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Proposal of a new quantitative method for postural comfort evaluation

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ABSTRACT

In Human–Machine Interface (HMI) design, several parameters have to be correctly evaluated in order to guarantee a good level of safety and well-being of users (humans) and to avoid health problems like muscular-skeletal disease. ISO Standards give us a good reference on Ergonomics and Comfort: ISO 11228 regulation; it deals with qualitative/quantitative parameters for evaluating Postural Ergonomics, using a "Postural Load Index", in push/pull, in manual loads' lifting and carrying and in repetitive actions; those parameters can represent the Ergonomics level of examined posture. While bibliographic references suggest different methods to make ergonomic evaluation like RULA, LUBA and REBA, 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 several schemes of comfort perception like Moes', Vink & Hallback's and Naddeo & Cappetti's ones; postural comfort is one of the aspect of comfort/discomfort perception and this paper proposes a new quantitative method for evaluating this aspect of comfort, based on anthropometric parameters and upper limbs posture. The target of this paper is to present and test a "general purpose" method of comfort-measurement that can be applied to different industrial cases: in workspace environments, in automotive passenger compartments, in aeronautic cockpit or in industrial assembly lines.

Relevance to industry: The method presented in this paper may allow industrial designers to provide an assessment of products' perceived comfort in the early stage of the product development process by making a posture-based quantitative evaluation; it also allows designers to make a comfort driven redesign of existing products' configuration for improving and innovating them.

1. Introduction and state of the art

In Human–Machine Interface (HMI) design, several parameters have to be correctly evaluated in order to guarantee a good level of safety and well-being of users (humans) and to avoid health problems like muscular-skeletal disease.

ISO 11228 is the only ISO Standard that can give us a good reference on ergonomics and comfort evaluation and its parameters can be synthesized in a "Postural Load Index" that represents the Ergonomics level of examined posture (Annarumma et al., 2008; Naddeo et al., 2010) but does not give us information about the perceived well-being.

Bibliographic references suggest methods like Rapid Upper Limb Assessment (RULA – McAtamney and Corlett, 1993), Rapid Entire Body Assessment (REBA – Hignett and McAtamney, 2000) and Loading of the Upper Body Assessment (LUBA – Kee and Karwowski, 2001) to perform ergonomic analyses that go by measurement of anthropometric parameters. 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 it is affected by individual judgments that can be analysed using quantitative/qualitative methods.

Over the past 30 years, we can find a lot of paper dealing with comfort and discomfort; the majority have tried to demonstrate and quantify the relationship between the environmental and physiological factors and the perceived comfort (Galinsky et al., 2000; Hamberg-van Reenen et al., 2008; Naddeo and Memoli, 2009); few papers explaining explicitly the concept of comfort are Helander and Zhang (1997), De Looze et al. (2003), Moes (2005) and Kuijt-Evers et al. (2004), while most of the others worked on the relationship between subjective perception of comfort/discomfort feeling and product/process/interaction/environment/users' factors.

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In Vink and Hallbeck (2012) is given an interesting schematization (Fig. 1B) of the mechanism of comfort/discomfort perception that comes from the Moes' (2005) model represented in Fig. 1A.

They start from the following main topics individuated in a wide literature overview, for introducing their model:

1) Sensory input (De Korte et al., 2012; Vink et al., 2012);
2) Activities conducted during the measurement with an influence on comfort (Groenesteijn et al., 2012; Ellegast et al., 2012);
3) Different bodily regions (Franz et al., 2012; Kong et al., 2012);
4) Effect of the product' contour on comfort (Kamp, 2012; D'Oria et al., 2010; Noro et al., 2012);
5) Physical loading (Borg, 1982; Kee and Lee, 2012, Di Pardo et al., 2008; Zenk et al., 2012).

Moes (2005) deals about a specific case on the topic of "seat-design" and 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).

Vink and Hallbeck (2012) have modified this model (Fig. 1B); in their opinion, 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. [6]) 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), you feel nothing (N), or it can lead to feelings of discomfort (D) [2] and the Discomfort could result in musculoskeletal complaints (M).

This model has been upgraded by Naddeo et al. (2014a), as shown in Fig. 2, in order to take into account expectations and perception modification due to testing devices.

All presented models take into account the body effects and the perceived effects that are useful to define the Maximum Level of Comfort (MLC) positions in human postures and are needed to make a comfort evaluation based on measurement of the angular Range of Motion (ROM) of each joint (Annarumma et al., 2008; Tilley and Dreyfuss, 2001; Cappetti et al., 2011; Apostolico et al., 2013).

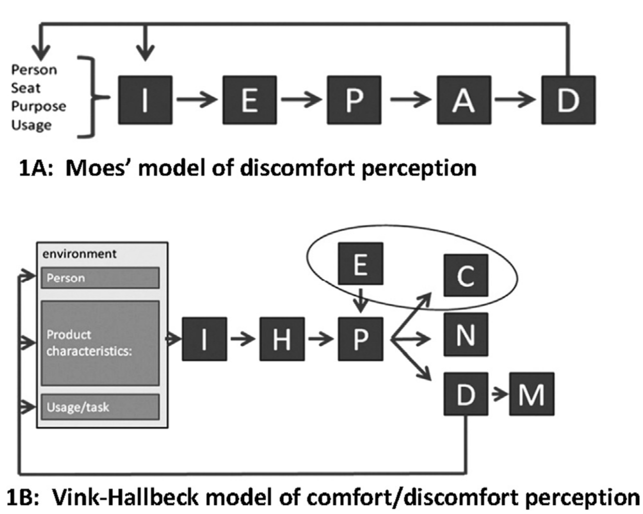

Fig. 1. Moes (A) and Vink & Hallbeck (B) models of discomfort perception.

Certain medical studies show that each joint has its own natural Rest Posture (RP) (Andreoni et al., 2002; Fagarasanu et al., 2004; Christensen and Nilsson, 1999), wherein the muscles are completely relaxed or at minimum strain level: When this occurs, the geometrical configuration corresponds to the natural position of the resting arms, legs, neck, and so forth. In Galinsky et al. (2000) it is demonstrated that the rest position minimizes musculoskeletal disease and optimize the comfort perception; in Apostolico et al. (2013), the problem of identifying and using the RP concept in ergonomic/comfort evaluations is addressed; in Christensen and Nilsson (1999) is presented an application in which the "neutral zero position" is defined as a parameter for calibrating mechanical instruments in measuring the neck's ROM. The RP concept has been used in Apostolico et al. (2013) for experimentally identifying the Range of Rest Posture (RRP).

It was demonstrated that anthropometric parameters can be used to evaluate users' well-being level (comfort), so, in present work, authors show the procedure used to build curves that represent comfort values along the entire range of postures (joint angle) for each human joint under consideration and proposes a method for postural comfort evaluation for improving the ISO standards' method.

2. Theory

This paper focuses on the numerical and experimental procedure for developing a comfort evaluation method for the upper part of the human body. The authors aim to demonstrate that this approach (based on the spatial configuration of body parts) allows us to define a quantitative method for comfort measurement, which is all-purpose and can be applied to different industrial cases: workplace environments, automotive passenger compartments, aeronautical cockpits, and industrial assembly lines. It can also be used in both the design phases and the optimisation and redesign phases of products and processes in order to improve the postural comfort of users/workers.

In this study, the H-point position was not taken into account because the comfort range of motion (CROM) and RRP can be defined for each human joint independently from H-point behaviour and position. For the evaluation of whole-body comfort, the H-point must obviously be taken into account.

A preliminary bibliographical analysis allows us to define the domain of "comfort function" as the set of angle values that characterises the movements of human joints (ROM). This strongly depends on the subset of values corresponding to a good ergonomic level (not necessarily a comfortable one).

The following joints were taken into account along with their main movements (degree of freedom [DOF]):

- Neck: flexion/extension, lateral flexion, rotation;
- Shoulder: flexion/extension, abduction/adduction;
- Elbow: flexion/extension, pronation/supination;
- Wrist: flexion/extension, radio/ulnar deviation;

In previous studies (Thompson Jon, 2010; Lantz et al., 1999; AMA Guide, 1988; Boone and Azen, 1979; Greene and Wolf, 1989; Luttgens et al., 2011; Koley and Singh, 2008; AAOS-Chicago, 1965; Norkin and Joice White, 2009), several ROMs were defined or suggested for each joint. We prefer to use, as with the CROM, the intersection of all ROMs as suggested in the literature, because non-common values are probably associated with an uncomfortable posture. For example, Table 1 presents the elbow CROM as given in