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The effect of spine discomfort on the overall postural (dis)comfort

Alessandro Naddeo[a,*], Rosaria Califano[a], Mariarosaria Vallone[b], Arianna Cicalese[c], Chiara Coccaro[d], Federica Marcone[e], Ervis Shullazi[f]

[a] Dept. of Industrial Engineering, University of Salerno, Italy
[b] MInistry of Education, Italy
[c] Whirpool EMEA, Italy
[d] UIP Biogem, Italy
[e] Amaris Geneva, Geneve (CH), Switzerland
[f] Oerlikon Friction Systems, Italy

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ABSTRACT

Currently, the word 'comfort' is often used in relation to the marketing of products such as chairs, cars interiors, clothing, hand tools and even airplane tickets. In this field of research, the aim of this study is to investigate the influence of spinal posture on postural (dis)comfort perception; the test case is the analysis of the interaction between humans and vending machines for purchasing food or beverages. A statistical sample of 20 healthy students (subjects) performed the required tests, with each participant asked to take a product from three different vending machines (snacks, drinks and coffee). The subjects' postures were acquired non-invasively using cameras; software and instruments for virtual prototyping were used for posture analysis and interaction modelling, both questionnaires (subjective) and comfort-analysis software (objective) were used to rate the perceived (dis)comfort. The results obtained from simulations and questionnaires were compared, and a method to weigh the effect of the perceived spinal discomfort on overall postural (dis)comfort was proposed. These results reveal a good correlation between subjective perception and objective evaluation obtained through simulations, confirming the validity of the proposed method.

1. Introduction

During the last two decades, the market has been impacted by several standards (e.g. EN ISO 14738, 2009; ISO 11226/2000; EN 1005-3/2009) that set geometric parameters for machine design whose aim is to improve the workers' safety. Meanwhile, the three parts of ISO Normative series 11228 (part 1, 2 and 3 - 2009) deal with ergonomics in the manual handling of objects. In ergonomics-driven product analysis, ISO 11228-3 is the most frequently applied standard, as it deals with risk evaluation for repetitive movements while using a particular product: after an initial screening of the checklist proposed by the ISO Standards, the risk evaluation is often (Annarumma et al., 2008) based on International standard ergonomic analysis methods, such as RULA (McAtamney and Corlett, 1993), REBA (Hignett and McAtamney, 2000), LUBA (Kee and Karwowski, 2001), STRAIN INDEX (Moore and Garg, 1995), OCRA (Occhipinti and Colombini, 1996; D'Oria et al., 2010), OREGE (Valentin at al., 2004), NIOSH (Konz, 1982; Waters et al., 1993). The ergonomics-driven design/redesign methods, such as the one applied in Christensen and Nilsson (1999), Bassi et al., 2016 and Califano et al., 2016 can be improved by taking account also factors causing (dis)comfort in order to work on them. But ergonomics does not mean comfort.

In Naddeo et al. (2014a), it was stated that each element involved in HMI experience can contribute to one or more kinds among four types of (dis)comfort: Postural, Cognitive, Physiologic and Environmental. This paper is focused on the postural (dis)comfort evaluation in Human-artefact interaction (Vink, 2014) and specifically, deals with users' postures while using a vending machine. A posture is defined by the human body's joints, positions and movements; several studies like Thompson, 2001 and Apostolico et al., 2013, addressed the need to understand the behaviour of human joints in terms of Range Of Motion (ROM) (Apostolico et al., 2013; Naddeo et al., 2015a), neutral (zero)

* Corresponding author.
E-mail address: anaddeo@unisa.it (A. Naddeo).

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positions (those which allow the maximum state of comfort) and Comfort Range Of Motion (CROM) (Fagarasanu et al., 2004; Christensen and Nilsson, 1999).

Looking back over the last 30 years, there are many papers (about 1500 from Scopus Database) dealing with (dis)comfort and posture; among them, only about 80 deal with postural comfort related to spinal comfort and few of them studied the mechanisms that are involved in spinal comfort perception. Jacobson et al. (2002) investigated the effects of spine discomfort on the quality of the sleep. In Zenk et al. (2007), and in Zenk et al. (2012), the overall seating comfort was correlated to the spine comfort through the intervertebral disk pressure. The lower the disc pressure is, the higher the perceived comfort is. In 2009, Franz et al., 2009 detected the behaviour of intervertebral discs' pressure while using a lumbar massage system integrated in a car-seat and correlated the measured pressure to the state of comfort of lumbar part of a subject. In Donnelly et al. (2009), a study on the effect of an Active Lumbar System (ALS) was studied in order to reduce the overall discomfort during 8-h shifts of policemen inside their cars. The ALS was able to modify the lumbar part of the spine's posture and the modifications were correlated to the reduction of perceived discomfort. In 2015, Meng et al., 2015 studied the effects of body height, weight and lumbar support prominence on driver's lumbar loadings by the Christophy musculoskeletal lumbar spine model and correlated the perceived comfort while seating to the lumbar muscles' loads. Wang et al. (2016) investigated the effect of back to long-time-sitting comfort by a qualitative analysis performed through questionnaires given to four subjects. Finally, in Li et al. (2017), a finite element method approach was used to correlate the pressure on the lumbar area to the perceived comfort while seating.

Regarding the field of application of this study, a wide-reaching research of papers (on Scopus, ISI-WOS and Google Scholar databases) dealing with ergonomic/comfort-related problems for vending machines did not provide any results. In the previously mentioned studies, the spine (dis)comfort perception is always studied as an effect of something (pressure, interaction, muscular load) but the weight of the spine (dis)comfort on the overall comfort has never been investigated. In order to investigate how the spine discomfort contributes to the overall (dis)comfort, a postural analysis was carried out using a cheap and effective method based on the simplification of 4D photogrammetry method, which did not affect the efficiency of the job/task (Naddeo et al., 2013a, 2014b). For (dis)comfort related analyses, we used a method (Naddeo et al., 2013a, 2013b, 2017; Vallone et al., 2015; Di Pardo et al., 2008; Bassi et al., 2016; Califano et al., 2016) based on the following four steps: 1) Direct and indirect (pictures) observations of users and vending machines; 2) information collection about vending machines and about the actions involved in retrieving the product and collecting the change; 3) data analysis; 4) comfort-index synthesis. Methods and instruments allowed us to perform (dis)comfort analyses that were efficient both in terms of design effort and development time. Finally, a hypothesis of a 'fusion rule' for objective comfort perception in the upper limbs and spine (dis)comfort was tested and correlated.

2. Material and methods

2.1. Purpose

The influence of spinal discomfort on overall postural (dis)comfort has been investigated through the study of the interaction between humans and three different vending machines (snack, drinks and a coffee machine – see Fig. 1).

2.2. Participants

Twenty master students participated in the experiment. None had a history of musculoskeletal disease. All the subjects were informed of the nature of the tests, and written consent was obtained. All the subjects were measured and classified, and their anthropometric measurements are given in Table 1 below.

2.3. Setup

The (dis)comfort evaluation was performed on vending machines (snack, drinks and a coffee machine) located in the University of Salerno, Italy. Three cameras were positioned to acquire the postures assumed by each subject for each vending machine. The cameras were positioned to acquire photos from three points of view: side (Camera C), behind (Camera B), and above (Camera A); the axis of Camera B is perpendicular to the sagittal plane and the axis of Camera C is perpendicular to the coronal plane. The setup for the central vending machine, as an example, is shown in Fig. 2. A simplified method based on Photogrammetry 4D (Naddeo et al., 2013a, 2014b) and the use of Kinovea® software allowed to acquire the subjects' movements and postures. These data were used also for setting dummies that allowed checking the acquired postures and simulating the way that customers pick up the product and retrieve their change.

The perception of (dis)comfort was recorded using a questionnaire. For each region of the upper limbs, perceived (dis)comfort was rated on a 5-point scale. For each action, both overall (dis)comfort and spinal (upper back and mid/lower back) discomfort were assessed. The questionnaire is shown in Fig. 3.

2.4. Simulation software

CATIA® V5R16 was used for the virtual-modelling of the user environment and the devices. Several elements were modelled individually and then combined. DELMIA® Digital Human Modelling (DHM) software was used for modelling a 'dummy' based on the real subjects' anthropometric measurements (Vallone et al., 2015; Di Pardo et al., 2008; Naddeo et al., 2017; Bassi et al., 2016; Califano et al., 2016). The virtual dummy has necessary characteristics in terms of flexibility, scalability and movements of body parts for our purposes here. Detected and measured angles were used in the DELMIA® simulation to replicate the anthropometric characteristics of involved subjects and to simulate the real postures as closely as possible by applying small corrections to the 'free' joints. All of the analysed postures (inserting coins, collecting change, and picking up the drink) were processed using this method. The comparison of photos and simulation screenshots was sufficient for tuning the simulation and obtaining very good[1] correlation results.

Objective-comfort[2] evaluations were performed using CaMAN® (Apostolico et al., 2013; Naddeo et al., 2015b; Naddeo et al., 2014b, 2015b, 2015b), a MATLAB® application developed at University of Salerno, which takes the angles describing subject posture as input, and which gives an index of upper limbs' postural comfort (CI) with a value range of 1–10 as output. CaMAN® indexes were compared with those obtained from the (dis)comfort questionnaires.

2.5. Procedure

The test protocol was explained to subjects 5 min before the test itself. Subjects were asked to take a drink or snack from each of the three vending machines. The sequence of use was changed for each subject in a randomized way. For each vending machines, three tasks

[1] The random evaluation of the upper extremities' positions of subjects after the valorization of joints' angles in the cinematic chain, gave an error lower than 10 mm.

[2] In CaMAN®, an Index of Postural Comfort (IPC), obtained as weighted mean of upper body parts' indexes, whose value is between 0 (absence of Comfort) and 10 (Completely in comfort) has been used. The absence of postural comfort has been considered as an uncomfortably situation.

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