Measurement of Upper-Limb Joint Angular Kinematics: A Comparative Study in Manual and Semi-automated Assembly Line

Ana Betty Abreu[1]; Joana Santos[2]; João Baptista[3]
[1] MESHO-FEUP, Portugal
[2] Scientific Area of Environmental Health, Research Center on Environment and Health (CISA/ESTSP.IPP) School of Allied Health Sciences, Polytechnic Institute of Porto, Portugal
[3] Research Laboratory on Prevention of Occupational and Environmental Risks, Porto Biomechanics Laboratory (PROA/LABIOMEP), Faculty of Engineering, University of Porto, Portugal

ABSTRACT
Assembly lines are the production system mostly used in industry in order to achieve higher production rates. Thus, workstations are getting more automated and operators tend to perform highly dynamic repetitive movements. As the work demands increase the biomechanical load of the soft tissues of the upper-limbs are also intensified. The operator's exposure to this work-related risk factor is a probable cause for the development of work-related musculoskeletal disorders. The main purpose of the study is to measure the range of motion of the upper-limb articulation of subjects in the same workstation in two different assembly lines when performing assemble work. For the data collection was used an inertial measurement system *Xsens MVN BIOMECH*. The data indicates that the operators have similar range of motion in the upper-limb articulation. It was possible to verify that the subjects in study perform repetitive movements and tend to adopt the work method defined.

Keywords: Assemble Work; Automation; Work-related musculoskeletal disorders

1. INTRODUCTION

The work-related Musculoskeletal Disorders (WMSDs) are the most prevalent occupational-related health disease in the European Union. The biomechanical load upon the body leads to the limit of the mechanical properties of the soft tissues. The physiological response occurs in form of deformation, inflammation, muscle fatigue and failure at a microscopic level. When this disease affects upper-limbs are designated upper limb work-related musculoskeletal disorders (UL-WMSDs). Risk factors of the development are: a) repetitive work in the job stations; b) static postures and c) lack of rest periods during the work journey (Byström, Hall, Welander, & Kilbom, 1995; EU-OSHA, 2010; Latko et al., 1999).Due to work organization changes companies' production systems have improved technologically in order to achieve higher rates of production. For the mass production, industries still have preference for assembly lines and assemble work. These production systems due to the technological innovation can achieve higher rates of production and customization of products. Nowadays, assembly lines are getting further automatized being possible the reduction of the workforce. The automation of stations has increased the a) repetitive and monotonous work; b) static postures and c) work pace and decreased the work/ rest ratio (Wells, Mathiassen, Medbo, & Winkel, 2007). Despite the contribution of technological development in providing solutions to reduce biomechanical load, production engineers remain more focused for the production systems themselves than for the ergonomic aspects of work as a whole. Thus, the major challenge for ergonomics is to design the work in order to prevent WMSD with no negative impact on production quality and productivity (Mathiassen, 2006; Neumann, Kihlberg, Medbo, Mathiassen, & Winkel, 2010). The purpose of this study is to compare the angular kinematic data of the right elbow, shoulder and wrist articulations between subjects in the same workstation in two assembly lines technologically different.

2. MATERIALS AND METHODS

2.1. Production System Design

To this field study was selected two assembly lines, a manual line and a semi-automated line. The selected assembly line produces the same family´s product – automotive door cables. Of the two assembly lines, the manual is the oldest one. Six workstations are organized along two parallel frameworks. In each workstation is an operator which places the components so that they can be assemble. Subsets are transported throw each workstation by a drag mat. The semi-automated line was built after the manual and the main purpose of the assembly line construction was to produce the same amount of cables reducing the workforce. In this case only three operators assembles the cable, being the rest of the production system automatized. The manual workstations have the same type of the working method and machines of the manual line. The subsets are transported by a mat with pallets were subsets are placed and transported throw each workstation. The cycle time of workstations of the two assembly lines is approximated six seconds (time that takes to assemble a subset).

2.2. Subjects

Seven healthy female subjects without any health complaints were included in this study. All subjects signed an informed consent. The average ages was 37.3 years old (range 24-55) and had work experience between 1 and 14 years. The operators were high skilled in the working process. The work schedule was at the second term of the day (14:00h to 22:00h) with a ten minute break during the work journey. The type of work performed in all workstations is considered

low force with repetitive movements of the wrist, elbow and shoulder. The postures adopted are mainly static using only the upper limbs to place the materials in the equipment. The operators followed the working method defined by process engineer.

2.3. Data Collection Procedure

Angular kinematic data collection was performed using *Xsens MVN BIOMECH*, an Inertial Measurement system in the plant floor, on workstations of the assembly lines selected after two hours of the beginning of the shift. The sensors modules were placed on the feet, lower legs, upper legs, pelvis, shoulders, sternum, head, upper arms, forearms and hands. In order to optimize the calibration all sensors modules were placed. Only the range of motion of the right upper limb articulations was analysed due to its dominance in the tasks performance (Table 1). Between each measurement the equipment was calibrated.

Table 1 Range of Motions and Degrees of freedom analyzed

Range of Motion of the Articulation	Degrees of Freedom
Shoulder adduction/abduction Shoulder flexion/extension Shoulder interior/exterior rotation	3 (x, y, z)
Elbow flexion/extension	1 (z)
Wrist flexion/extension Wrist ulnar/radial deviation Wrist pronation/supination	3 (x, y, z)

2.4. Statistical Data Analysis

For statistical analysis of the angular kinematics was used R, version 3.1.1., a free software environment for statistical computing and graph. As the samples were in time series, a cross correlation analysis and statistical significance testing was calculated between subjects in the same workstations in both assembly line (Manual and Semi-automated).

3. RESULTS AND DISCUSSION

The correlation values between subjects in same workstation in the manual assembly line were mostly strong. Of the 42 r values, 35 were strong: r (1 to 0.5); 6 moderate r (0.3 to 0.5); and 1 weak r (0.1 to 0.3). The stronger correlation values were reached in most of three DOF (number of independent motions that are allowed to the body) of shoulder ROM (distance and direction a joint can move between the flexed position and the extended position). In respect of the Semi-automated assembly line it was detected further significant differences in ROM of articulations among subjects in the same workstation, thus no relation between subjects in study was detected. Of the 28 correlation values, 16 were strong: r (1 to 0.5) and 12 r (0.3 to 0.5). No weak correlation were encountered. The stronger correlation values were also on shoulder ROM. Through the data analysis it was possible to verify that the articulations ROM of operators are similar between subjects in study workstations (Figure 1; Figure 2). The patterns between subjects in same workstation proves that operators adopt similar movements in assemble work. Repetitive work and highly dynamic movements are performed which can be a risk factor to the development of WMSDs (EU-OSHA, 1999; WHO, 2003; Mohammadi, 2012). Significant values difference between subjects in semi-automated assembly line were identified. This fact could be due a limitation of the inertial measurement system used (*Xsens MVN BIOMECH*) and of plant and assembly line conditions. Due to the assembly line high level of automation it requires the use of auxiliary systems for error detection. The electromagnetic radiation could influence the correct *Xsens* wireless-sensors reading (Brodie, Walmsley, & Page, 2008). The weaker correlation may also be due to the working-method adopted by some workers during the execution of tasks. Even though work method is defined in the development of the assembly line, operators tend to adopt some changes in order to achieve higher levels of production and fell comfortable performing the task

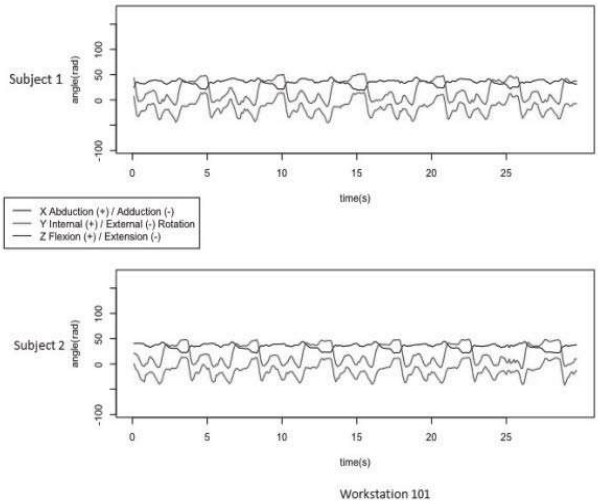

Figure 1 Shoulder Range of Motion between subject one and two - Manual Line

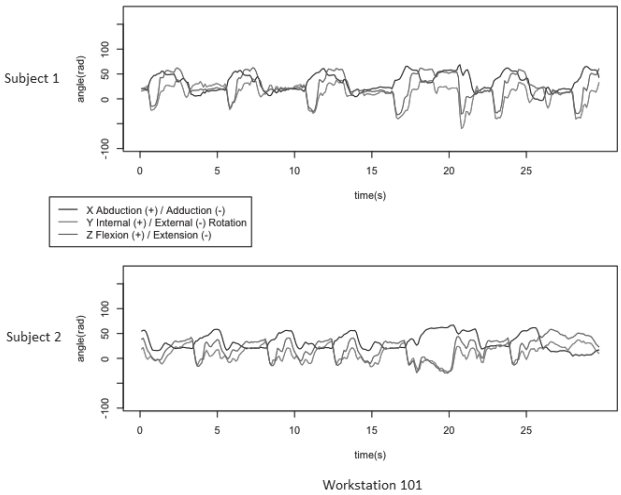

Figure 2 Shoulder Range of Motion between subject one and two –Semi-automated Line

4. CONCLUSIONS

The movements of the upper limb articulations are similar among subjects in study. This fact proves that operators tend to adopt the defined work method in the assemble work. It was also verified that repetitive movements are performed by operators in assemble work.

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