Method for Movement and Gesture Assessment (MMGA) in Ergonomics

Giuseppe Andreoni , Marco Mazzola, Oriana Ciani, Marta Zambetti, Maximiliano Romero, Fiammetta Costa, and Ezio Preatoni

Politecnico di Milano, INDACO Dept., via Durando 38/A,
20158 Milan, Italy
{giuseppe.andreoni,marco.mazzola,oriana.ciani,marta.zambetti,
maximiliano.romero,fiammetta.costa,ezio.preatoni}@polimi.it

Abstract. We present a technique for the ergonomic assessment of motor tasks and postures. It is based on movement analysis and it integrates the perceived discomfort scores for joints motions and the time involvement of the different body districts. It was tested on 8 subjects performing reaching movements. The experimental protocol was designed to have an *a priori* expected comfort ranking, namely, higher values in presence of more uncomfortable tasks. The validation of the Method for Movement and Gesture Assessment (MMGA) in the ergonomic evaluation of a reaching task gave promising results and showed the effectiveness of the index. Possible applications of the method might be the integration into CAD tools and human motion simulation to provide an early comparative evaluation of the ergonomics of the prototyping process and workplace redesign in industry.

Keywords: Proactive Ergonomics, Ergonomic Index, Movement and Posture Analysis, Occupational Biomechanics, Assessment technique; Joint discomfort.

1 Introduction

Researches on the comfort/discomfort assessment of work-spaces and work-tasks is largely present in ergonomics literature [1]. Over the past 30 years, a significant number of methods, whose aim is to improve the ergonomic assessment, have been published. A short list of these tools would include: QEC, manTRA, RULA, REBA, HAL-TLV, OWAS, LUBA, OCRA, Strain Index, SNOOK tables and the NIOSH lifting equation [2]. They can be roughly classified into two main categories: qualitative and quantitative methods. Among the latter, OWAS [3], PATH [4], and RULA [5] indexes are probably the most cited and applied, together with the revised NIOSH equation for manual lifting [2].

The Rapid Upper Limb Assessment (RULA) has been developed for the ergonomic evaluation of workplaces. It consists in reporting disorders/troubles that are related to upper limbs. The RULA assessment is based on the observation of the postures that are adopted whilst undertaking the tasks. Depending on the aim of the analysis, this index considers either the posture that is maintained for the longest time or the one that appears the worst (in biomechanical and ergonomic sense) among all

V.G. Duffy (Ed.): Digital Human Modeling, HCII 2009, LNCS 5620, pp. 591–598, 2009.

the adopted. After recording and scoring the single posture(s) the final score is obtained by adding the single contributions; then it can be compared to the Action Level List that provides a guide for further action for the improvement of the ergonomics of the analysised work situation.

The problem of a quantitative assessment of postural stress and load was recently faced by Kee and Karwowski [6]. They proposed the " postural loading on the upper body assessment" (LUBA), which refers to a dataset of perceived discomfort scores (ratio values) for a set of joint motions. They defined a composite index that accounts for the hand, arm, neck and back joints and the corresponding maximum holding times in static postures. The postural classification scheme they developed was based on the angular deviation of each joint from the neutral position. Articular angles were assigned to different classes and were given a score of discomfort through a statistical approach. The score of each class was normalized to the perceived discomfort value of elbow flexion, which exhibited the lowest level among all joint motions and, therefore, was set as a reference point. Four distinct action categories were considered for fixing evaluation criteria concerning stresses of working postures, and for providing practitioners with proper corrective interventions. The proposed method may be used for evaluating and redesigning static working postures in industry. Nevertheless it does not provide information about the discomfort level of the whole body and it refers to a quantification of a qualitative analysis of human posture.

The aim of this work was to develop a new method of classification of comfort/discomfort, concerning the whole body movements. This method started from the LUBA approach, and defined an innovative index that combined the joint kinematics with a joint discomfort function "weighted" on the masses of the body areas participating in the movement.

2 Materials and Methods

We propose a new method for quantifying the ergonomics of working tasks based on the kinematics of the executed movement. This method is based on the measurement of the joint motion, and, consequently, on the availability of proper technologies, such as: optoelectronic systems for motion analysis; a set of electro-goniometers; a stereo video-recording and a dedicated software for further data processing. The starting point for the ergonomic index computation is the body kinematics, which is expressed as joint angles through a biomechanical model (as in the case of motion analysis systems or video-recording techniques), or through direct measure (as in the case of the already mentioned electro-goniometers).

The Method for Movement and Gesture Assessment (MMGA) index comes from the composition of three factors: a) the joints kinematics, b) an articular coefficient of discomfort for each joint, c) a coefficient estimating the "weight" of the ergonomic contribution of each joint to the movement.

For the lower limb we applied an upper-limb corresponding scale, weighted on the mass of the lower-limb portion involved.

a) Joint kinematics. Joint kinematics ($\alpha(t)$) was measured through the Vicon Motion Analysis System mod. 460 (Vicon Motion Systems Ltd, Oxford, UK), equipped with 6 M series tv-cameras whose sampling rate was 120 Hz. The tv-cameras were placed all-round the subject at 2,20 mt in height.. The standard Vicon Plug-in-Gait marker set was used implementing a total body biomechanical model with 33 reflective markers. Anthropometric measures and dedicated algorithms were used to estimate and filter 3D coordinates of internal joint centres and joint angles. The following variables were considered for this study: wrist, elbow, knee and ankle flex-extension; shoulder and hip flex-extension, intra-extra rotation and abd-adduction; trunk flex-extension, rotation and lateral bending. Each movement was time-normalised to 100 points, independently from the actual duration, to allow intra- and inter-subject comparisons.

b) Discomfort score. The coefficient of discomfort (φ) for each *j*-th joint at time *t*, $\varphi_j(\alpha(t))$, was computed through a spline fitting of the discomfort ranks derived from the LUBA method (Fig. 1) along the joint range of motion estimated from anthropometric dataset [7].

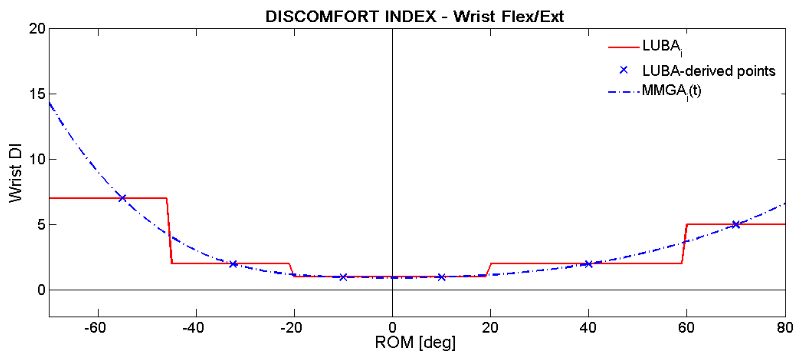

Fig. 1. Example of definition of the coefficient of discomfort concerning the wrist flex-extension angle. At each joint angle $\alpha(t)$, corresponds a discomfort score $\varphi(\alpha(t))$.

c) Body normalization. According to the data from Zatsiorsky and Seluyanov [8], the comfort index of each joint was assigned a percentage ergonomic contribution (∂_j), which was proportional to the mass of the single *j*-th distal body district (for the *j*-th joint) participating in the movement.

To resume:

$$\text{MMGA}(t) = \sum \varphi_j(\alpha(t)) \times \partial_j \tag{1}$$

and after time-integration:

$$\text{MMGA} = \sum_t MMGA(t) \tag{2}$$

with t = 1, …, 100, for the whole task.

Subjects. 8 subjects participated in the preliminary study for the evaluation of the MMGA index. Their main characteristics are reported in table 1. All the subjects were volunteers, chosen among healthy undergraduate students or researchers. A preference was given to the balance between male/female number and to height distribution. So we chose to have as many different conditions as possible to test the method sensitivity and effectiveness

Table 1. The characteristics of the subjects participating in the research

Subject ID	Sex	Height (cm)	Weight (kg)	Dexterity (R/L)
S1	M	190	90	R
S2	F	170	56	R
S3	F	155	50	R
S4	M	167	62	R
S5	F	166	52	R
S6	M	178	68	R
S7	M	181	80	L
S8	F	171	60	L

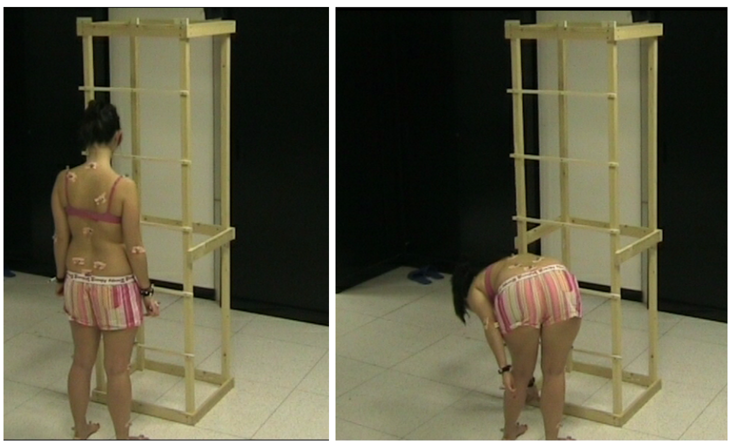

Fig. 2. An example of the experimental setup. The initial (on the left side) and final (on the right side) postures of a subject reaching the lowest point on the left column of the grid. The adopted motor strategy (trunk flexion and torsion with legs kept extended) should be noticed.

Experimental setup. The subjects were asked to reach 21 points on a firm surface structured in a 3D grid of 7 rows (row inter-distance: 30 cm) by 3 columns (columns inter-distance: 30 cm). They were asked to align their lateral malleoli to a reference line and to keep their feet in that position throughout the reaching sequence. The line was subsequently set at 2 distances from the grid: the first was customized on each subject's leading forearm length; the second was 40 cm farther. This mock-up allowed us to reproduce the most part of the reaching tasks experimented in the real life during interaction with products and environment. The extent of the movement at different levels of height and depth was coherent with an expected rank of difficulty reflecting a better (or poorer) ergonomic condition. Each subject repeated the sequence of reaching movements three times. No indication about the motor strategy to be followed was given. All the trials were processed to verify intra-subject repeatability. The best trial in terms of quality of data (all markers always visible and correctly reconstructed in the 3D space) was selected for the computation of kinematic parameters (i.e. joint angles) and of the MMGA index representative for that subject and that movement.

3 Results

The tasks evaluation provided a discomfort classification of the man-product interaction. This was expressed in term of reaching comfort as expected by the experimental design. Comfort scores appeared coherent with the difficulty level designed *a priori* for the different conditions (Fig. 1).

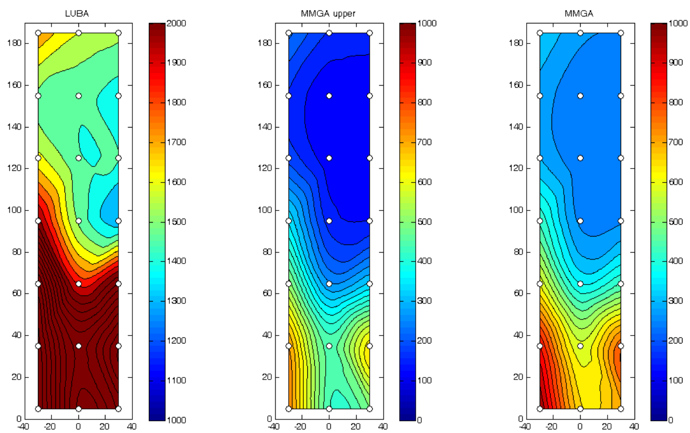

Fig. 3. The ergonomic assessment of the reaching tasks (21 points, one subject) according to the LUBA index (*left*), the MMGA index excluding the lower limbs (*center*), and the complete MMGA index (*right*). Isolevel lines of comfort are dysplayed. Note that colors for LUBA and MMGA have a different scale, due to the different magnitude of indexes.

For a better understanding of the differences between the two mehods, we implemented a dedicated Matlab© (The MathWorks, Inc.) routine for comparing the MMGA index with respect to the LUBA index (Fig. 3). We chose to adopt a visual representation of iso-comfort lines in the reaching plane. We compared the LUBA index to the MMGA index both in its complete formulation and excluding the lower limbs (as in the LUBA method).

At a first glance a good accordance is shown, even if there is a significant offset (more than 1000 points) between the magnitude of the indexes from the two methods. LUBA appears significantly higher. This may be the consequence of the very "rough" steps that LUBA draws in assigning ergonomic scores to articular ranges.

The implementation of the lower limb contribution in the MMGA method makes it more complete.

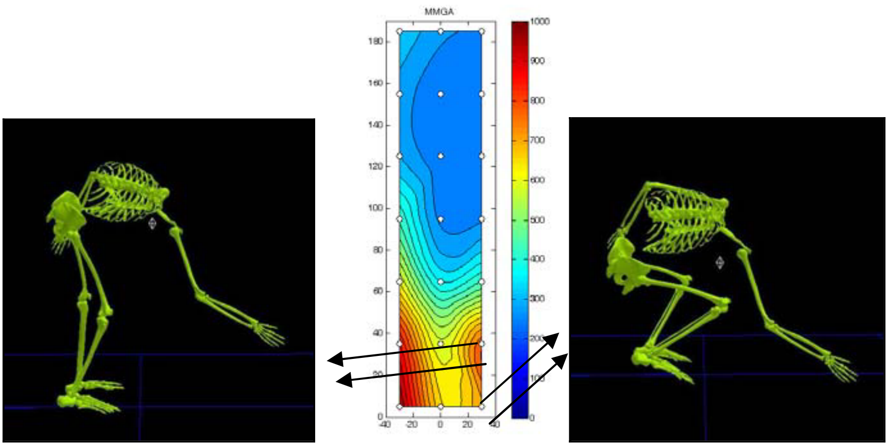

Fig. 4. Example of the capability of the MMGA method to detect changes in motor strategies that reflect different ergonomic conditions. MMGA values (*center*), and the final postures in reaching 2 near points but with change in the strategy of lower limbs movement (*left* and *right*).

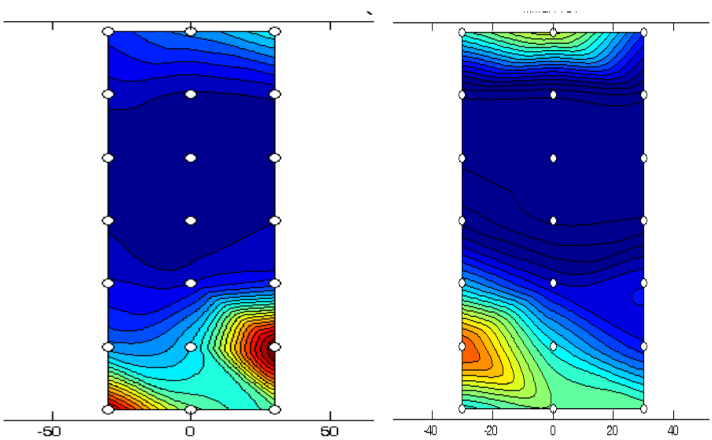

Fig. 5. Example of the results of the MMGA index for a right-handed subject (*left*) and a left-handed subject (*right*). The symmetrical behaviors reflect each own dexterity.

Moreover it allows for a better and resolute discrimination of ergonomic motor strategies. For instance Fig. 4 presents the MMGA scores together with the representation of the subject's movement (final postures, shown through the biomechanical model adopted) .

The fine resolution of the MMGA methods may be appreciated. It appeared able to differentiate between critical ergonomic conditions even though the actual environmental and task conditions were very similar. In the above mentioned case the passage from the 6^{th} to the 7^{th} row determined a change in the kinematic strategy adopted by the subject. Namely, he/she turned from a more "correct" knee-flexion strategy used in reaching the lowest point, to the more ergonomically critical one, characterised by extended legs and increased trunk flexion.

Furthermore, it was possible to discriminate the dexterity of the subject by simply observing the graphical results (Fig. 5).

4 Conclusion

The goal of a well-designed assessment tool is: (i) to consider the information that has been gained through research concerning the causes and the impact of strain on the human system; (ii) to organize surveys to assess and predict if and when this strain is reaching hazardous levels and may thus induce work-related musculoskeletal disorders. The MMGA index aims to provide a quantitative value for the ergonomic ranking of motor tasks. It combines information about joints' kinematics, articular comfort ranges and body parts involvement during the subject's interaction with environment and products.

The MMGA index provides a complete assessment also for lower limbs that the LUBA analysis doesn't include. When considering only the same body districts for both indexes, with respect to the LUBA index a good correspondence is shown for the MMGA score.

The method does not provide an absolute evaluation of the comfort/discomfort score for a general environment yet, however it works in comparative analysis between similar but competitive conditions (comparison among two or more situations or products whose one is assumed as reference).

The MMGA index has proved to differentiate the comfort level of easy tasks providing a coherent ergonomical ranking of movements; e.g. in the ergonomic assessment of tasks related to usability (such as opening and closing the upper doors of the white goods likes refrigerators) it presented the worst MMGA index values for tasks supposed to be less comfortable, such as the interaction with the higher and the lower part of the fridge.

The data from the MMGA index currently relate to a quantitative computation of the joints motion captured on real subjects but it might be integrated into a human motion simulation software for implementing proactive ergonomic analysis in the virtual prototyping process.

Acknowledgments. This work was supported by a grant from Fondazione Politecnico di Milano and Indesit Company S.p.A..

References

1. David, G.C.: Correcting Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. Occupational Medicine 55, 190–199 (2005)
2. Waters, T., Putz-Anderson, V., Garg, A., Fine, L.: Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36, 749–766 (1993)
3. Karhu, O., Kansi, P., Kuorinka, I.: Correcting working postures in industry: a practical method for analysis. Applied Ergonomics 8(4), 199–201 (1977)

4. Buchholz, B., Paquet, V., Punnett, L., Lee, D., Moir, S.M.: PATH: A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. Applied Ergonomics 26(3), 177–187 (1996)
5. McAtamney, L., Corlett, E.N.: RULA: a survey method for the investigation of work-related upper limb disorders. Applied Ergonomics 24(2), 91–99 (1993)
6. Kee, D., Karwowski, W.: LUBA: an assessment technique for postural loading on the upper body based on joint motion discomfort and maximum holding time. Applied Ergonomics 32(4), 357–366 (2001)
7. Tilley, A.: The measure of man and Woman. In: Bema (ed.), Milano, Italy (1993)
8. Zatsiorsky, V., Seluyanov, V.: The mass and inertia characteristics of the main segments of the human body. In: Matsui, H., Kobayashi, K. (eds.) Biomechanics VIII-B, International series of Biomechanics, vol. 4B, pp. 1152–1159. Human Kinetics Publishers, Champaign (1983)