16, 17].

As we said before we are not interested in the ergonomic evaluation that includes time evaluation, so we have considered all the worst values (towards time duration) in the Pom tables; this choice allows us to evaluate postures' comfort independently from the time factor [18].

All the postures in which the driver has his hands on the steering wheel [19] are evaluated using modified comfort curves (as described before) [20, 21].

Arm position during gear change and air-conditioner actuation are considered like free-arm position because the comfort value epends on the trajectory followed during the approach to the leverage (or to the knob) since an instant before touching the command.

The gear change has been considered like a very short-time event so that the value of comforts comes from the postures reached after the gear-change and with free-hand (not yet abutted on the knob).

In Table 3 you can see all the angles coming from the simulation of described movements [22].

In yellow colour you can see all the values of the angles that go out from comfort ranges defined before; those postures allow us to discard the solution evaluated like not comfortable ones [20].

Table 3.
Joints angles values

SHOULDER			ELBOW		WRIST	
Flexion	Abduction	Extension	Flexion/ Estension	Pronation - supination	Radio-ulnar deviation	Flexion/ Estension
15.7100	18.9700	0	51.7700	60.3000	12.7000	15.1600
45.6000	10.9300	0	48.8500	32.4200	11.5300	18.4400
43.2200	15.3700	0	5.7800	77.0000	17.4700	29.7400
45.6000	10.9300	0	48.8500	32.4200	11.5300	18.4400
2.1300	4.0000	0	65.9200	77.0000	21.8000	14.1100
45.5400	11.6100	0	48.8700	30.3000	10.7700	18.9300
42.5000	19.1800	0	4.9600	77.0000	24.3400	29.2100
45.5400	11.6100	0	48.8700	30.3000	10.7700	18.9300
0	5.6500	0	74.0500	77.0000	39.6700	10.7400
45.5400	11.6100	0	48.8700	30.3000	10.7700	18.9300
40.9600	22.1700	0	4.8200	77.0000	28.3500	27.4400
45.5400	11.6100	0	48.8700	30.3000	10.7700	18.9300
7.6700	12.6600	0	45.9500	77.0000	41.5600	20.0200
45.5400	11.6100	0	48.8700	30.3000	10.7700	18.9300
43.8600	10.4100	0	51.1600	36.3800	13.0200	17.0900
45.6000	10.9300	0	48.8500	32.4200	11.5300	18.4400
25.3300	10.5000	0	62.1200	43.2700	8.3600	13.9000
45.5500	12.4400	0	49.1100	27.8600	9.7100	19.8800
57.6400	12.4100	0	33.6800	36.1700	21.0000	13.0800
33.9500	8.3300	0	59.5200	25.1400	8.8000	27.6100
33.3900	4.1500	0	65.0600	37.1400	10.2600	21.6700
60.4800	12.3900	0	30.4200	28.9100	20.4800	14.0400
65.3400	11.5100	0	22.8300	36.4600	26.7300	10.9700
28.2600	4.5800	0	67.5300	26.8800	6.0700	29.7400
29.2600	1.1900	0	70.2600	34.7900	10.7100	24.7000
66.3400	10.0600	0	22.7700	37.5000	25.6300	9.0000

Table 4.
Pom values

	Shoulder adbuction	Shoulder extension	Shoulder flexion	Elbow Pronation supination	Elbow Flexion extension	Wrist Flexion extension	Wrist Radio-ulnar deviation
1	0.9390	1	0.9938	0.5000	0.7208	0.9891	0.8946
2	0.9890	1	0.9976	0.9967	0.9950	0.9709	0.9242
3	0.9664	1	0.7905	0.5000	1.0000	0.8410	0.7236
4	0.9890	1	0.9976	0.9967	0.9950	0.9709	0.9242
5	1.0000	1	1.0000	0.5000	0.6000	0.9931	0.6000
6	0.9863	1	0.9976	1.0000	0.9950	0.9675	0.9408
7	0.9372	1	0.7995	0.5000	1.0000	0.8494	0.6000
8	0.9863	1	0.9976	1.0000	0.9950	0.9675	0.9408
9	0.9999	1	1.0000	0.5000	0.6000	0.9998	0.6000
10	0.9863	1	0.9976	1.0000	0.9950	0.9675	0.9408
11	0.9079	1	0.8181	0.5000	1.0000	0.8759	0.6000
12	0.9863	1	0.9976	1.0000	0.9950	0.9675	0.9408
13	0.9817	1	1.0000	0.5000	0.7932	0.9590	0.6000
14	0.9863	1	0.9976	1.0000	0.9950	0.9675	0.9408
15	0.9909	1	0.9982	0.9774	0.9972	0.9795	0.8857
16	0.9890	1	0.9976	0.9967	0.9950	0.9709	0.9242
17	0.9905	1	0.9554	0.9022	0.6000	0.9938	0.9799
18	0.9827	1	0.9976	0.9998	0.9953	0.9602	0.9606
19	0.9828	1	0.9914	0.9789	0.9648	0.9961	0.6000
20	0.9965	1	1.0000	0.9988	0.9997	0.8734	0.9743
21	1.0000	1	1.0000	0.9717	0.9941	0.9444	0.9508
22	0.9829	1	0.9894	0.9999	0.9548	0.9933	0.6000
23	0.9868	1	0.9855	0.9768	0.9265	0.9996	0.6000
24	1.0000	1	0.9945	0.9995	0.9893	0.8410	0.9980
25	1.0000	1	0.9971	0.9873	0.9822	0.9118	0.9420
26	0.9920	1	0.9846	0.9688	0.9262	0.9998	0.6000

The final comfort index has been obtained as sum of Pom factors evaluated for each posture; this approach is different from the OCRA one that takes into account only the lowest value among Pom's ones; we've not considered the product of Pom factors because this operation precludes the possibility to identify a priority way of action in order to improve the final index modifying, with accurate design review, Pom factors values [22, 23, 24].

In our test-case the maximum value for Comfort index is equal to 7 (seven) because there're seven degree of freedom whose Pom factor can reach 1 (one) as maximum value. We've used ratio between current value and maximum value in order to compare different postures and different sets of dashboards; the output value take intrinsically into account the physical behaviour of human during his seating and operating while driving [25].

In our test case we've discovered that the relevance of elbow pronation-supination value on the whole comfort result. It affect the absolute result and, consequently, the percentage result; we've also made an evaluation of postures eliminating this value from the evaluation and we've discovered that elbow pronation-supination value mainly affects the comfort of the postures taken during gear changes; the most important result is that now we can give a design-help to project-management in order to improve the car-comfort only changing, for example, the gear leverage knob, that affect the knob-handling improving significantly the elbow pronation-supination Pom and consequently the whole comfort index [23, 26, 27].

Table 5.
Comfort results

	Posture	Comfort index	Comfort Index (Pom for elbow pronation-supination=1)	% Comfort	% Comfort (without elbow pronation-supination)	% Variation
1	Right hand on gearshift ungeared	6.0373	6.5373	86.2471	93.3900	7.1429
2	Left hand on steering-wheel ungeared	6.8734	6.8767	98.1914	98.2386	0.0472
3	Right hand on gearshift in first gear	5.8215	6.3215	83.1643	90.3071	7.1428
4	Left hand on steering-wheel in first gear	6.8734	6.8767	98.1914	98.2386	0.0472
5	Right hand on gearshift in second gear	5.6931	6.1931	81.3300	88.4729	7.1429
6	Left hand on steering-wheel in second gear	6.8872	6.8872	98.3886	98.3886	0
7	Right hand on gearshift in third gear	5.6861	6.1861	81.2300	88.3729	7.1429
8	Left hand on steering-wheel in third gear	6.8872	6.8872	98.3886	98.3886	0
9	Right hand on gearshift in fourth gear	5.6997	6.1997	81.4243	88.5671	7.1428
10	Left hand on steering-wheel in fourth gear	6.8872	6.8872	98.3886	98.3886	0
11	Right hand on gearshift in fifth gear	5.7019	6.2019	81.4557	88.5986	7.1429
12	Left hand on steering-wheel in fifth gear	6.8872	6.8872	98.3886	98.3886	0
13	Right hand on gearshift in reverse gear	5.8339	6.3339	83.3414	90.4843	7.1429
14	Left hand on steering-wheel in reverse gear	6.8872	6.8872	98.3886	98.3886	0
15	Right hand on steering-wheel, no turn condition	6.8289	6.8515	97.5557	97.8786	0.3229
16	Left hand on steering-wheel, no turn condition	6.8734	6.8767	98.1914	98.2386	0.0472
17	Right hand on air conditioning command	6.4218	6.5196	91.7400	93.1371	1.3971
18	Left hand on steering-wheel while air command actuation	6.8962	6.8964	98.5171	98.5200	0.0029
19	Right hand on steering-wheel, 20° left turning	6.5140	6.5351	93.0571	93.3586	0.3015
20	Left hand on steering-wheel, 20° left turning	6.8427	6.8439	97.7529	97.7700	0.0171
21	Right hand on steering-wheel, 20° right turning	6.8610	6.8893	98.0143	98.4186	0.4043
22	Left hand on steering-wheel, 20° right turning	6.5203	6.5204	93.1471	93.1486	0.0015
23	Right hand on steering-wheel, 30°left turning	6.4752	6.4984	92.5029	92.8343	0.3314
24	Left hand on steering-wheel, 30°left turning	6.8223	6.8228	97.4614	97.4686	0.0072
25	Right hand on steering-wheel, 30° right turning	6.8204	6.8331	97.4343	97.6157	0.1814
26	Left hand on steering-wheel, 30° right turning	6.4714	6.5026	92.4486	92.8943	0.4457

Another result we've highlighted is linked to the elbow discomfort during gear change; this kind of discomfort is very well known by car-designers that often add, to car-equipment, an arm between car seats in order to allow the car-driver to abet his elbow.

The effect due to an added arm between seats is similar to the effect that the abet on the steering-wheel has on arms and wrist postures; the musculoskeletal structure, in this case, has an added abet and is not involved in sustaining the arm own weight. This result gives us another witness of good behaviour of our Comfort evaluation method [27].

6. Conclusions and future developments

In this paper we have demonstrated that also in macroscopic analysis, like the used test-case, our Comfort evaluation method works very well; it gives to designers not only a new method to choose the best posture among several proposed ones but also a powerful design solution for analyzing the critical elements of a work-environment and identifying the element to improve in order to increase the comfort of use.

We have also demonstrated that our method gives us better results than the ones given by ergonomic evaluation standards like ISO-OCRA, because those kinds of standards gives results about ergonomic analysis that are out of comfort range.

Some of those results have been experimentally verified making a numerical/experimental correlation with statistical results coming from FIAT research centre database.

Future developments will be directed towards the study of intelligent methods for weighting, in hierarchic way, the Pom factors values for different joints in order to personalize the evaluation to the application. Furthermore it's possible to introduce the time effect and to built functions like Pom = F (time) in order to completely integrate our method in OCRA evaluation procedure.

Another research will deepen the study about Pom factors curves: those curves can be optimized taking into account new designs' specification: in this paper we have, for example, modified the original Pom curves for evaluating postures in which the arms are abutted on the steering-wheel; this approach can be used in several using conditions in which a designers can imagine a worker/user could meet.

Finally we will analyze and integrate this kind of comfort evaluation with a new evaluation procedure that can take into account also cognitive aspect of ergonomic/comfort analysis; this new approach, that is well known by psychologists and communication scientists, wants to gives to designer a predictive tool for understanding something about the principles that oversee the Human Machine Interface in designing command panel of machines; today, for example, designers uses their direct experience for positioning commands on a dashboard of a car, making several choices driven only by their feel with matter. Our method comes to change this approach and objectify it.

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