Postural comfort evaluation: Experimental identification of Range of Rest Posture for human articular joints

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5 authors, including:

Nicola Cappetti
Università degli Studi di Salerno

Alessandro Naddeo
Università degli Studi di Salerno

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ORIGINAL PAPER

Postural comfort evaluation: experimental identification of Range of Rest Posture for human articular joints

Alessandro Apostolico · Nicola Cappetti · Carmine D'Oria · Alessandro Naddeo · Marco Sestri

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Abstract In this paper we introduce and describe a new concept in human-measurements operation that seems to be very useful for comfort evaluation: the Range of Rest Posture (RRP). Our study is focused on the identification of RRP -inside the comfort range of motion (CROM)—for the following human joints: neck, shoulder, elbow, wrist and ankle. Method used is based on a wide experimental work on 85 healthy individuals (43 males and 42 females) ranging in age from 20 to 30 year. The main target of this work is the experimental definition of CROM and identification of RRP; Experimental data has been processed by statistical methods for identifying the best statistical distribution in order to fit experimental data. Main result is the identification of RRP in CROM of main human joints involved in upper and lower limbs movements. In RRP weve found several maximum level of comfort positions in human postures: those position seems to be one of the most important information in comfort evaluation analysis. The state of the art about comfort/discomfort evaluation shows the need of an objective method to evaluate effect in the internal body and perceived effects in Moes (Contemporary ergonomics. Taylor & Francis, London, 2005) and Vink and Hallback (Appl Ergon 43:271–276, 2012) scheme of comfort perception; postural comfort is one of the aspect of comfort/discomfort perception and this paper helps to put a piece in the puzzle of posture evaluation. On the basis of papers results, a comfort evaluation method can be developed using RRP, CROM and building a composition rule that takes into account also lumbar comfort and H-point. Our work does not use ROM and CROM values coming from literature because each of these values has been experimentally identified.

Keywords Comfort evaluation · Rest Posture · Human joints · Range of motion

A. Apostolico · N. Cappetti (✉) · C. D'Oria · A. Naddeo · M. estri
Department of Industrial Engineering, University of Salerno,
Via Ponte don Melillo 1, 84084 Fisciano (SA), Italy
e-mail: ncappetti@unisa.it

A. Naddeo
e-mail: anaddeo@unisa.it

1 Introduction

Postural comfort can be defined as the measure of the level of well-being perceived by humans when interacting with a working environment; this level is very hard to detect and measure because its affected by individual judgments that can be analysed using quantitative/qualitative methods but always varies on articular joints angles that characterize the workers body during tasks execution.

In the past 30 years its possible to find more than 100,000 scientific papers dealing with comfort and discomfort; most of these speak about relationship between environmental factors (like temperature, humidity, applied forces etc.) that can affect the perceived comfort/discomfort [1]. Several papers follow the assumption that there is a relationship between self-reported discomfort and musculoskeletal injuries and that this injuries affect the perceived comfort [2]; However, the theories relating comfort to products and product design characteristics are rather underdeveloped; the few papers explaining the concept of comfort are Helander and Zhang [3], De Looze et al. [4], Moes [5] and Kuijt-Evers et al. [6]. A literature overview allows us to identify five main topics about the relationship between subjective perception of comfort/discomfort feeling and product/process/interaction/environment/users factors:

1. Sensory input (De Korte et al. [7] and Vink et al. [8]);

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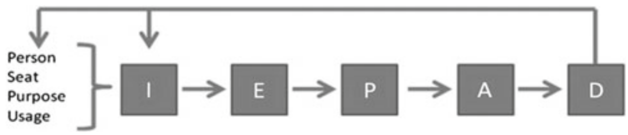

Fig. 1 Moes model of discomfort perception

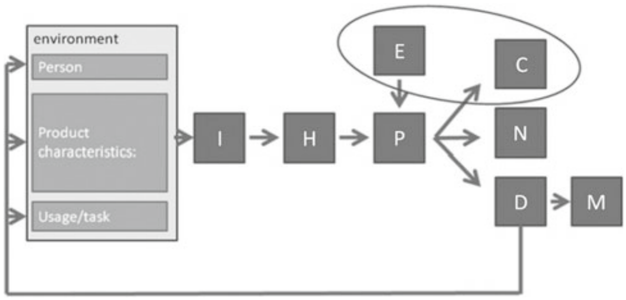

Fig. 2 Vink–Hallbeck model of comfort/discomfort perception

2. Activities during the measurement that influence comfort (Groenesteijn et al. [9], and Ellegast et al. [10]);
3. Different body regions (Franz et al. [11], and Kong et al. [12]);
4. Effect of contour of the product for the comfort experience (Kamp [13], Naddeo et al. [14] and Noro et al. [15]);
5. Physical loading (Lee et al. [16], Naddeo et al. [17] and Zenk et al. [18]).

On these basis in [6] is given an interesting schematization of the mechanism of comfort/discomfort perception that comes from the following Moes [5] model represented in Fig. 1.

In this model five phases in the process before discomfort is experienced are represented: (I)—interaction, (E)–effect in the internal body, (P)—perceived effects, (A)—appreciation of the effects and (D)–discomfort. Moes [5] also describes that this process is dependent on the person, the seat, the purpose and why the seat is used. Moes [5] describes that if a person uses a seat with a specific purpose, the interaction (I) arises. For example, this interaction can consist of the pressure distribution of the contact area between the subject and seat. An interaction results in internal body effects (E), such as tissue deformation or the compression of nerves and blood vessels. These effects can be perceived (P) and interpreted, for instance as pain. The next phase is the appreciation (A) of the perception. If these factors are not appreciated, it can lead to feelings of discomfort (D). This model has been modified by Vink and Hallbeck [19] in the following in Fig. 2.

The interaction (I) with an environment is caused by the contact (could also be a non-physical contact, like a signal in the study of De Korte et al. [7]) between the human and the product and its usage. This can result in internal human body effects (H), such as tactile sensations, body posture change and muscle activation. The perceived effects (P) are influenced by the human body effects, but also by expectations (E). These are interpreted as comfortable (C) or you feel nothing (N) or it can lead to feelings of discomfort (D).

In this model the internal body effects and the perceived effects plays a fundamental role in the comfort/discomfort perception/evaluation and the definition of maximum level of comfort (MLC) positions in human postures seems to be one of the most important tasks in this kind of comfort evaluation model [20,21] especially if based on measurement of the angular range of motion (ROM) of each joint.

Some medical studies show that each joint has its own natural Rest Posture (RP) [22,23]; in this Rest Posture human muscles are completely relaxed or at minimum strain level: when it happens the geometrical configuration corresponds to natural position of resting Arms/Legs/Neck and so on. This position seems to minimize musculoskeletal disease and optimize the comfort perception (Galinsky et al. [1])

No studies seems to deal with the problem of identification and use of RP concept in ergonomic/comfort evaluation; a 1999th paper shows an application in which is defined the neutral zero position like a parameter for calibrating a mechanical instruments for measuring the necks ROM. Other paper on comfort evaluation deals with postural configuration of Spaceman/spacewomen [24,25]: in this study authors want to investigate how the prolonged gravity absence can affect the body postural configuration in resting position; this last papers results cannot be used for our purposes.

Authors, in this paper, want to show a new method for an objective evaluation of internal body effect (such as body posture and muscle activation) and of perceived effects on several body-parts based on the use of the Range of Rest Posture (RRP). Paper target is focused on numerical/experimental method for individuation of Range of Rest Postures inside the comfort range of motion (CROM) for the following human joints: neck, shoulder, elbow, wrist and ankle; those ranges will be combined for creating a posture evaluation method useful to assess the whole comfort/discomfort perception. In this study the H-point position has not been taken into account because CROM and RRP can be defined for each human joint in independent way from H-point behaviour. In future whole-comfort evaluation method development, H-point has to be obviously taken into account.

2 Methods

2.1 Comfort range of motion

Each ROM describes the limits of variability of a human joint; authors have defined each ROM using references coming from several Orthopaedics treatises [26]. In natural human-ROM (for each joint) there is a subset of positions in which

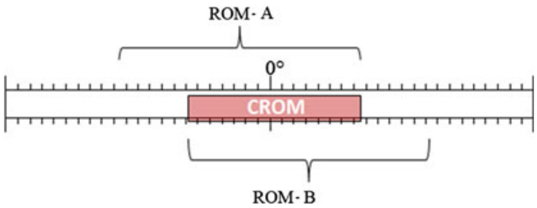

Fig. 3 Intersection between two ROMs

Fig. 4 Definition of RRP

humans feel to stay in comfort: this subset can be defined as the CROM (Fig. 3). No bibliographic sources tell us how can we determine the width of ROMs and how can we describe and identify the CROM into the ROM; this paper presents a new experimental method to check the natural human ROMs and to determine CROMs for each human joint to be taken into account for comfort evaluation.

Hypothesis made in this work is the following: for each human joint its possible to define one function that represents the articular range of motion, also if the joint shows different articular limits for different percentiles, gender or other characteristics. This hypothesis is valid when the studied postures are far from the articular limits that define the critical postures for ergonomic standards: that is our case because comfort studies take into account only the postures that give a very good ergonomic evaluation! Our study checks and defines CROM for the following human joints and their Degrees Of Freedom (DOF):

- Neck: flexion/extension, lateral flexion (bending), rotation [27,28];
- Shoulder: flexion/extension, abduction/adduction [29–35];
- Elbow: flexion/extension, pronation/supination;
- Wrist: flexion/extension, radio-ulnar deviation;
- Ankle: dorsal-plantar flexion.

For each joints DOF the CROM have been defined like intersection of all suggested comfort range in several bibliographic references [30,36].

2.2 Range of Rest Posture

As all of us know, each human, due to uniqueness of his body anatomy, feel to be in comfort in several positions but only one position is recognized by human like the Rest Posture (RP): this fact is valid for each joint we take into account and weve checked that RP is different for each human. When analyzing data coming from experimental test we have to process the identified RPs using a statistic approach in order to extract synthesized (and valid) data for the whole statistical sample. For this reason, this paper introduces a new subset of positions in which articular joints can be considered statistically in rest: Weve named this range as Range of Rest Posture (RRP) and each angular value in RRP can be considered like a maximum comfort joints angle.

Statistical analysis of acquired data is used to identify width and position of RRP in ROM (Fig. 4). This analysis starts with the experimental planning, in order to define research target and information extrapolation method and, through the choice of the size of statistical sample and the evaluation of comforting postures, ends with the identifying of the RRP. RRP have been determined starting from two kinds of postural configuration:

1. Standing human
2. Seated human

These configurations are the most probable, widespread and meaningful in Working Environment and allow us to detect several interesting data, so have been chosen for laboratories tests.

2.3 Experimental measurement of Rest Postures

The experimental tests start with the collection of anthropometric measures [37,38] that are needed to select the percentile of the human sample and to define the Rest Posture for each joint; this phase has been made using a photographic survey method and an image processing software: the first one allows to collect information about joints without the use of invasive/contact systems that, often, can limit or affect the natural positioning of the joints [2], the second one is a fast and safety method to extract and manage the acquired information.

The photographic environment, composed by a closed black-walled laboratory, a photo-camera on its tripod, a Cartesian reference System and the human that has to be photographed (Fig. 5), has been studied in order to make possible the postures acquisition both in standing and in seated position. The black wall behind the human is equipped with a scaled grid in order to have a reference for taking angles measurements; the reference system is calibrated in order to avoid and/or forecast errors due to barrel/pillow effect in photographic acquisition.

The human body, ideally made by segments whose 3D dimensions are not unimportant, has been modelled with a schematized multi-body system in which the joints are connected each other by lines segments (a segment, for example, stand for an arm). Angles have been defined between/around these lines. Information about the photographic environment is shown in the following pictures.

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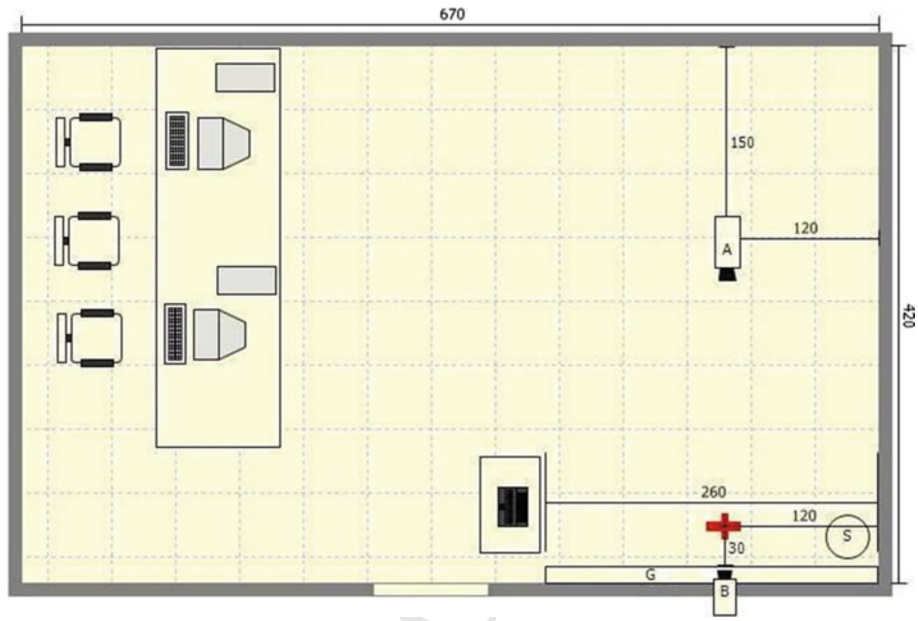

Fig. 5 Laboratory layout: *A* digital camera Samsung D60: focus height = 1.20 m on a rigid tripod that has been fixed to the ground; *B* digital Webcam Logitech: focus height = 2.20 m on a rigid tripod that has been fixed to the ground; *G*: uniform grid (2.60 m × 2.00 m), printed on a paper sheet (more than 200 g/m^2) that is rigidly linked to the wall *S*: a chair with a full-tuning seat (in height), in order to take pictures to ankles with hanging legs, with a system to make angular measurements. * human position for taking pictures in frontal and sagittal planes (Camera A) and in transverse plane (Camera B). Software used for image processing is Kinovea® release 0.8.7

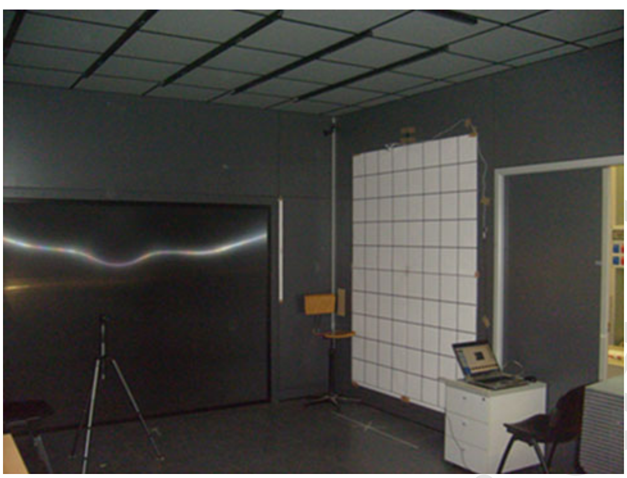

Fig. 6 Closed black-walled laboratory

The chosen statistic sample consists of 43 Men and 42 Women chosen among university students: height range of the sample: between 149 and 195 cm, age between 20 and 30 years old and absence of muscular-skeletal diseases.

Pictures taken during photographic session have been modified in order to correct the fisheye and distortion effects due to camera positioning. The calibration of corrective factor has been made by comparing the picture of the uniform grid with the same uniform grid (in Fig. 6). Subjects have been selected following the described criteria and have been trained on experimental procedure and on work targets.

In the following paragraph, the measuring procedure, the DOF involved in measurements and the photographic analysis are synthetically described. The following measurements can be taken also after the photographic session:

- Flexion/extension (A) is defined as the angle between two segments; the first one along the arm-axis and the second, in vertical direction, starting from the Humerus head.
- Abduction/adduction (B) is defined as the angle between two segments; the first along the arm-axis and the second one, in vertical direction, starting from Humerus head.

The measurement of forearm neutral position, for defining elbow articulation state, has been made starting from the zero-geometric position and asking to tester to completely relax himself.

2.3.1 Shoulder

The shoulder articular joint (Fig. 7), whose DOF are linked to arms movements, can be easily checked and measured in Rest Posture simply by positioning of the arm (left and right) along the body (thorax) near the geometric-zero position and asking to tester to completely relax him: in this position the picture is taken. The same procedure works well for both RP of the arm, simply changing the photographic plane.

In order to measure the angle, those reference points have to be taken:

- Humerus head has to be identified as the centre of the circle defined by three points opportunely taken (positioned) on the shoulder;
- Elbow centre is the ideal centre of the sphere identified by four points (not aligned and not belonging to the same plane) opportunely taken on the elbow;

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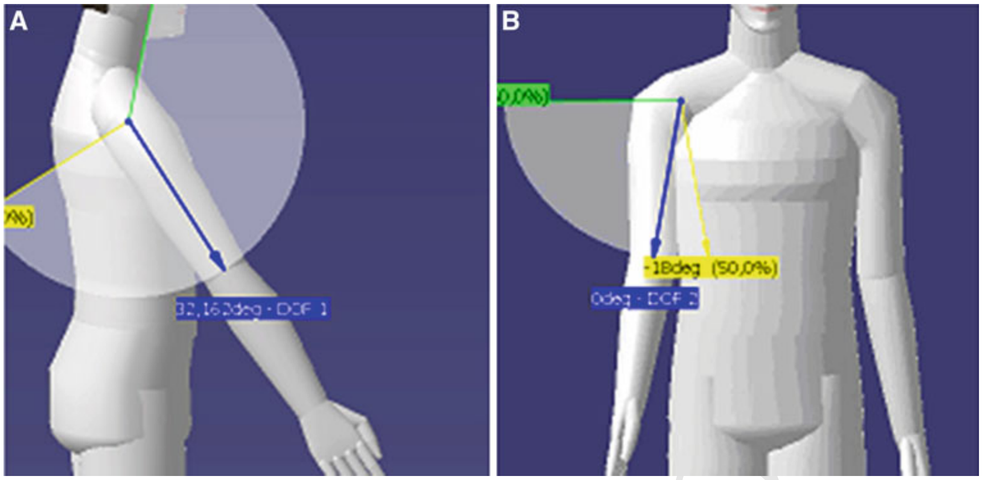

Fig. 7 Shoulder D.O.F.

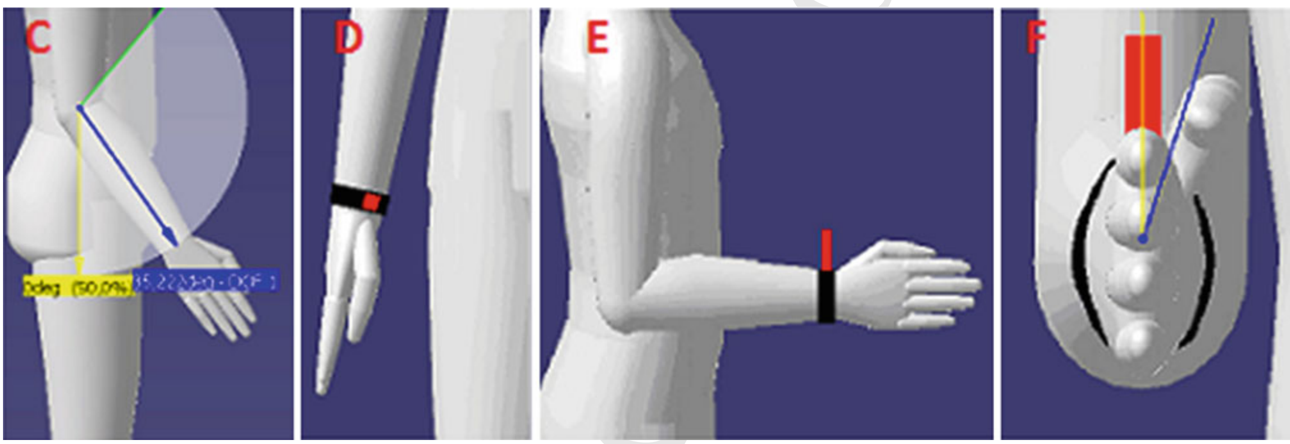

Fig. 8 Elbow D.O.F.

- Wrist centre is the ideal centre of the sphere identified by four points (not aligned and not belonging to the same plane) opportunely taken on the wrist;
- Ankle centre it has to be identified as the centre of the circle defined by three points opportunely taken (positioned) on the ankle;
- Head centre is the ideal centre of the sphere approximating the skull bones.

2.3.2 Elbow

The elbow joint is interested by two kinds of measurement (Fig. 8):

- Flexion/extension (C) is defined as the angle between two segments: the first oriented along the line passing through the Humerus head and the centre of the elbow, the second one is oriented along the arms axis and passes through the centre of the elbow;
- Pronation-supination (D-E-F): the definition of this ROM is more difficult because we have to help us blocking a bracelet on the wrist of the tester with a rigid pin linked on it parallel to thumbs-up position. The calibration of this measure has to be made as follows: the pin has to be orthogonal to the frontal plane when the arm is in geometric zero position; after that we asked to tester to completely relax his arm: during relaxation all testers naturally rotate the wrist around its axis (arm axis). Nevertheless, in this position its impossible to capture a picture for measuring the rotation; in order to override this problem weve imposed, through a passive guided motion (PROM), the 90° rotation of the arm around the elbow articular joint. In this configuration the measure can be taken with a single picture.

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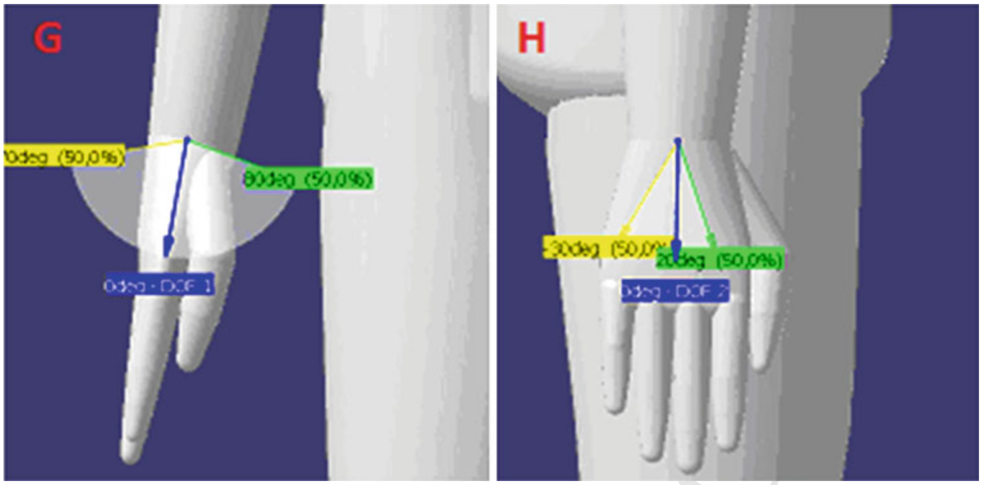

Fig. 9 Wrist D.O.F.

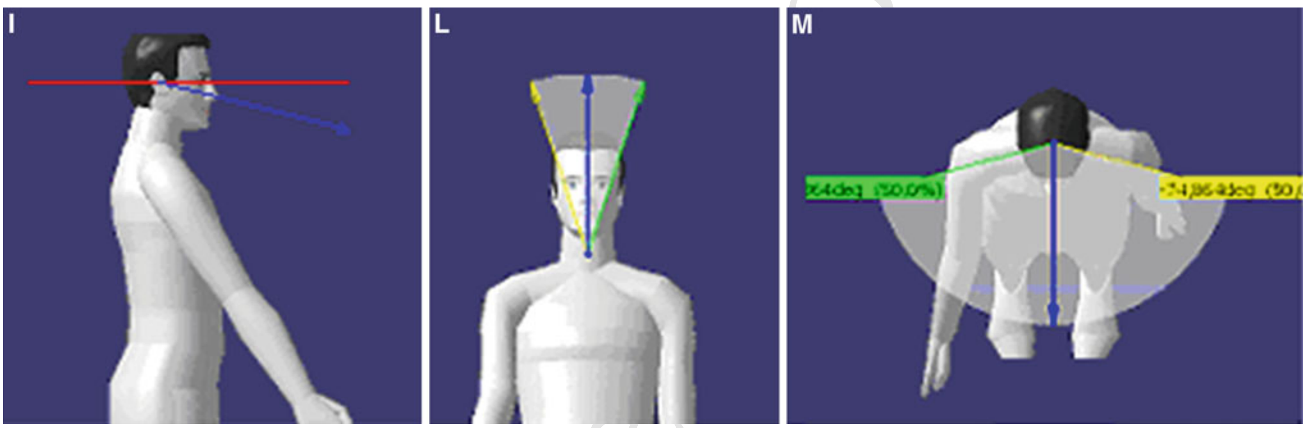

Fig. 10 Neck D.O.F.

2.3.3 *Hand*

The Rest Posture of the hand (Fig. 9) has been characterized by using RRP for Wrist, Flexion-Extension and Radio-Ulnar Deviation, as following:

- Flexion-Extension (G) is defined as the angle between two segments: the first oriented along the prolongation of arm-axis and the second one is oriented along a line passing through the thumbs base and the first phalanx of the index finger in straight position.
- Radio-Ulnar deviation (H) is defined as the angle between the prolongation of the arm-axis and a second segment along a line that passes through the centre of the wrist and the conjunction point between the middle finger and the ring finger on the metacarpal bone.

In experimental analysis weve noticed a particular behaviour of the hands: the gravity force affects significantly the hand position by conditioning the position of wrist articular joint: for this reason, in this case, the zero-geometric position is coincident with Rest Posture.

2.3.4 *Neck*

Neck articular joint (Fig. 10), and its three RP, can be measured in the same way of the other joints simply asking to tester to close his eyes and relax himself. This condition gives us a warranty towards the tester behaviour so that his position is not affected by external reference point or, instinctively by environment factors. RP are defined as follows:

- Flexion/Extension (I) is defined as the angle between the horizontal plane (parallel to ground) passing through the centres of the hears (under the hypothesis of head symmetry) and a plane defined by three point: the same two hears centres and the nose base. We have to say that this is the only parameters weve defined using a method different from what posturologists suggest: this choice has

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been made because of the easiness in defining the angle using pictures taken by one camera.

- Lateral flexion (L) is the angle defined between two segments: the first is a vertical line passing through the centre point between the scapulas while the second one is a line passing through the same centre and the centre point between eyes.
- Rotation (M) is defined as the angle between the segment defined through the Humerus heads and a segment passing through the rotation centre of the neck and the nose base, projected on the ground plane.

2.3.5 Ankle

For ankle joint measurement in Rest Posture (Fig. 11), weve seated the tester on a chair in a way so that his foots were hanged.

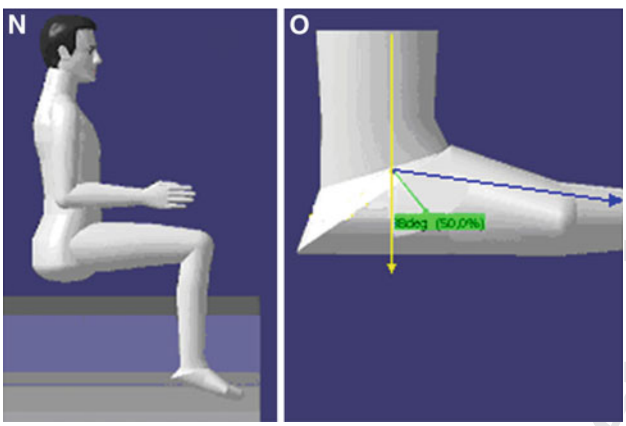

Fig. 11 Ankle D.O.F.

- The Dorsal-Plantar flexion (N-O) is defined as the angle between two segments: the first one is on a line passing through the centre of the knee (under the posterior ligament) and the malleolus while the second one is defined along a line passing through the same centre of malleolus and the median point between second and third metatarsus.

In Fig. 12 several pictures, used to angles measurements, are shown.

3 Results

3.1 Elaboration of statistical data

Data acquired in experimental phase have been organized on the basis of tester characteristics (gender, percentile, and so on) and by articular joints D.O.F.; after that they have been processed using statistical techniques. Using inferential instruments, a continue distribution function has been individuated for tester population for each articular joints D.O.F. [40]; In the following paragraph the procedure that has been applied for the pronation-supination of womens elbow analysis is described. All articular joints data have been processed in the same way.

Collected data has been analyzed in order to choose the best probability distribution for representing them (among Normal, Weibull and Lognormal); for this kind of collected data its easy to understand that the best distribution to choose is the 3-parameter Weibull one. The following Table 1 and Figs. 13, 14, 15 show an example of that.

Fig. 12 Angle measurements for man

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Table 1 Prono-supination of womens elbow

Range	Frequency
−51.0 to −42.2	2
−42.1 to −33.3	1
−33.3 to −24.5	5
−24.5 to −15.7	19
−15.7 to −6.8	10
−6.8 to 2	5

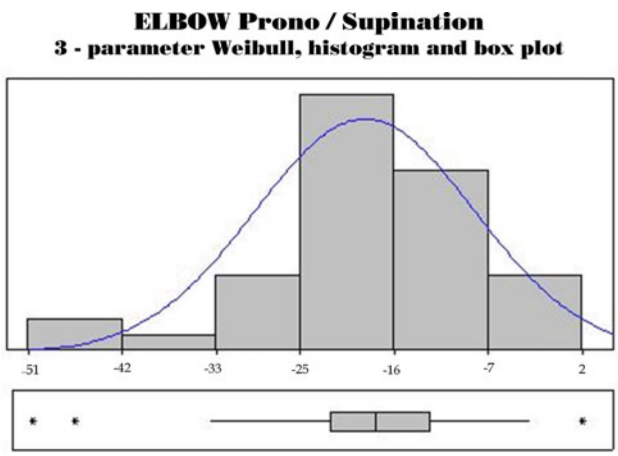

Fig. 13 Box plot

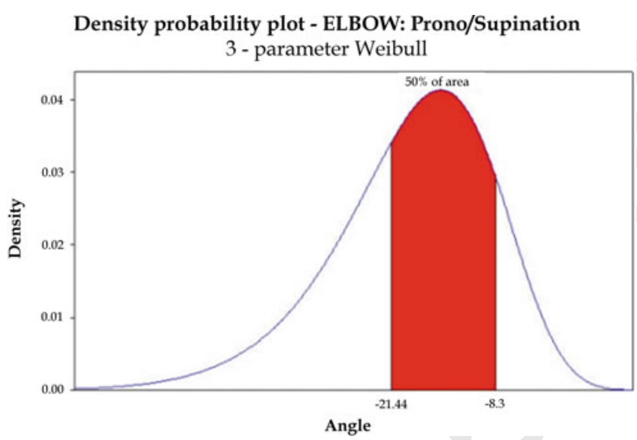

Fig. 14 Density probability plot

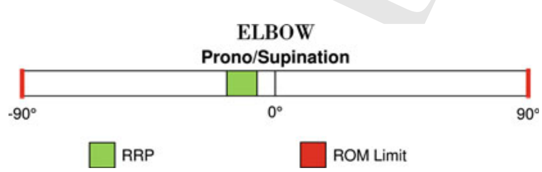

Fig. 15 Summary of results

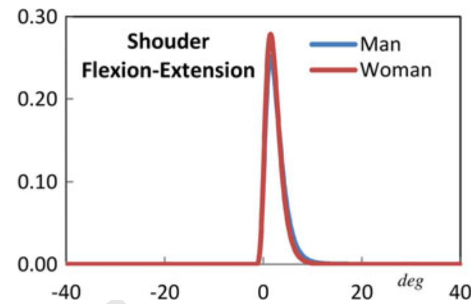

Fig. 16 Distribution of shoulder flexion-extension Rest Posture

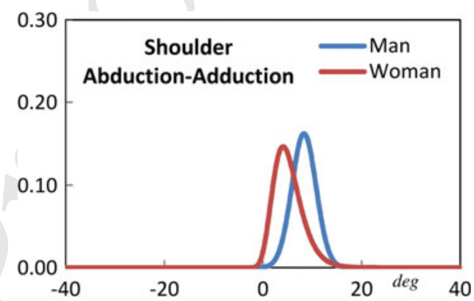

Fig. 17 Distribution of shoulder abduction-adduction Rest Posture

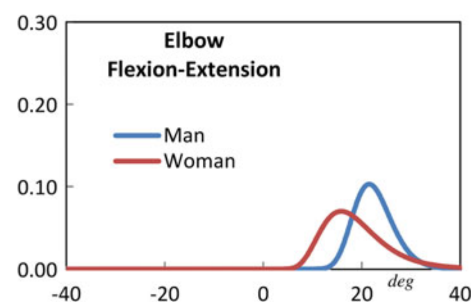

Fig. 18 Distribution of elbow flexion-extension Rest Posture

Using the chosen statistical distribution its possible to define a values range, into the main range weve defined (ROM), in which we consider that the articular joint is in Rest-posture; weve chosen this range, that weve defined as Range of Rest Posture (RRP), as the domain for which the area (centered on the mode value—see the previous images) under the Weibull curve is about 50 % of the total Weibull area. The same analysis made for the female-elbow articular joint has been made for all the studied articular joints, using, for each of them, the best statistical distribution (Figs. 16, 17, 18, 19, 20, 21, 22, 23) to define the RRP.

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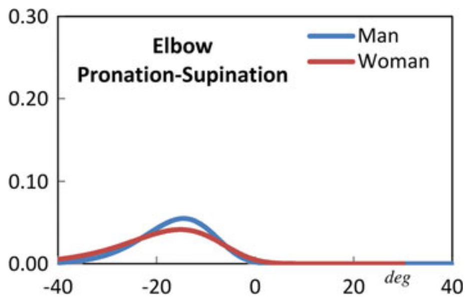

Fig. 19 Distribution of elbow prono-supination Rest Posture

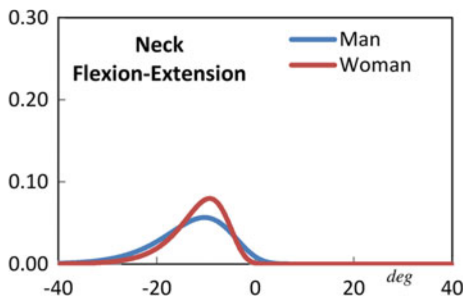

Fig. 20 Distribution of neck flexion-extension Rest Posture

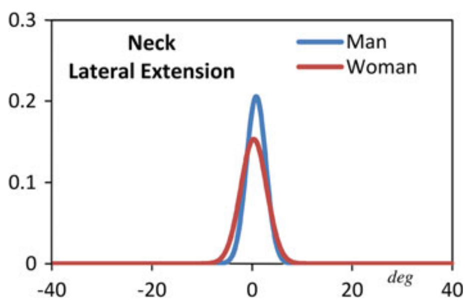

Fig. 21 Distribution of neck lateral extension Rest Posture

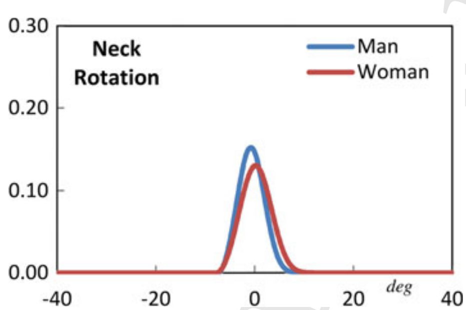

Fig. 22 Distribution of neck rotation Rest Posture

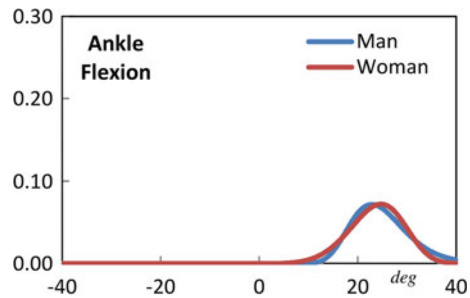

Fig. 23 Distribution of ankle flexion Rest Posture

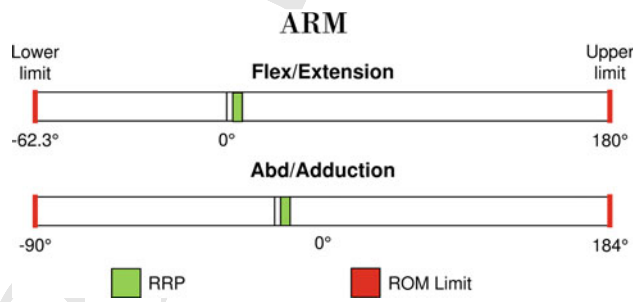

Fig. 24 Shoulder RRP and CROM

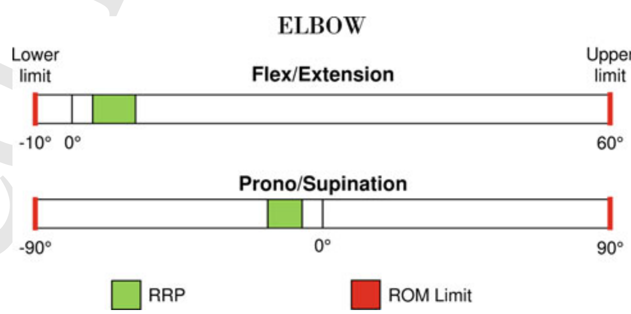

Fig. 25 Elbow RRP and CROM

4 Discussion

Some parameters like shoulder abduction/adduction RRP are well modeled by asymmetric curves because the Rest Posture is strongly affected by gravity force (due to arms own weight) and by nearness of the arm to the body. The same behavior has been found in articular joints whose Rest Posture is affected by the body-part weight. The counter-proof is given by the neck behavior whose RRP has the shape of a Gaussian curve with the mean centered in a value coincident with mode and median.

All statistical distributions, representing the behavior of the articular joints, respect what suggested by posturologists.

Interesting information given by this experimental analysis is that no differences can be highlighted between male and female behaviors. This discovered behavior can allow us to define just one RRP for each joints DOF for the whole statistical sample giving also the limits to the ROM for the entire population. ROM is defined as the intersection of all Ranges of Motion acquired on testers. In the following Figs. 24, 25, 26, 27, and 28 you can find a review of ROM and RRP.

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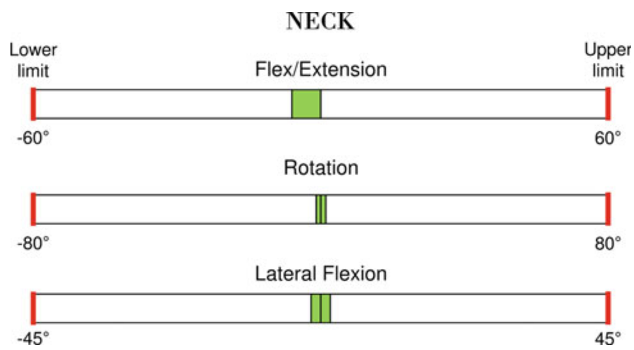

Fig. 26 Neck RRP and CROM

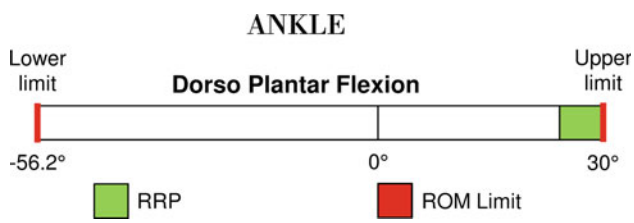

Fig. 27 Ankle RRP and CROM

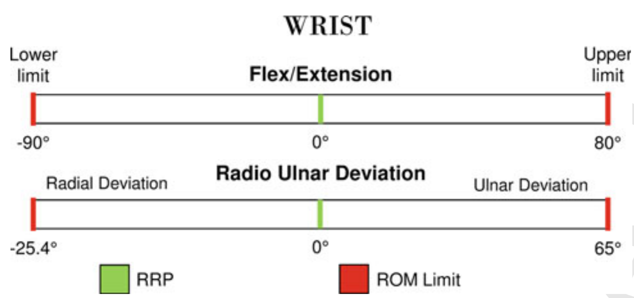

Fig. 28 Wrist RRP and CROM

At this stage of our research activity weve investigated only postures that involve human in seated position and in standing position without loads applied. In these positions H-point doesn't affect the Joints behavior so that it has not been taken into account. At this stage of the research no rules for combining joints comfort values has been implemented. Even if the development of an evaluation rule seems to be necessary for industrial application, authors want deeply investigate how to compose joints evaluation for different industrial applications There are some parameters that are not affected by positioning the human body in standing or in seated position i.e. the neck parameters while other parameters are strongly affected by positioning of the human body like shoulders or legs Rest Posture!

Another investigation that has to be done is the rest-posture evaluation in condition for which one or more body-parts are rest on supports (like an elbow on a table or a wrist on a mouse!); those configurations can be studied like a free limbs configuration modified with a penalty/prizing functions to modify the comfort level.

The last investigation that has to be done is the comfort level changes between a free limbs configuration and an under-loads limbs configuration. These postures are affected by equilibrium problem (due to changing in Center of gravity of the limbs) and by a force factor (related to muscular-skeleton fatigue).

5 Conclusion

The main result of this work is a new approach to determine, for several articular joints, the postural ranges in which the comfort reaches the better value. Another very interesting result is the determination of the exact angular ranges corresponding to Rest Postures (as statistically defined). This results find their utility in the modified Moes model [19] for analyzing internal body effects and the perceived effects because seems to be the first attempt to objectivise the human joints comfort performance without using EMG [16–18,20–42] or other experimental methods like [43–45].

Several papers like [17,43] and [46] deal with studies about ranges of motion but this paper is the first in which the new concept of Range of Rest Posture is introduced and can be used to evaluate Human Joints Comfort. In fact, comfort curves have been obtained starting from a wide references study, whose information has been used to define articular joints CROM by posturologists and medical data, and conducting a complicated experimental phase. The experimental tests have been made on two different statistical samples, so wide that the acquired data cannot be affected by unforeseeable and illogical errors. After that, acquired data have been processed by statistical inference instruments in order to obtain continuous curve describing the probability distribution of the Rest Posture in a wide statistical sample of humans whose age is between 20 and 40 years old. Using these curves weve extracted some characteristic data like the mode and the area distribution under the curve. Then weve selected a sample for which 50 % of data are distributed around the mode value: this approach allowed us to eliminate out of statistic data (potentially not significant). Range of Rest Posture (RRP), like defined in the paper, can be very useful to define and evaluate maximum comfort postures in several work-tasks in which upper and lower limbs are involved; those tasks will be useful also to identify postures whose comfort level is too low. This comfort-check can be used, for example, for re-design the work-tasks or the work-spaces in order to improve comfort values. This application seems to be the most powerful for the described and implemented method.

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