Assessment of ergonomic risk in industrial field: analysis of the operators' body postures through wearable sensors

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Abstract: Work-related musculoskeletal disorders (WMSDs) are currently among the most widespread pathologies which affect workers in several occupational fields. Non-neutral postures, especially when maintained for prolonged periods of time, represent a relevant risk factor for WSMDs and thus, the correct assessment of worker's exposure is a crucial issue in order to prevent, or at least reduce, their onset. Qualitative methods (i.e. direct observation, questionnaires) are the most widespread techniques to characterize posture under actual working conditions, but they provide limited information and are time-consuming. The present study aimed to propose an ecological method to assess as non-neutral trunk posture under actual working conditions. A single miniaturized wearable inertial sensor located in the low-back has been employed to evaluate trunk flexion features in two workers engaged in manual material handling tasks, during 4 hours of a regular work shift. Data collected were processed following an exposure variation analysis (EVA) in order to evaluate intensity, frequency and duration of the exposure. An ergonomic risk level was then associated following the National Institute for Occupational Safety and Health guidelines (NIOSH, 2014). The obtained results suggest that the proposed approach is suitable to support the identification of potentially harmful strategies adopted by the workers or may help to recognize the necessity to reorganize the workstations to improve the working conditions.

Keywords: Inertial Sensors, Trunk Flexion, Work Related Musculoskeletal Disorders (WMSD)

1. Introduction

The Strategic Framework on Health and Safety at Work 2014-2020 defines work-related musculoskeletal disorders (WMSDs) as one of the main challenges to address underlining that, for EU Community strategies, its prevention represents a priority area to improve workers' health and well-being (de Kok et al., 2019). WMSDs refers to a wide range of disorders or injuries affecting person's inner body parts as muscle, nerves, ligaments, tendons, joints, cartilages and spinal disc (OSHA, 2000) and they commonly involved body regions such as low back, neck, shoulder, upper and lower extremity (Punnett and Wegman, 2004). These disorders occur when the physical requirements of activities in the workplace do not conform to physical capabilities of the worker. Generally, the most common risk factors associated with WMSDs onset are awkward posture, prolonged static work, repetitive movements, manual material handling, forceful exertion and vibration. According to the data reported by the European Statistic on Accident at Work (ESAW), one of the sectors in which workers perceive most clearly the risk of non-fatal accident is the manufacturing sector (Eurostat, 2017). In absolute terms, non-fatal accidents in the EU-28 in manufacturing sector, 625 thousand people had non-fatal accidents in 2017, 18.7 % of the total. Wholesale and retail trade (12.3 %), human health and social work activities (11.3 %) and construction (11.3 %) also each accounted for more than one tenth of all non-fatal accidents at work. The ESAW reported that, a decrease of 6.4% in the incidence rate (number of non-fatal accidents at work for every 100000 persons employed) is achieved between 2011 and 2017 and it was considerably greater than the decrease for the number of non-fatal accidents, reflecting growth in the number of persons employed (Eurostat, 2017). In this scenario, it appears crucial to define a proper ergonomic design of the workplace aiming at meeting physical jobs with workers' natural capabilities to prevent the development of WMSDs. To this end, the ergonomic analysis should be based on two key aspects: (i) the evaluation of the risk factor will results in WMSDs and (ii) the evaluation of the intensity, duration, frequency or the possible combination of these factors (David, 2005). The number of studies about WMSDs has largely increased in recent years. Antwi-Afari et al. (Antwi-Afari et al., 2017) analyzed the effects of lifting weights and posture on spinal biomechanics. Acaröz Candan et al. (Acaröz Candan, Sahin and Akoğlu, 2019) investigated the risk factors and the different disorders occur among female workers in a hazelnut factory. Major and Vézina (Major and Vézina, 2015) presented an analysis of the different strategies applied to manage injuries and disorders in seafood processing. Albers et al. (Albers, Estill and MacDonald, 2005) analyzed the ergonomics interventions to prevent WMSDs in building installation tasks. In (Nath, Akhavian and Behzadan, 2017; Yan *et al.*, 2017; Nath, Chaspari and Behzadan, 2018), authors analyzed the use of smartphone as wearable sensor in preventing WMSDs generated by awkward posture.

In this paper, we aim to present an ecological method to assess intensity, frequency and duration of non-neutral trunk posture on the basis of the exposure variation analysis (EVA) proposed by Mathiassen and Winkel (Mathiassen and Winkel, 1991), under actual working conditions using inertial sensors (IS). The IS are a class of devices which are becoming widespread in occupational ergonomics to collect data about worker's movement and posture (Lim and D'Suoza, 2020) and that have already been successfully tested as tool useful to integrate the biomechanical risk assessment in other categories of workers (Porta et al., in press; Asante et al, 2018). In particular, to assess the feasibility of this approach, we monitored two workers employed in mechanical processing operation for 4 consecutive hours of a regular work-shift. Trunk flexion patterns were classified accordingly to the National Institute for Occupational Safety and Health guidelines (NIOSH, 2014). The physical profile of the working tasks was assessed using wrist worn accelerometers. The main goal of the proposed methodology is to provide a quantitative tool to identify potentially harmful strategies adopted by the workers or may help to recognize the necessity to reorganize the workstations to improve the working conditions.

2. Material and Methods

2.1 Participants

Two workers were selected from a mechanical engineering company (assembly department) where they were currently employed. Their anthropometric and demographic data were respectively: age 46 and 32 years, height 180 and 172 cm, body mass 93 and 65 kg, and seniority of work of 11 years, free from any sign of musculoskeletal disorders in the previous six months. They participated to the study on a voluntary basis. Purposes and methodology of the study were carefully explained and they signed an informed consent form.

2.2 Experimental protocol

Workers' trunk posture was assessed using a lightweight miniaturized wearable IS (G-Sensor, BTS Bioengineering S.p.A., Italy) which includes tri-axial accelerometer, gyroscope and magnetometer. Although this device is mainly employed in clinical field to analyse gait and functional mobility through dedicated protocols, it has also the capability to collect onboard accelerations and angular velocities of the body district to which is placed.

In the case of the present study, the device was placed on the low back (Fig. 1), using a dedicated semi-elastic belt approximately at their first lumbar vertebrae (L1), according to what described in previous similar studies which investigated the optimal position of the sensor to investigate trunk flexion (Faber et al., 2009). Participants were also requested to wear two activity trackers validated for clinical use (Actigraph GT3X, ActiGraph Corp., USA) on both wrists (Fig. 1) to quantify and classify the physical activity (PA) carried out during the shift. In this case, the acquisition frequency was set to 30 Hz. These devices were employed only to verify whether the existence of possible differences in terms of physical engagement between the two participants. Wrist acceleration were acquired onboard and then downloaded via USB cable at the end of the shift. Prior to the experimental trials, the participants were asked to perform maximal flexion, lateral bending and rotation to assess their baseline capabilities in terms of spine mobility.

2.3 Data Processing

Raw accelerations and angular velocities recorded onboard by the low-back IS at 50 Hz frequency, were processed by means of a custom routine developed in Matlab (R2019a, MathWorks, USA) to estimate and classify trunk flexion angles as follows (NIOSH, 2014) (Figure 2 shows an example of raw data with NIOSH threshold overlapped):

- Mild: flexion angle = 30° - 60°
- Moderate: flexion angle = 60° - 90°
- Severe: flexion angle > 90°

Figure 1: Left: Sensors placement. Right: devices employed in the study

Subsequently, in order to reduce the large amount of raw data obtained from IS to a restricted set of essential parameters by which the exposure pattern is still sufficiently captured, we used an approach based on Exposure Variation Analysis (EVA) (Mathiassen and Winkel, 1991). In particular, the duration of exposure associated with each posture class was calculated, using time periods of 0-2s, 2-4s, and >4s. At last, we calculated the time spent in each of the combinations of posture class and time period classes in terms of either frequency or percentage of the total working time.

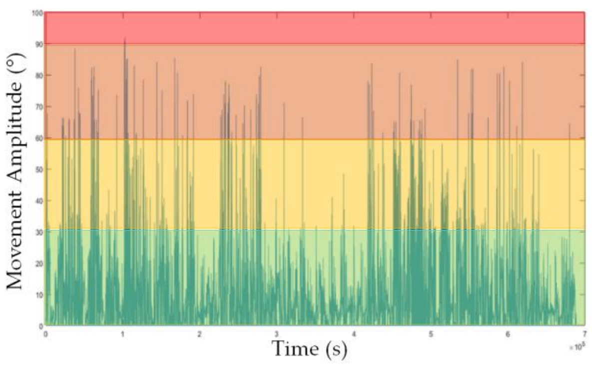

Figure 2: Example of trunk flexion vs. time where overlapped are shown NIOSH thresholds

Data acquired from wrist-worn activity trackers was processed using the dedicated software provided by the manufacturer (Actilife v6.13.4 ActiGraph Corp., USA), to obtain number of steps and PA intensity classification performed on the basis of the cut-points proposed by (Hildebrand *et al.*, 2014).

3. Results

Even though both workers were employed at the same company division, they showed substantially different pattern of physical activity (PA) and trunk flexion during the 4 hours of monitoring. In particular, subject 1 carried out 1758 steps/hr. spending 22.4% in light PA, 49.7% in moderate PA and 27.9% in vigorous PA, whereas subject 2 carried out 771 steps/hr. spending 71.4% in light PA, 16.6% in moderate PA and 12.0% in vigorous PA. A corresponding marked difference in terms of trunk flexion was also detected. In fact, while Subject 1 spent 10.6% of the monitored time with his trunk in mild flexion, 1.0% of the time in moderate flexion and 0.1% in severe flexion; whereas subject 2 spent only 1.0% of the time in mild flexion and 0.2% in moderate flexion. In Figure 3 are shown the diagrams which represent the distribution of flexion angles in terms of frequency and durations.

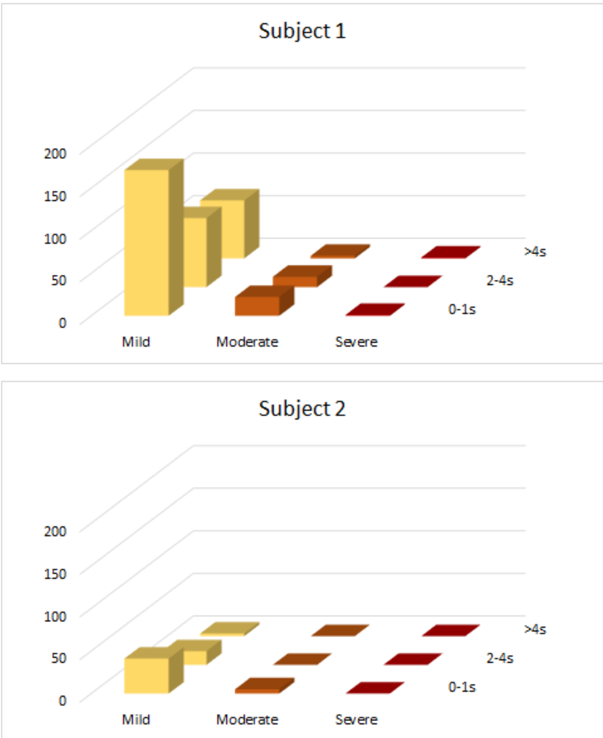

Figure 3: Trunk flexion patterns in terms of amplitude frequency and duration for the two tested workers

4. Discussion

A number of jobs are high physically demanding. Among those, we can include metalworking industries workers, who are characterized by a high incidence of low back disorders (van Vuuren *et al.*, 2005). In order to prevent or reduce the onset of such disorders is necessary to have available tools able to precisely identify potentially harmful strategies adopted by the workers or that may help to recognize the necessity to reorganize the workstations aiming at improving the working conditions. Often, exposure assessment is based on job title, but this can led to misclassification, in particular when jobs are characterized by high variability, but also because of the intrinsic approach of each individual to the working task according to his anthropometry, experience or physical fitness (Burdorf, 1992). To this reason, inertial sensors (IS) may represent a valid option as simple quantitative tool able to assess the exposure to physical risk factors such as non-neutral posture in real-work conditions, allowing to perform the assessment at an individual level. Here we have shown how, with this simple setup, is possible to highlight completely different movement strategies even when the job assignment is the same. In fact, subject 1 spent more than 10% with is trunk in mild flexion, thus reaching the threshold that was identified in previous studies to put individuals at increased risk to develop low back disorders (Hoogendoorn *et al.*, 2000), whereas subject 2 spent only 1% of the working time in the same posture.

These preliminary results show how a simple, non-invasive setup which exploits the capabilities of wearable IS may be useful in classifying non-neutral trunk posture, by providing detailed data regarding the amplitude, duration, and frequency of trunk flexion. This approach might also be used to investigate inter-subject variability in flexion movements, possibly associated with anthropometry, experience, or subjective tolerance to biomechanical stress. Although further studies on larger cohorts are needed, this approach appears promising and potentially suitable for diverse tasks in which trunk flexion represents a critical component of biomechanical risk.

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