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Influence of automation on biomechanical exposure of the upper limbs in an industrial assembly line: a pilot study

Joana Santos[a], Ana Betty Abreu[b], Pedro Fonseca[c], Carlos Carvalhais[d], J. Santos Baptista[e], Rubim Santos[f], Mário Vaz[g]

[a]Environment and Health Research Center (CISA/ESS.PPorto), School of Health, PT & Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI), PT & Center for Rehabilitation Research (CIR/ESS.PPorto), School of Health, Polytechnic Institute of Porto, PT (jds@ess.ipp.pt) ORCID: 0000-0002-2777-3244. [b]Faculty of Engineering, University of Porto, PT (mho12023@fe.up.pt). [c]Porto Biomechanics Laboratory (LABIOMEP), PT (pedro.labiomep@fade.up.pt) ORCID: 0000-0002-4885-4924. [d]Environment and Health Research Center (CISA/ESS.PPorto), School of Health, PT & Epidemiology Research Unit (EPIUnit), Institute of Public Health, University of Porto, PT (caa@ess.ipp.pt) ORCID: 0000-0002-4352-4555. [e]Associated Laboratory for Energy, Transports and Aeronautics, LAETA (PROA), Faculty of Engineering, University of Porto, PT (jsbap@fe.up.pt) ORCID: 0000-0002-8524-5503. [e]Center for Rehabilitation Research (CIR/ESS.PPorto), School of Health, Polytechnic Institute of Porto, PT (rss@ess.ipp.pt) ORCID: 0000-0002-7394-7604. [g]Associated Laboratory for Energy, Transports and Aeronautics, LAETA (PROA), Faculty of Engineering, University of Porto, PT (gmavaz@fe.up.pt) ORCID: 0000-0002-6347-9608.

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Abstract

Automation of assembly work was originally developed to increase operation efficiency and to reduce workload. However, a considerable number of unanticipated ergonomic problems have been observed such as the interaction between humans and automated systems. The aims of this study were to quantify joint angle positions (shoulder, elbow and wrist) of workers in two assembly lines with different mechanization levels and analyse the performance of an inertial motion capture system. Seven experienced female assemblers participated in this study. The measurements were performed in the workplace with a full-body inertial measurement system (Xsens MVN BIOMECH system). Maximum cross-correlation between angle-time courses was calculated to quantify the waveform similarities. In manual line, there are larger variations of joint angles than in the semi-automatic one. The analysis of cross correlation coefficients revealed that electromagnetic interferences are potential limitations to the use of these systems under field conditions.

1. INTRODUCTION

One of the main challenges for ergonomics is to design the work to prevent work-musculoskeletal disorders (WMSD) without negative impact on production quality and productivity (Wells, Mathiassen, Medbo, & Winkel, 2007). The changes in a worker's capability must be regarded in the conception of redesigned and new assembly lines (Winter et al., 2012). However, WMSD are still prevalent across Europe and have a great impact in the quality of life of the workers (Eurofound, 2012). Indeed, upper limbs repetitive tasks are one of the main sources of risk for workers of the manufacturing industries (Lavatelli, Schaub, & Caragnano, 2012). In fact, work organization has been changing through the years mostly due to technological advances, legal and political changes and competitiveness among companies.

The growth of mass production and automated technologies led to the emergence of new ergonomic problems due to work intensification (Coury, Alfredo Léo, & Kumar, 2000). This trend in contemporary manufacturing industries is associated with the selection of serial or parallel flow production strategies and the reduction of waste in the production system (rationalization) (Palmerud, Forsman, Neumann, & Winkel, 2012; Westgaard & Winkel, 2011). According to a systematic review carried out by Westgaard & Winkel (2011), rationalization of production had a great impact on musculoskeletal and mental health of the workers. They also recognized that more research on ergonomic intervention is needed to understand the prerequisites of sustainable production systems (balance between production performance and worker wellbeing).

Assembly lines are flow-oriented production systems developed to achieve, in a more efficient way, higher production rates of standardized products (Boysen, Fliedner, & Scholl, 2007). Several authors investigated new methods to optimize assembly systems, disregarding ergonomic issues (Battini, Faccio, Ferrari, Persona, & Sgarbossa, 2007; Toksari, Işleyen, Güner, & Baykoç, 2008; Wei & Chao, 2011; Yeh & Kao, 2009). However, assembly tasks are characterized by strictly standardized procedures with short cycle times (less than 30s), little task variation, repetitive movements and reduced breaks or pauses which supports the importance of integrating ergonomic approaches in the design of these production systems (Battini et al., 2007; Neumann, Winkel, Medbo, Magneberg, & Mathiassen, 2006). The automation level of assembly processes may have implications on physical workload. Neumann et al. (2002) reported that the automation of assembly work and transport in production lines increased productivity and reduce mechanical load on operators. A comparative study carried out by Wong & Richardson (2010), showed that the operators had more complaints associated to musculoskeletal pain while working in a Lean Production Line (systematic method for waste minimization within a manufacturing system, without sacrificing productivity) than in a conventional one.

Assessment of physical exposures (e.g. joint kinematics and kinetics) is important for understanding the risk of WMSDs and defines ergonomic interventions (Qin, Lin, Faber, Buchholz, & Xu, 2014). Currently, some authors consider that quantification of physical exposure in work environment is essential due to the influence of organizational factors or physical constrains in working procedures (Garg & Kapellusch, 2009; Marras, Cutlip, Burt, & Waters, 2009). Motion capture systems enable a detailed analysis of tasks, allowing ergonomic improvements in the production system design. However, considering the three-dimensional (3D) systems, they reveal some limitations related to the complexity and space requirements (e.g. Vicon Motion Systems; Los Angeles, California) or accuracy when applied in the field. Inertial measurement systems (e.g. Xsens; Enschede, Netherlands) are a possible alternative for portable 3-D motion capture to carry out evaluations in work environments. Besides requiring less space, they are low-cost and fully wearable motion analysis systems (Cutti, Giovanardi, Rocchi, Davalli, & Sacchetti, 2008). Santos et al. (2016) stated that future research should be focused on the improvement of the experimental protocols and instrumentation, in order to the outcomes represent adequately the actual working conditions. The present study was conducted in a multinational corporation with production of mechanical cables for automotive industry. This company has implemented the lean production system (LPS) and assembly lines constitute the most of production area. The automation/mechanization of assembly processes has been modified to improve production efficiency and ergonomic conditions. Accordingly, the aim of this field study is to quantify differences in the upper-limb mechanical exposure between workers working in assembly lines with different mechanization levels. As stated by Santos et al. (2016), considering the importance of examine the ability of inertial motion capture system in real conditions, it was evaluated the application and performance of this system.

2. MATERIALS AND METHODS

The present study was conducted in a multinational corporation with production of mechanical cables for automotive industry. This company has implemented the Lean Production System (LPS) and assembly lines cover almost the entire production area. The automation/mechanization of assembly processes has been modified to improve production efficiency and ergonomic conditions.

2.1. Production system design

The production systems studied consisted of two assembly lines: the manual and the semi-automated line. The manual production line is the oldest one. Both assembly lines have *andon* (a visual aid which alerts and highlights where action is required) and *poke-yoke* (mistake proof, that allow fixing problems immediately and avoids the problem of setting aside a great amount of rejects) systems, so all problems are immediately reported (maintenance, quality and components supply). Moreover, these lines are producing the same product – automobile door cables. At the beginning of each shift, the operator carries out a thorough check of the main of the cable quality. Every two hours a product quality verification takes place. Other controls are also made by each operator such as: a) safety items, i.e., all the equipment has its safety protections placed and they must be operative; b) 5S (workplace organization), i.e., cleaning and organization of the workstation. The company has three fixed shifts (morning: 6:00-14:00; afternoon: 14:00-22:00; night: 22:00-6:00). Each shift has a break of fifteen minutes. The manual line included six workstations with a parallel configuration (Figure 1).

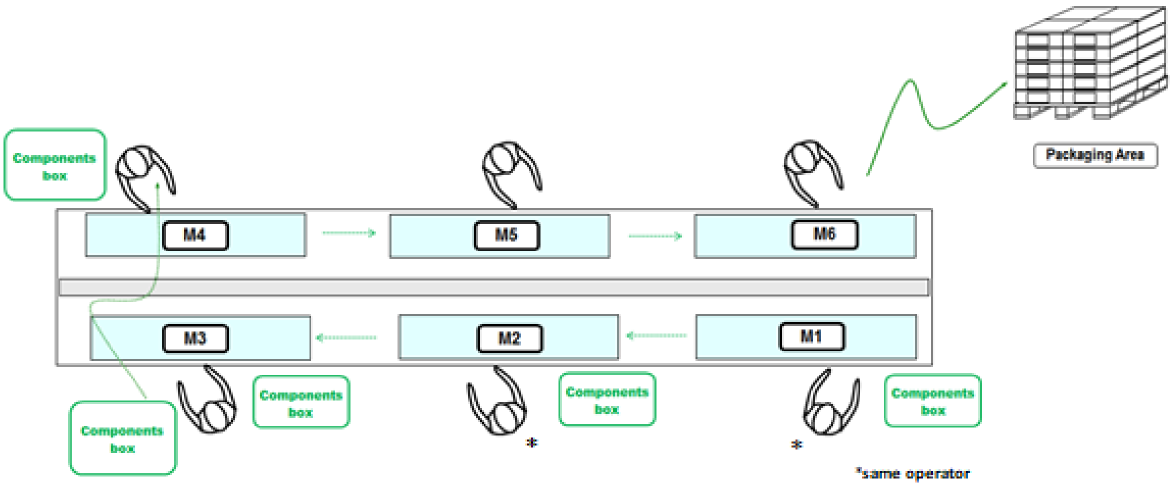

Figure 1. Layout of manual line

The Workstations M1 and M2 are performed by the same operator. The operator presses the control buttons after completing each subset. The subsets are transported through each workstation by a drag mat. In the case of the semi-automated line, only three operators assemble the cables (Figure 2).

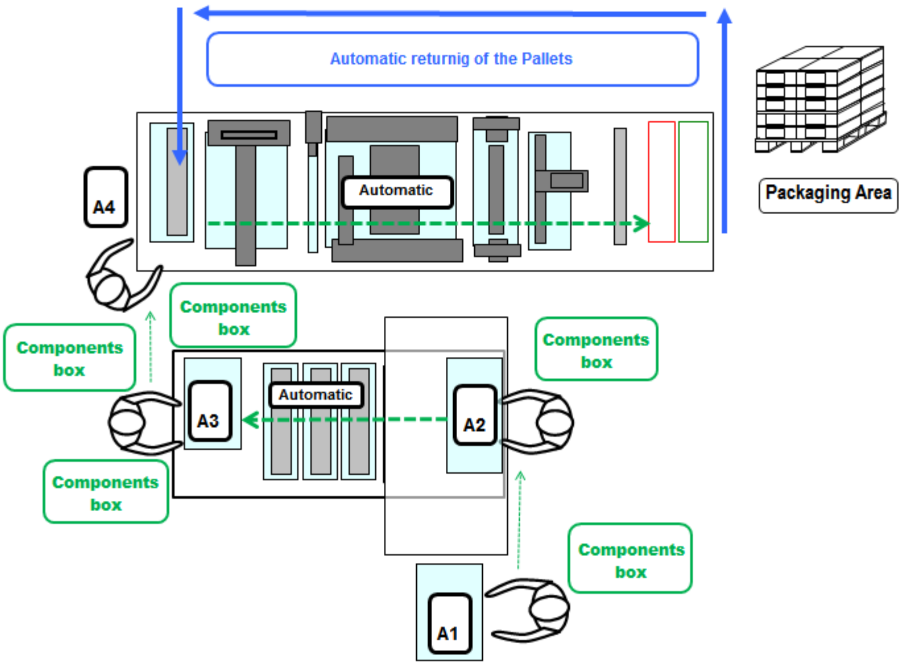

Figure 2. Layout of semi-automated line

"Lubricate conduit", "press second cable terminal" and "rehearsal and recording ink into the final product" are automated processes in semi-automated line. The structure of the lines is different due the automation of some operations. The Workstations A1 and A2 are performed by the same operator. The packing task was not considered in this study.

Table 1 shows a description of both lines in terms of tasks and time cycle.

Table 1. Characteristics of the manual and semi-automated production lines (n=7)

	Workstation	Task	Cycle Time
Manual Line			
	M1	Ream the extremity of conduit	1 (per conduit)
	M2	Lubricate and assemble outer tube in the conduit	5
	M3	Assemble and press terminals of the conduit	5.5
	M4	Assemble the cable in the conduit and cut the edge of the cable	5
	M5	Press second cable terminal	6.7
	M6	Rehearse and record ink into the final product	6
Semi-automated Line			
	A1	Ream the extremity of conduit	1 (per conduit)
	A2	Assemble the outer tube in the conduit and place the subset in the automatic pallet of the equipment	5.5
	A3	Assemble and press terminals of the conduit	5.5
	A4	Assemble cable in the conduit	6.7

2.2. Subjects

Seven experienced female assemblers were recruited and accepted to participate in this field study. All workers belonged to the afternoon shift and were right-handed. Their average age was 37.3 years old (range: 24-55 years) with 5.7 years (range: 1-14 years) of working experience. The participants signed an informed consent approved by the School of Health of Polytechnic Institute of Porto Ethical Committee. None of the subjects reported any pain or musculoskeletal disorders. Table 2 shows anthropometric and body composition data of the sample.

Table 2. Anthropometric data and body composition of the sample

		Manual Line	Semi-automated Line
Anthropometric Data (Standing)	Stature (cm)	161.55 (± 6.36)	155.00 (± 3.91)
	Eye height (cm)	149.54 (± 6.17)	145.02 (± 4.50)
	Shoulder height (cm)	134.14 (± 5.31)	129.08 (± 3.75)
	Elbow Height (cm)	103.25 (± 5.15)	98.02 (± 2.05)
	Wrist height (cm)	71.09 (± 3.62)	68.95 (± 2.86)
	Shoulder breadth (bi-deltoid) (cm)	42.75 (± 2.98)	41.77 (± 3.72)
	Elbow-wrist distance (cm)	31.11 (±1.90)	29.85 (± 0.46)
	Forward Reach (cm)	66.19 (± 2.78)	63.73 (±1.34)
Body Composition*	Weight (Kg)	59.68 (± 9.76)	52.75 (±11.10)
	Skeletal Muscle Mass (Kg)	22.35 (± 1.69)	21.40 (± 2.83)
	Body Fat Mass (Kg)	17.98 (± 1.44)	16.85 (± 1.20)
	Body Fat Percentage (%)	29.83 (± 8,78)	24.75 (± 6.01)
	Body Mass Index (BMI)	22.95 (± 4,18)	21.45 (± 3.04)

*Body composition was determined by bioelectrical impedance analysis (BIA).

2.3. Data collection procedure

Upper limb movements (joint angle) were collected during a normal working day in all workstations of both lines after two hours of assembly work. Video recordings were carried out simultaneously with direct measurements of operators' upper-limb mechanical exposure, using a high velocity camera (Casio EX-FC 100, Japan). Implemented task rotation schemes in the production area made it easier data collection procedures. The seven selected participants had skills to perform all tasks of the workstations of both assembly lines. In each workstation were assessed two participants, after completing at least four work cycles. This procedure was performed to not interfere with the line efficiency. The duration of this procedure was 10 min. per subject. When necessary, magnetic interferences were minimized by waiting 30 s in a normal condition, to restore the initial accuracy of the device.

2.4. Instrumentation

The movements of the participants were recorded by a full body inertial motion capture called Xsens MVN BIOMECH system (Xsens Technologies BV, the Netherlands). This system can estimate body segment orientation and position changes by integration of gyroscope and accelerometer signals which are continuously updated using a biomechanical human body model. The equipment has 17 MTx sensors with two Xbus Masters. The MTx sensors are an inertial and magnetic measurement unit that contains 3D gyroscopes, 3D accelerometers and 3D magnetometers (Roetenberg, Luinge, & Slycke, 2009). Before each trial, the inertial acquisition system was calibrated with the anthropometric data of the subjects (Xsens Technologies B.V., 2011). Data capture was done through a graphical interface (Moven Studio V3.1; Xsens Technologies BV, the Netherlands). A kinematic coupling algorithm (KiC^{TM}) was implemented to reduce magnetic disturbances. Positions of anatomical landmarks were placed according to the orientations of the sensors in combination with the biomechanical model. Figure 3 shows the location set for the sensor's modules. Inertial data were collected at a sampling rate of 100 Hz. Due to the dominance in the performance of assembly tasks, data were analyzed from the angular position of the right arm.

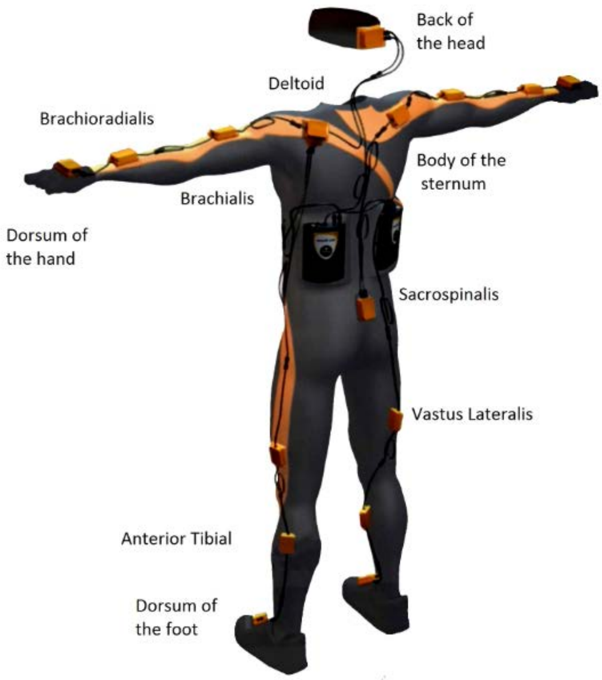

Figure 3. Positioning of inertial sensor modules

2.5. Statistical Analysis

Descriptive statistics of joint angles over time were calculated to the subjects at each workstation. The waveform similarity over work cycles was calculated to evaluate inter-trial repeatability using the maximum cross-correlation. Cross-correlation was determined between subjects in each workstation and between subjects in the workstations of the A1 vs M1, A3 and

M3 vs A4 vs M4 of the two assembly lines in study (Manual vs. Semi-automated). Maximum cross-correlation values quantified the waveform similarity with values between 0.1 and 0.3 as weak, 0.3 and 0.5 as moderate and 0.5 and 1 as strong (DeGroot & Schervish, 2011). All statistical analyses were complete using R version 3.1.1. A p-value less than 0.05 was regarded as statistically significant.

3. RESULTS

The upper-limb mechanical exposure was assessed by direct measurements of joint angles of the right arm (dominant hand) in real-occupational setting (Figure 4).

Figure 4. Workplace measurements

Table 3 shows means and percentiles of joint angles at each workstation. The manual line exhibited a wider range (5-95th percentiles) of motion for the shoulder, in particular for the abduction/adduction and internal/external rotation at workstation M3. In the workstation M2 it was also found a large variation for the joint flexion/extension angle. Ulnar wrist deviation was reached values above 20° at all workstations. In the semi-automated line, the elbow flexion angle was higher than 60º (118.53º) in the workstation A2. Additionally, the wrist ulnar/radial deviation angle ranged between -11.55° and 31.52°. As at the manual line, ulnar wrist deviation reached amplitudes higher than 20°. Wrist flexion/extension angle showed a higher variation than the manual line.

In manual line, the waveform similarity between subjects in each workstation was greater for shoulder joint than for the other regions. Wrist joint showed the smallest cross correlation coefficients values. Similar results were found to the semi-automated line. This can be explained given the subjects involved, with different statures and motions. However, the comparative analysis between workstations of two lines (Table 4) indicates that M4 and A4 had very good repeatability among workers for shoulder abduction/adduction movement. All coefficients were statistically significant ($p<0.001$).

4. DISCUSSION

The development of assembly lines with high levels of automation aims to reduce the physical workload, and consequently minimize WMSD and also to increase the productivity. The results of inertial motion capture system for joint angles showed that the manual line had the greatest variation of the joint amplitude, in particular to the shoulder, elbow and forearm. However, in both lines elbow and wrist reached values of joint angles are above the threshold recommended by ISO 11228-3 2007 (International Organization for Standardization, 2007): forawkward posture: >60°, and for elbow and >20° for wrist. Palmerud et al (2012), found that wrist deviation and wrist flexion (on the non-dominant side) were significantly lower in a conventional serial flow assembly line, where workers perform a few number of assembly actions, than in a parallel assembly line with a long-cycle flow. Other study carried out by Womack, Armstrong & Liker (2009) also showed that no significant differences were found in wrist and shoulder postures between a lean automobile-manufacturing (5–8 production workers per team) and a traditional automobile-manufacturing plant (18–20 production workers per team).

Table 3. Mean (SD) and percentiles of joint angles. Flexion, abduction, ulnar wrist deviation, pronation and internal rotation are positive (+); extension, adduction, radial wrist deviation, supination and external rotation are negative (-)

Joint	Motion	Manual Line						Semi-automated Line			
		M1	M2	M3	M4	M5	M6	A1	A2	A3	A4
Mean angle (°) *Percentiles (°)*											
Shoulder	***AB/AD***	*20.79 (±0.19)*	*34.51(±0.35)*	*12.89 (±0.68)*	*18.65 (±7.35)*	*9.91 (±0.81)*	*17.64 (±0.72)*	*13.24 (±1.96)*	*33.30 (±0.35)*	*13.87 (±6.67)*	*6.70 (±1.49)*
	5th	10.73	22.01	**-5.33**	15.19	**-7.74**	6.37	9.00	9.07	-0.54	-5.67
	50th	21.48	35.64	**9.67**	17.96	**7.66**	18.60	11.68	30.68	10.34	5.84
	95th	29.91	41.61	**29.92**	23.,69	**31.86**	26.82	24.56	60.36	32.37	23.04
	IN/EX	*19.78 (±1.84)*	*15.07(±1,50)*	*17.60 (±0.28)*	*-3.19 (±2.97)*	*24.93 (±2.72)*	*11.93 (±0.79)*	*20.62 (±5.48)*	*10.34 (±1.21)*	*19.04 (±4.33)*	*41.44 (±3.04)*
	5th	30.86	-36.60	**-10.25**	-12.87	0.29	**-3.06**	0.11	-24.29	-9.75	16.24
	50th	40.92	-16.19	**18.89**	-2.94	28.88	**9.45**	22.18	13.65	22.27	44.10
	95th	39.78	11.66	**43.94**	7.26	37.99	**34.94**	30.21	33.34	36.76	59.91
	F/E	*10.48 (±0.53)*	*18.44 (±1,40)*	*31.15 (±0.39)*	*11.12 (±1.91)*	*32.78 (±3.46)*	*24.80 (±1.08)*	*12.82 (±13.24)*	*22.61 (±2.90)*	*34.77 (±4.87)*	*30.91 (±0.81)*
	5h	39.05	**-6.17**	13.06	2.87	5.17	6.78	5.31	-19.40	3.63	16.01
	50th	86.39	**14.22**	30.73	10.92	38.28	23.96	12.78	23.78	34.98	30.08
	95th	34.06	**47.66**	45.38	19.83	47.30	42.12	19.23	53.83	56.02	45.19
Elbow	***F/E***	*80.55 (±0.08)*	*50,06 (±1,51)*	*37.64 (±0.41)*	*65.47 (±5.47)*	*48.97 (±1.50)*	*60.90 (±4.47)*	*66.44 (±11.13)*	*77.11 (±26.15)*	*38.13 (±4.84)*	*55.03 (±7.97)*
	5th	40.25	25.95	24.12	50.10	27.86	**20.08**	53.25	**33.80**	5.33	37.09
	50th	86.34	52.04	36.81	65.99	47.11	**51.37**	67.68	**75.31**	37.00	55.94
	95th	95.13	69.95	52.83	75.94	79.73	**111.76**	74.32	**118.53**	65.81	71.96
Forearm	***P/S***	-2.77 (±1.77)	13.20 (±1.58)	7.84 (±0.34)	-1.91 (±4.42)	5.02 (±8.28)	-10.25 (±5.02)	-28.74 (±0.28)	19.39 (±26.77)	18.84 (±7.11)	6.35 (±14.97)
	5th	-14.19	4.85	**-17.78**	-20.08	-10,64	-25.09	-41.75	-8.58	-4.96	-18.31
	50th	-7.55	12.89	**10.09**	-2.27	0,82	-10.07	-33.99	22.20	19.33	10.19
	95tn	26.52	22.71	**32.27**	14.21	38,19	4.07	8.09	36.75	41.87	20.72
Wrist	***R/U***	*13.21 (±1.46)*	*14.39 (±0.99)*	*11.19 (±3.68)*	*20.71 (±7.63)*	*12.43 (±0.79)*	*15.78 (±0.42)*	*12.46 (±2.34)*	*11.13 (±7.02)*	*25.03 (±4.84)*	*14.56 (±22.13)*
	5th	0.33	-14.76	-3.83	5.89	-6.35	-5.13	4.95	**-11.55**	3.18	-9.58
	50th	13.07	19.11	11.72	22.85	12.76	15.03	10.66	**11.74**	24.52	16.14
	95th	27.83	28.81	23.26	34.45	31.80	43.46	31.14	**31.62**	52.40	33.06
	F/E	*-27.66 (±1.68)*	*-6.96 (±3.73)*	*-41.53 (±0.44)*	*-10.29 (±12.68)*	*15.48 (±10.82)*	*-22.45 (±9.22)*	*-52.19 (±15.98)*	*-28.74 (±2.94)*	*-25.53 (±4.85)*	*-31.09 (±10.46)*
	5th	-41.02	-19.39	-58.62	-29.46	0.52	-40.83	-63.50	-46.56	**-60.02**	-47.04
	50th	-27.80	-8.60	-43.98	-7.57	14.18	-23.85	-54.12	-29.84	**-25.22**	-32.59
	95th	-13.08	10.67	-18.75	5.17	35.39	0.41	-31.77	-9.03	**11.38**	-9.23

Table 4. Coefficients of cross correlation of the upper-limb joints

Manual Line								
		Shoulder			**Elbow**	**Forearm**	**Wrist**	
Workstation	**Subjects**	(x) Abduction (+) / Adduction (-)	(y) Internal (+) / External (-) Rotation	(z) Flexion (+)/ Extension (-)	(z) Flexion (+)/ Extension (-)	(y) Pronation (+)/ Supination (-)	(x) Ulnar deviation (+) / Radial deviation (-)	(z) Flexion (+)/ Extension (-)
		r	*r*	*r*	*r*	r	*r*	*r*
M1	1 *vs*. 2	**0.5**	**0.5**	**0.7**	**0.7**	**0.7**	**0.5**	0.4
M2	1 *vs*. 2	**0.7**	**0.5**	**0.6**	**0.7**	**0.6**	**0.8**	**0.6**
M3	1 *vs*. 2	**0.7**	**0.6**	**0.6**	**0.6**	**0.5**	0.3	**0.5**
M4	1 vs. 2	**0.6**	**0.6**	0.3	**0.5**	0.2	0.3	0.4
M5	1 vs. 2	**0.7**	**0.7**	**0.7**	0.4	**0.6**	0.4	**0.5**
M6	1 vs. 2	**0.6**	**0.7**	**0.7**	**0.6**	**0.6**	**0.5**	**0.6**
Semi-automated Line								
A1	1 *vs*. 2	**0.7**	**0.6**	**0.6**	**0.5**	**0.5**	0.4	**0.5**
A2	1 *vs*. 2	**0.5**	0.4	0.4	0.4	0.4	0.3	0.3
A3	1 *vs*. 2	**0.7**	**0.6**	**0.5**	**0.5**	0.4	**0.6**	0.4
A4	1 *vs*. 2	0.3	**0.5**	**0.5**	**0.6**	0.3	0.3	**0.5**
Manual Line vs Semi-automated Line								
M1 *vs*. A1	1 vs. 1	0.3	0.4	0.4	0.3	0.4	**0.5**	0.3
	1 vs. 2	**0.5**	0.4	0.4	**0.5**	0.3	0.3	0.3
	2 vs. 1	0.4	0.2	0.3	0.4	0.4	**0.7**	0.3
	2 vs. 2	**0.5**	0.3	0.4	**0.6**	0.4	**0.5**	**0.5**
M3 *vs*. A3	1 vs. 1	**0.7**	0.4	**0.5**	0.3	0.4	0.3	0.1
	1 vs. 2	**0.8**	**0.5**	0.4	0.3	0.4	0.4	0.3
	2 vs. 1	**0.6**	**0.5**	0.4	**0.5**	0.3	0.3	**0.5**
	2 vs. 2	**0.6**	0.4	0.4	0.3	0.4	0.3	0.3
	1 vs. 1	0.2	0.4	0.4	0.2	0.3	0.4	0.4
M4 *vs*. A4	1 vs. 1	**0.5**	**0.5**	0.3	0.3	0.2	**0.5**	0.3
	1 vs. 2	**0.6**	0.3	**0.5**	0.3	0.2	0.4	0.4
	2 vs. 1	**0.5**	0.2	0.4	0.4	0.3	0.4	0.3
	2 vs. 2	**0.7**	0.4	**0.5**	0.3	0.4	0.3	0.1
	1 vs. 1	**0.8**	**0.5**	0.4	0.3	0.4	0.4	0.3

*All cross-correlations showed P-value less than 0.001.

In fact, automation with human interaction is essential to lean manufacturing (Genaidy & Karwowski, 2003) and there is no consensus about the effects of Lean Production Systems (LPS) on the musculoskeletal health. Some authors referred positive impacts of LPS (Hunter, 2008; Johansson & Abrahamsson, 2009), while others reported negative effects. The results of Balogh et al., (2006) study showed that increased mechanization of assembly lines implies absence of posture and movements' variation and, in the case of the semi-automated line, more constrained postures were found. As stated before, several studies focused on automation and optimization of assembly systems without considering ergonomic aspects (Battini, Faccio, Ferrari, Persona, & Sgarbossa, 2007; Toksari, Işleyen, Güner, & Baykoç, 2008; Wei & Chao, 2011; Yeh & Kao, 2009). The results of this study may also have been influenced by other factors such as age, gender, body mass index (BMI), arm and forearm circumferences and physical activity (Chapleau et al., 2013). Also, work design and planning may have influenced the results. Although the company has implemented automation, there are indications that the work design requires movements and postures which added to personal factors, may have led to the obtained results.

The application of an inertial motion capture system can estimate angular kinematics for the upper limbs in assembly-line workers. In the records performed, the cross correlation obtained for the similarity of movements was from moderate to strong. However, this similarity is more evident when comparing workers from the manual line. These results can be explained by the influence of several poke yokes systems (using electromagnetic radiation) installed in the semi-automated line. Additionally, the semi-automated line was near to a wireless access point and plastic injection machines. According to Brodie, Walmsley & Page (2008), metal physical barriers increased measurement errors in the inertial systems. The same was concluded by Robert-Lachaine et al. (2017a, 2017b) in their studies. In general, the weaker cross correlation values were found for the wrist joint which can be explained by the proximity of this body region with the machinery.

Hence, these results must be interpreted with caution because inertial motion capture systems depend on kinematic characteristics of a task such as motion speed (Kim & Nussbaum, 2013). Comparing the tasks of the different lines (manual line vs semi-automated line), the differences between subjects are more obvious. Although they have comparable tasks, system accuracy may have been affected by the movement characteristics involved in the tasks. The present field study has some limitations. Data collection was performed in a short work time periods (ten minutes) to avoid interference to with production. Additionally, when the worker presses the control buttons in the assembly line, some disturbances are observed in the data capture system (Moven Studio V3.1; Xsens Technologies BV, the Netherlands). It was found that over the time, the inertial system was influenced by the typical magnetic interferences of an industrial environment (Robert-Lachaine et al., 2017b). Another limitation was associated with the small sample size, due to difficulties in subject's recruitment in field studies (in industrial context) and pressure from the production managers to avoid time and production losses. In this particular case, the directive board of the company, allowed to carry out the study in those two assembly lines, with the respective group of workers involved. Despite these constraints, it is important to develop more studies in real work environments and to know the actual ergonomic health condition of industrial workers.

5. CONCLUSIONS

The results of this study suggest that the mechanization of the manual to the semi-automated line conducted to a lower range of motion. However, both lines showed constrained elbow and wrist postures. In fact, it seems that automation does not always result in reduced ergonomic risks. There are indications that work organization design may require movements, which combined with personal factors, led to these findings. The results also demonstrated that the applications of a full-body inertial measurement in assembly work, under realistic conditions have some restrictions possibly caused by the influence of metal physical barriers and electromagnetic interferences detected during data collection. Future studies using inertial motion capture systems should minimize the impact of these disturbances as much as possible. The optimized use of these devices during work tasks will be a useful tool to provide data for occupational health and safety professionals to improve ergonomic conditions in workplaces.

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