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(WMSDs issue) A novel wearable system for the online assessment of risk for biomechanical load in repetitive efforts☆

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ABSTRACT

Work-related Musculo Skeletal Disorders (WMSD) are considered the third main reason for disability and early retirement in the U.S. and are widespread in many occupations, involving both heavy and light biomechanical loads. In Italy, only taking into account the years 2009–2010, it is estimated an exponential increasing in the number of WMSD reports. In particular a 159.7% increment has been reported compared to the 2006 statistics. In this context, it is clear how important correctly diagnosing this kind of pathology is becoming. Traditional methods for WMDS assessment are based on observational techniques, in which experts manually segment, label and evaluate movements with the help of pro-forma sheets. Since these methods are currently based on visual inspection and subjective judgment, they could benefit from objective measurements in terms of both reliability and repeatability. Moreover an automatic tool for ergonomics assessment would vastly reduce the time that an expert needs to carry out the same assessment manually. In this context a novel wearable wireless system capable of assessing the muscular efforts and postures of the human upper limb for WMSDs diagnosis is proposed. The system, being non-obstructive, can be used to monitor workers in ecologic environment while they are carrying on their everyday tasks. A real-time assessment is obtained according to two of the most common indexes for the analysis of risk factors on workplaces: the Rapid Upper Limb Assessment (RULA) and the Strain Index (SI). The system exploits inertial measurement units (IMUs) to reconstruct the upper limb posture, modeled as a 7 degrees of freedom (DoF) kinematic chain. As far as muscular efforts are concerned, surface EMG sensors are used to assess forearm flexor muscles strain. As an example of the proposed system application the results of a first data collection campaign regarding super-market cashiers during everyday real-life operations is reported.*Relevance to industry*: The presented system has a high potential impact on industry as a timely intervention on the WMSD factors may reduce pathologies and reduce the recovery of expert workers.

1. Introduction

According to international statistics, in the last years Work-related musculoskeletal disorders (WMSDs) have become one of the main concern for workers health and safety. The growing interest on WMSD is explained by the increase of case reports and by the impact of WMSD on industry production.

In particular, according to the Italian government agency for the insurance against work-related injuries, WMSDs, differently from other work-related injuries, have shown a constant growth as it is shown in Table 1 (Italian Government Agency for Injured Workers (AMNIL), 2013). More recent data show a further increase of approximately 4.000 cases (+15%) with respect to 2010 (Italian Government Agency for Injured Workers (AMNIL), 2013).

WMSDs usually arise from common movements, such as lifting, intensive keying, forceful pinching and gripping, that are not

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Table 1
WMSDs incidence for the 2006–2010 years interval (Italian Government Agency for Injured Workers (AMNIL), 2013).

Type of WMSD	2006	2007	2008	2009	2010	Var. % 2006–2010
Vertebral disk diseases	2.828	3.276	4.130	6.629	9.368	231.3%
Tendinitis	3.124	3.842	4.461	6.036	8.525	172.9%
Carpal tunnel syndrome	1.731	1.477	1.668	2.435	4.819	178.4%
Arthrosis	1.588	1.938	1.965	2.343	1.971	24.1%
Others	795	907	886	1.057	1.455	83.0%
Total	10.066	11.440	13.110	18.500	26.138	159.7%

particularly harmful, but that become hazardous in specific work situation in which several repetitions of these movements are done without sufficient recovery time or they are done too fast.

Risk factors are usually classified into three main groups: individual, psychosocial, and physical. Examples of individual and psychosocial factors are: job-related stress and dissatisfaction, low organizational support, high work demands.

Considering the physical category the most influential causes are recognized to be workload in repetitive activities and body postures (Aarås et al., 1988; Forcier et al., 2008; Kilbomet al, 1994). For that reason, traditional techniques for assessing WMSDs focus in particular on observing the angular deviation of a body segment form its neutral position, force exertion, and repetition. Those techniques can be gathered in three groups: self-reports, observational inspection or by instrument-based techniques (David, 2005).

Self-reports methods usually consist of questionnaires that must be filled by the monitored workers. Those methods are straightforward and easy to use, but are prone to give a distort information due to the subjectivity of the worker perception. Moreover, factors affecting self-reports answers are eventually pre-existing MSDs and psychosocial factors.

Observational inspection consists of the visual analysis of recording observations with the help of pro-forma sheets. This family of methods focus mainly on postural observation, workload or a combination of the two. Among these methods the Rapid Upper Limb Assessment (RULA) (McAtamney and Nigel Corlett, 1993), which assesses biomechanical and postural loading on the human body focusing mainly on neck, trunk and upper limbs, is one of the most used. Other examples are the NIOSH Lifting Index (Waters et al., 1993) and the Job Strain Index (SI) (Steven Moore and Garg, 1995). The first evaluates the risks related to manual handling of load during lifting tasks, while the latter focuses on the muscular effort component focusing on the wrist-hand complex, and gives a net threshold to rank the risk factors of different jobs. Being practical, inexpensive and not intrusive, observational methods can be used in several workplace conditions, but they heavily rely on the analyst's skills in terms of evaluating quantitative parameters such as joint angles and loads displacement by visual inspection. For this reason the introduction of a measurement tool to capture some or even most of the parameters involved in the calculation can greatly enhance the exploitation of these methods.

Instrument-based techniques rely on direct measurements from sensors attached to the workers body. Since it is crucial to minimize the disturbance caused by instrumentation to the user, the most used solution are wearable and hand-held devices. Very common solutions employ motion capture devices to reconstruct the body posture. Vignais et al. (2013) presented a wearable body sensor network composed of inertial units and goniometers. The body posture is assessed with a 20 Degrees of Freedom (DoF) biomechanical model and joint angles are used for the RULA assessment. The system is capable of giving a visual feedback of the RULA score to the user. In this context only postural risks assessment are considered by the method. In addition to body posture several works monitor also force exertion and load during the task execution. Usually this is done with grip/force sensors (Freivalds et al., 2000) or with surface EMG sensors, which are more suitable to measure hand and finger forces in the workplace without interfering with a worker's normal movement patterns (Mogk and Keir, 2006). In fact, in a comparative study of Trask et al. (2007), several different methods are taken into accounts (observations, interviews, EMG, inclinometry, and vibration monitoring) showing the capability of EMG monitoring equipment to provide data focused on only one risk factor, but with a very high level of detail. Moreover several metrics (mean, peaks, percentiles, cumulative exposure, rate of change) can be investigated through EMG, with the downside of being a costly solution compared to traditional observational methods. EMG can be used as a tool for non-standard assessment (Spyropoulos et al., 2013; Søgaard et al., 2001). In the first case the authors employ video-based tracking methods to capture kinematic parameters and surface EMG sensors to define possible indicators of fatigue accumulation for the shoulder. Two lifting tasks, with different ranges are analysed during common operations in a supermarket. In the second force sensors are added to EMG and optical motion tracking. Considering EMG assessment in the context of standard scoring methods, it has been used both for complementing a modified version of the RULA scoring system (Pérez-Duarte et al., 2014) and as an alternative to the visual inspection according to the BORG scale, since it is shown the two assessments are strongly correlated (Jones and Kumar, 2010). An example of the latter application has been studied by Cabeças (2007), where EMG is used as an alternative to observational methods in computing the SI score. The authors conclude that, once defined appropriate trigger levels for the muscular activation, EMG is a valid alternative to visual inspection in the SI computation. This is true in particular when efforts are not clearly associated to hand/wrist movements and when non-cyclical high-frequency activities are assessed. In the context of assessing WMSDs, several factors interact at the same time, thus it is crucial to monitor all of them. In general it has been shown that methods assessing different factors lead to different risk evaluations. For this reason using more than one method at the same time can help prioritize interventions and ensure a more thorough evaluation of risk factors. On the other hand, the use of more than one method can rapidly lead to unacceptably high costs for the practitioner both from a time and money view point (Chiasson et al., 2012). In this context an automatic online assessment system, taking into account several factors and consequently several different risk scoring methods, would give a meaningful evaluation, without the cost drawback of multiple observational assessments. For this reason the problem of gathering motion and muscular effort data that could serve WMSDs risk assessment has been approached. The authors presented in Peppoloni et al. (2014) a preliminary version