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**FEUP** FACULDADE DE ENGENHARIA  
UNIVERSIDADE DO PORTO

# **ANGULAR KINEMATIC ANALYSIS OF THE UPPER-LIMB JOINTS IN ASSEMBLE WORK**

**A COMPARATIVE STUDY IN TWO ASSEMBLY LINES**

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DISSERTAÇÃO DE MESTRADO APRESENTADA

À FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO EM ENGENHARIA DE SEGURANÇA E  
HIGIENE OCUPACIONAIS



## MESTRADO EM ENGENHARIA DE SEGURANÇA E HIGIENE OCUPACIONAIS

Dissertação apresentada para obtenção do grau de Mestre  
Engenharia de Segurança e Higiene Ocupacionais  
Faculdade de Engenharia da Universidade do Porto

# ANGULAR KINEMATIC ANALYSIS OF THE UPPER-LIMB JOINTS IN ASSEMBLE WORK A COMPARATIVE STUDY IN TWO ASSEMBLY LINES

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2014



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## **ACKNOWLEDGEMENT**

I wish to thank a particular group of people for their contribution in the development of this research.

First of all, I would like to express my deep gratitude to Professor Joana Carvalho dos Santos for her patient guidance, enthusiastic encouragement and useful critiques. For her valuable and constructive suggestions during the planning and development of this research work. Thanks for being throw all the good and bad moments.

I would like to express my very great appreciation to Professor João Manuel Abreu dos Santos Baptista.

I would also like to thank the automotive industry that allowed the developing of this research in their assembly lines and for all the assistance in the plant data collection.

I wish to acknowledge the help provided by Pedro Fonseca in the data collection.

I am particularly grateful for the assistance given by Nuno Marques.

To Nelson Ferreira, a special thank for the patient support and companionship.

Finally, I wish to thank my parents for their support and encouragement throughout my study.



## ABSTRACT

Upper limb work-related musculoskeletal disorders (UL-WMSDs) are still the occupational disease with high incidence among workers in the industrialized countries.

One of the most organizational changes was due the technological advances. The development and introduction of automated systems has been successful in terms of improving the precision and economy of operations. Automation technology was originally developed in order to increase the precision of operations while, at the same time, reducing operator workload and training requirements. However, a considerable number of unanticipated problems have been observed such as interaction between human operators and automated systems. The automation of assembly lines could have increased stress, workload demands, working time and decreased of the job stability among workers. Other aspect of the automation systems is the increase of work-pace and consequently the repetitive movements in the performance of tasks in assemble work.

The aim of this study is to make a comparative study of the angular kinematics of the upper limbs joints between subjects in two assembly lines (semi-automatic assembly line vs. manual assembly line) in a Manufacture company of parts and accessories for automotive industry. For that purpose was used an inertial measurement system *Xsens MVN BIOMECH*, in seven healthy operators when performing assemble work.

The results show a strong correlation between subjects in the manual assembly line proven that operators have similar patterns of the ROM of the upper limb articulations in the performance of the tasks.

In the semi-automated, even fewer strong correlations were achieved between subjects. No relation between subjects was detected. Likewise in manual assembly line, it was verified a strong articulation movement pattern between subjects.

In the ROM of upper limbs articulations between subjects in assembly lines studied it was possible to verify that 27.4% of the correlation calculated are strong (0.5 to 1), 64.3% have moderated correlation (0.3 to 0.5) and only 8.3% have weak correlation (0,1 to 0,3). It was not detected no correlation or very weak correlation between subjects studied in the similar workstations.

This fact probably means that even with the improvement of the assembly line in technological aspects the range of motion of the upper limb articulation are the identical between subjects. It apparently indicates that human factors were not taken in account in the workstation design and manufacture.

**Key Words:** *Kinematics; Upper Limb; Musculoskeletal Disorders; Assemble Work; Work Design;*

## RESUMO

As Lesões músculo-esqueléticas nos membros superiores relacionadas com o trabalho (LMEMSRT) continuam a ser a doença ocupacional com maior incidência nas cidades industrializadas.

Ao longo dos anos os avanços tecnológicos conduziram a mudanças organizacionais significativas nas empresas. O desenvolvimento e introdução de sistemas automatizados nos postos de trabalho e equipamentos tem sido bem-sucedida em termos da melhoria da precisão das operações e economia das empresas. A automatização tinha o objetivo de aumentar a precisão das operações, enquanto era também obtida redução da carga biomecânica dos colaboradores e respetivos requisitos de formação. Contudo, algumas dificuldades foram detetadas, nomeadamente na interação homem-máquina. A automatização das linhas de montagem pode ter aumentado os níveis de estresse, as exigências relativas ao trabalho, horas trabalhadas e a diminuição da estabilidade do posto de trabalho. Outro aspeto influenciado foi o aumento do ritmo do trabalho e por conseguinte o aumento dos movimentos repetitivos na realização de tarefas de montagem manual.

O objetivo deste estudo é realizar uma análise comparativa da amplitude movimentos das articulações dos membros superiores dos colaboradores de duas linhas montagem (linha de montagem semiautomática vs. linha de montagem manual) numa Indústria de Fabricação de componentes e acessórios para a indústria automóvel. Para a recolha dos dados foi utilizado um equipamento de medição inercial *Xsens MVN BIOMECH*. Sete colaboradoras saudáveis participaram neste estudo aquando da realização de tarefas de montagem manual nas linhas de montagem.

Os resultados do estudo e os padrões dos movimentos indicam que existe forte correlação na amplitude de movimentos adotados entre as colaboradoras nos mesmos postos de trabalho de ambas as linhas.

Na linha de montagem semiautomática foi encontrado um menor número de valores na gama de correlações fortes. Contudo, não foi verificado a não correlação entre os sujeitos nos mesmos postos de trabalho avaliados.

Na amplitude de movimentos das articulações dos membros superiores entre as colaboradoras das linhas de montagem em estudo foi possível verificar que 27.4% estão na gama da correlação forte (0.5 to 1), 64.3% na gama de correlação moderada (0.3 to 0.5) sendo que 8.3% encontravam-se na gama de correlação fraca (0,1 to 0,3). Não foi verificada a não correlação ou correlação muito fraca entre os indivíduos nos postos de trabalho semelhantes em estudo.

Os resultados provavelmente indicam que mesmo com a automatização e melhoria das condições tecnológicas na linha de montagem semiautomática não foi tido em conta os fatores humanos dos indivíduos dado que a amplitude de movimentos adotado é semelhante em ambas as linhas.

**Palavras-Chave:** *Cinemática; Membro Superior; Lesões Músculo-esqueléticas; Trabalho Manual; Design do Trabalho;*

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## **ABBREVIATIONS**

ALB – Assembly Line Balancing

BMI – Body Mass Index

DOF – Degrees of Freedom

EU – European Union

GPS – Global Positioning System

IMU – Inertial Measurement Unit

LPS – Lean Production System

LLD – Lower Limb Disorder

Mo-Cop – Motion Capture System

MSD – Musculoskeletal Disorder

ROM – Range of Motion

UL-WMSDs – Upper Limbs Work-related Musculoskeletal Disorders

WMSDs – Work-related Musculoskeletal Disorders

LMEMSRT – Lesões músculo-esqueléticas nos membros superiores relacionadas com o trabalho



# **PART 1**



# 1 INTRODUCTION

Revolutionary changes in organization of work over the years conveyed to several impacts in quality of working life and for health and safety of workers in companies. Those changes were:

- Reduce of the workforce;
- Increase of the number of temporary workers and contractor-supplied labor;
- Adoption of more flexible and lean production technologies.

Pros of work organization changes are mostly related with the increase of flexibility, responsibility and learning opportunities that can lead to the satisfaction and well-being of workers.

The main causes of the work organization change was due to the economics change, client's demands, mass production, customized products, technology development, and politics (NIOSH, 2003).

For the mass production, industries still have preference for assembly lines in order to accomplish the client's demands and reducing of the inherent costs. These types of 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 diminished of the workforce.

Automation development created an autonomous system that required little if any human involvement and therefore reduced or eliminated the opportunity for human error. Automation of workstations could substitute human action without any larger impact on the system reducing workforce costs (i.e., workers safety and training). Thus, even highly automated systems still requires workers involvement and therefore coordination between human and machine (Sarter, N. B., Woods, D. D., & Billings, 1997). This fact can lead to the increase of ergonomic risk factors.

The mass production, the automation of workstations and the implementation of manufacture production systems as Lean disregarding the human factors can lead to the development of work musculoskeletal disorders (WMSDs). When this type of 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 (Luger, Bosch, Veeger, & de Looze, 2014).

In a comparative study of Balogh *et al* (2006) among semi-automated, manual and automated workstations, results has shown that improvements made from the manual to the semi-automated line implied lower muscular activities and more possibilities for muscular recovery. The improvement of ergonomic conditions prevents illnesses, reduces absenteeism and improves productivity, product quality, and workers' quality of life (Baraldi & Kaminski, 2011). On the other hand the absence of specific ergonomic criteria in the development of workstations increases intensity and monotonous movements (Neumann, Kihlberg, Medbo, Mathiassen, & Winkel, 2010).

In this study is going to be developed a comparative evaluation in two types of assembly lines in a manufacture company of parts and accessories for automotive industry. For that purpose it will be evaluated the right upper-limb movements adopted by operator's in a manual assembly line and in a semi-automatized line using an inertial motion capture system *Xsens MVN BIOMECH*.

The final purpose of this study is to compare the angular kinematic data of the right elbow, shoulder and wrist articulations of the operators of the two assembly lines and propose improvements measures in order to enhance the health and well-being of worker's in assemble work.



## 2 STATE OF THE ART

### 2.1 Musculoskeletal Disorders

The musculoskeletal disorders (MSDs) can be described as inflammatory and degenerative disease and disorder of the musculoskeletal tissues as muscles, tendons, ligaments, joints, and blood vessels that result in pain and loss of physical function in the body.

These type of injuries can be aggravated or induced by work and how it is performed designated by work-related musculoskeletal disorders (WMSDs). The disorder restricts the workers participation in society, work and has several negative impacts to state, companies and operators (Table 1) (Devereux & Buckle, 1999; Eurofound, 2007; Golubovich, Chang, & Eatough, 2014).

Table 1 Negative impact of WMSDs for States, Companies and Workers (CRPG, 2005)

State	Companies	Workers
<b>Health costs</b>	Increase of the absenteeism	Loss of wage income
<b>Increase of the compensation for disabilities</b>	Increase of the costs due to the substitution of the operator	Loss of quality of life
<b>Higher administrative costs</b>	Decrease of the production rate (i.e., the new operator is not trained in the work method)	Lack of motivation
<b>Rehabilitation costs</b>	Increase of training costs	Lack of involvement in family life

WMSDs depends on the part of the body that is affected and the nature of work:

- Occupations related with long periods of repetitive and static work, that can lead to the inflammation of the tendons of the wrists and forearms;
- Occupations concerning static positions that enable pain and function impairment of the muscles on the shoulder and neck region;
- Nerve compression occurring in the wrist and forearm;
- Occupations regarding manual handling or heavy physical tasks that can develop degenerative disorders in the spine, usually in the neck or lower back areas. Those can occur in the hip or knee joints.

WMSDs are a significant danger to health and quality of life of workers in a vast range of occupations (e.g., and industries (e.g., service, construction, transportation, manufacturing), nursing, clerical work, airplane baggage handling, cleaning, truck driving, firefighting) (Golubovich et al., 2014).

These types of illness are considered chronic and mostly occur after prolonged exposure to work-related risk factors conditions as: a) awkward postures, b) repetitive strain, c) vibrations; d) carrying of heavy loads; e) applying force or pressure, f) exposure do low temperatures and g) insufficient recovery time (Table 2) (Latko *et al.*, 1999; WHO, 2003). Other risk factors have been described:

- Patient-related factors (e.g., genetic background and history of disease);
- Non work-related factors (e.g., lifestyle, recreational activities, and activities in the home) (Bongers, Ijmker, van den Heuvel, & Blatter, 2006).

The treatment and recovery can usually be unsatisfactory due to the chronic causes leading to permanent disability and loss of employment (Devereux & Buckle, 1999; Eurofound, 2007).

The most regular WMSDs cases recognized as occupational musculoskeletal diseases of the Member States were epicondylitis of the elbow (16054 cases) and tenosynovitis of the hand or wrist (12962 cases). Additionally there were 17395 cases of carpal tunnel syndrome, a neurological disease of the wrist (EU-OSHA, 2010).

Table 2 Main factors of the development of WMSDs (adapted by Lakto et al (1999); WHO, (2003))

Factor	Possible health result or consequence	Working Example
<b>Exertion of high intensity forces</b>	Acute overloading of the tissues	Lifting, carrying, pushing, pulling
<b>Handling heavy loads over long periods of time</b>	Degenerative diseases especially of the lumbar spine	Manual materials-handling
<b>Frequently repeated manipulation of objects</b>	Fatigue and overload of muscular structures	Assembly work; Long time typing; Check-out work
<b>Working in unfavorable posture</b>	Overload of skeletal and muscular elements	Working with heavily bent or twisted trunk or hands and arms above shoulders
<b>Static muscular load</b>	Long lasting muscular activity and possible overload	Working overhead; Working in a confined space
<b>Muscular inactivity</b>	Loss of functional capacity of muscles, tendons and bones	Long term sitting with low muscular demands
<b>Monotonous repetitive manipulations</b>	Unspecific complaints in the upper extremities (RSI)	Repeated activation of the same muscles without relaxation
<b>Exposition to vibrations</b>	Dysfunction of nerves reduced blood flow; Degenerative disorders	Use of vibrating hand tools; Sitting on vibrating vehicles
<b>Physical environment factors</b>	Interaction with mechanical load an aggravation of risks	Use of hand-held tools at low temperatures
<b>Psychosocial factors</b>	Augmentation of physical strain, increase in absence of work	High time pressure, low job control, low social support

## 2.2 Costs and Statistics of Musculoskeletal Disorders

The most prevalent occupational-related health disease in the European Union are the WMSDs. Others that have high occurrences are neurologic diseases, lung diseases, diseases of the sensory organs, and skin diseases (Figure 1) (EU-OSHA, 2010; Eurofound, 2007).

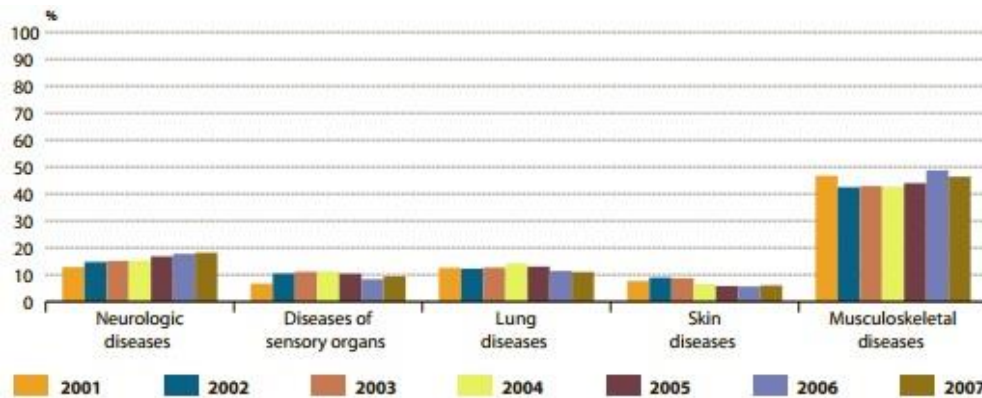


Figure 1 Percentage distribution of occupational diseases, 2002-2005 EU-OSHA, (2010)

European Union has been seeing an increase in the number of workers with WMSDs and is estimated that forty million workers are affected by these health problems. WMSDs are a cause of alarm not only because of the health effects on individual workers, but also because of the economic impact on businesses and the social costs to European countries. The accurate extent of costs within the workplace is difficult to assess and compare due to the different organization of insurance systems and the lack of standardized assessment criteria. Nevertheless, in European Union is predictable that financially the costs of the WMSDs are between 0.5% and 2% of the Gross Domestic Product (GDP).

The most prevailing health problems among workers in European Union are backache and muscular pain (combined index of pain in shoulders, neck and/or upper/lower limbs). In 2005, 24.7% of the European workers in the EU-27 complained of back pains, 22.8% of muscular pain in the arms and legs, and 45% affirmed that worked in painful or tiring positions (EU-OSHA, 2010).

Since 2000, the percentage of workers exposed to repetitive movements has increased reaching 62.3% in 2005. The Portuguese, the Romanians, the Lithuanians, the Latvians, the Greeks, the Poles and the Finns are the most exposed to the repetitive movements and carrying of heavy loads. On the contrary the Danes, the Italians, the inhabitants of Luxembourg, the Dutch, the Belgians, the Irish and the inhabitants of Malta, are the least exposed to this type of risk (Eurogip, 2007).

### **2.3 Development of Upper Limbs Musculoskeletal Disorders**

WMSDs are divided in subcategories such as Back Disorders (BD), Upper Limb Disorders (ULDs) and Lower Limb Disorders (LLDs). The most common WMSD in the European Union and in industrialized world are the Upper Limb Work-related Musculoskeletal Disorders (UL-WMSDs) (Finneran & O'Sullivan, 2010). These type of disease refers to injuries that affects the anatomical sites of the hand, arm, shoulder and neck. It occurs mostly due to the type of work and the intensive use of the hands.

The group of workers that seems to be more affected are: a) industrial assembly line workers, b) workers at supermarket checkouts, c) garment sewing machinists, d) musicians and e) keyboard users (EU-OSHA, 2010).

A wide number of member states of the EU (i.e., Sweden and Great Britain) have studied representative samples of the workforce with regard to WMSDs. Results have shown that problems for the neck and upper limb are second in importance only to back disorders (Devereux & Buckle, 1999).

The relation between musculoskeletal problems and physical exposure has become progressively evident. 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. The disorders are characterized by the type of tissue affected: a) muscle, b) tendon/ligament, c) nerve, d) circulation, e) joint, f) bursa (Table 3).

The main disorders reported by the industry are epicondylitis, tendinitis and carpal tunnel syndrome (Byström, Hall, Welandar, & Kilbom, 1995; Latko et al., 1999; EU-OSHA, 2010).

Researchers from the United States, Denmark, Finland, Sweden and England developed a conceptual model which reveals the possibilities that can lead to the development of WMSDs (Devereux & Buckle, 1999). The model indicates a group of interacting concepts as exposure, dose, capacity and response. Worker activity is the dose that affects the soft tissues. Consequently the dose will cause a physiological and biomechanical reaction. If during the long exposure period of the dose the body does not have the time to regenerate the responses will keep appearing until some type of structural tissue deformation occurs in the form of pain, swelling and limitation of the worker's movement (Figure 2) (Buckle & Devereux, 2002; Devereux & Buckle, 1999).

Table 3 Neck and upper limb musculoskeletal disorders; adapted by (Buckle & Devereux, 2002)

Tendon-related disorders	Nerve-related disorders	Muscle related disorders	Circulatory/vascular type disorders	Joint-related disorders	Bursa-related disorders
Tendinitis/peritendinitis/tenosynovitis/ synovitis	Carpal tunnel syndrome	Tension neck syndrome	Hyphothenar hammer syndrome	Osteoarthritis	Bursitis
Epicondylitis	Cubital tunnel syndrome	Muscle sprain and strain	Raynaud’s syndrome		
De Quervain’s disease	Guyon canal syndrome	Myalgia and myosistis			
Dupuytren’s contracture	Pronators syndrome				
Trigger finger	Radial tunnel syndrome				
Ganglion Cyst	Thoracic outlet syndrome				
	Cervical syndrome				
	Digital neuritis				

Nowadays the psychosocial work environment may also enhance the development of WMSDs due to the organization of work and the perceptions or beliefs held by workers regarding the way work is organized. The work-related psychosocial factors can be high perceived job stress and high jobs demands (Figure 3) (Bongers et al., 2006).

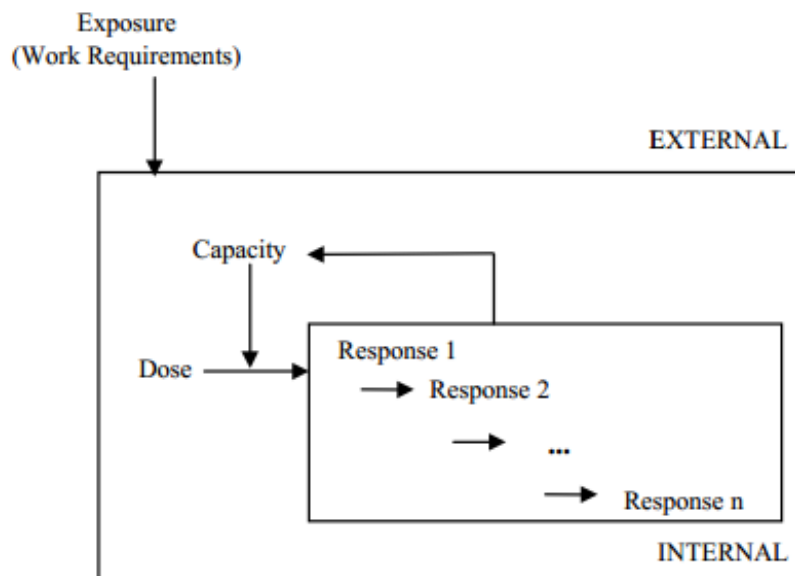


Figure 2 Pathways involved in the pathogenesis of UL-MSDS (Buckle & Devereux, 2002)

The musculoskeletal and peripheral nerve tissues are also affected by individual characteristics and systemic diseases such as rheumatoid arthritis, gout, lupus and diabetes. Risk varies by age, gender, socioeconomic status, and ethnicity. Other suspected risk factors include obesity, smoking, muscle strength and other aspects of work capacity (Punnett & Wegman, 2004).

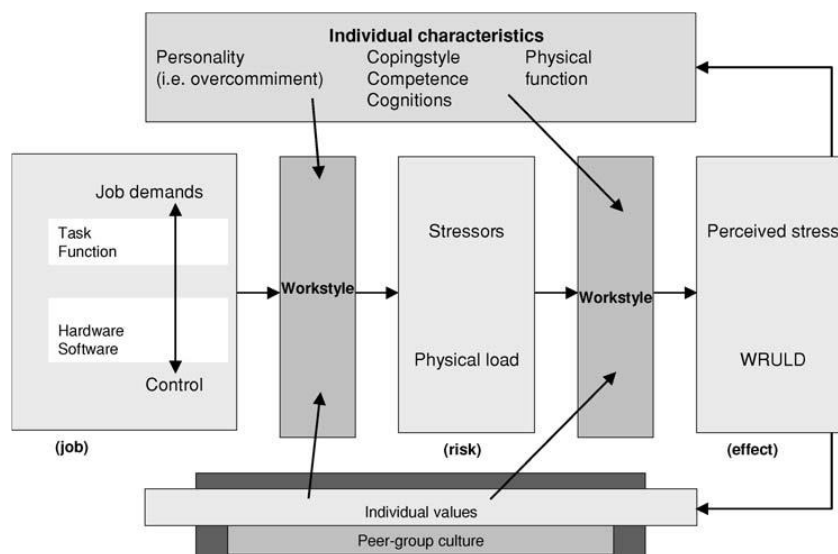


Figure 3 Relations between risk factors of psychosocial and individual origin for neck and upper limb problems (Bongers et al., 2006)

## 2.4 Work Organization and the Impact in Worker's Health

The work organization has been changing through the years mostly because of economic, technological advances, legal, politics and competitiveness among companies.

Initially the manufacture of goods were produced on craft production systems with high quality although the production rate was low. Henry Ford developed and operationalized the concept of mass production. It consisted in lowering the work cycle time, by dividing the operations in elementary tasks, where each worker was expected to perform only a single task. Workers required high physical task exertion, low mental requirements, and little social contact with others (teamwork). The work included: a) mechanical pacing; b) repetitiveness; c) low skill requirements; d) performance of a tiny fraction of the product; e) limited social interaction and f) predetermination of tools and techniques.

Companies due to the economic changes, technological development, enhance of product/service demands, higher quality and customized products had the need to change work organization systems. Organizations are adopting new and flatter management structures (i.e., Lean Production System) that results in downward transfer of management responsibility and decentralized control (NIOSH, 2003)

Lean Production System (LPS) was first developed by Toyota into what is known as the Toyota Production System (TPS) in 1945 and it is based in two main pillars:

- Just In Time (JIT) that consists in producing the right amount needed with the parts and time needed;
- Automation with human touch, whenever are defects or troubles in the working system the workers stop the machines (Genaidy & Karwowski, 2003).

LPS lies in principles of teamwork, communication, continuous improvement and waste elimination that leads to better quality, productivity and market responsiveness. A LPS pursues

the decrease of non-value added work (waste) which in the context of automotive industry in grouped into seven categories:

- Overproduction: producing sooner or more than the next downstream customer requires;
- Waiting: idle time;
- Defects: time lost making or fixing defective parts;
- Inventory: parts waiting in process or in finished goods storage;
- Material handling: redundant movement of parts;
- Processing waste: redundant or inefficient steps in the process;
- Motion waste: movement that is inefficient or adds no value (Womack, Armstrong, & Liker, 2009).

The LPS is further characterized by having a) general resources (multi-skilled workers, general-purpose machines, fewer functional specialists); b) decentralized authority; c) lateral communication across functional boundaries; d) faster response time and e) higher degree of integration of both conceptual and execution of production tasks, cited by Genaidy & Karwowski, 2003.

The increment of competitiveness among industrial companies made the working processes more demanding. It was necessary to improve the workforce with the aim to increase the efficiency and effectiveness of work establishing the best work practices (productivity, quality of work and human health).

LPS putting into practice improves the productivity, products quality, human organization, reduces the non-value added work and helps companies to progress. It also provides alterations in all aspects of work, since the production system to the physical work characteristics, all these factors can have a direct influence to the worker’s health and lead to the development of WMSDs (Figure 4) (Womack et al., 2009).

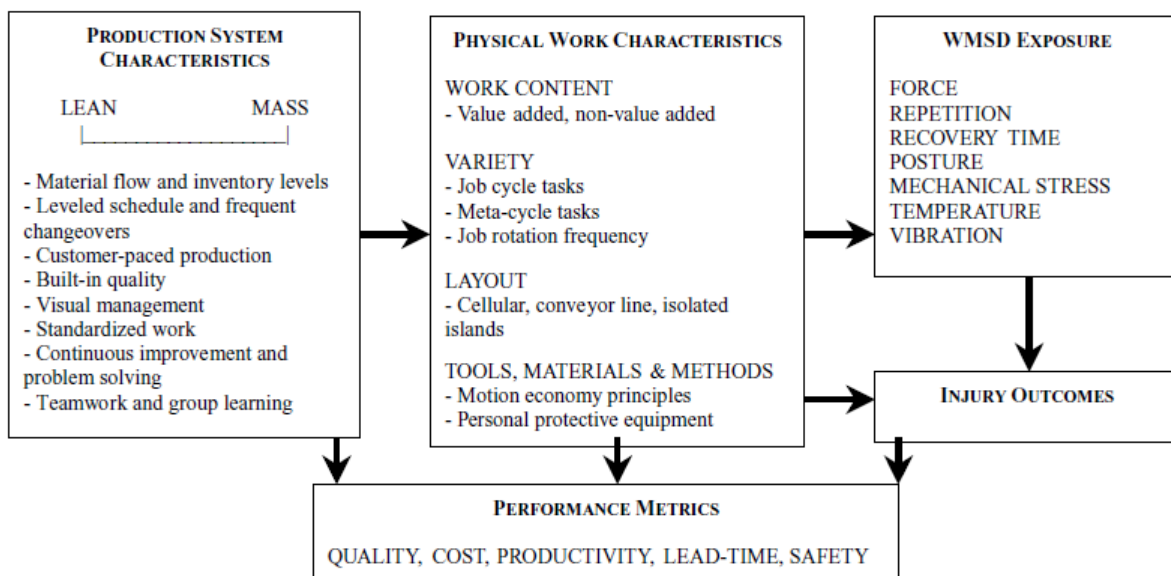


Figure 4 Conceptual framework for links between lean manufacturing implementation, work characteristics, and injury outcomes (Womack et al., 2009).

In addition to the LPS, companies also have implemented complementary systems in order to improve quality of products and reduce non-value work such as:

- *Kanban* (directly connect with JIT system) that controls the logistical chain of the production system establishing a limit of the materials in order to the production system doesn't produces more or less than is required;
- *Heijunka*, process that also reduces the waste producing in a constant and predictable rate;
- *Jidoka* that has a directly connection with JIT, were the operators in each workstation can detect abnormalities of the product and have the capability to solve the problem. Normally the workstations/ equipment's have some devices that can detected the abnormalities and notifies the operator, as *poka-yokes* and *andon* devices.
- *Kaizen* is a system directly connected with continuous improvement activities, such as solving problems techniques (*5 why's*, *ishikawa*), work organization and standardization (*5S*) and worker's safety (Womack et al., 2009).

There is plenty debate if the LPS improves or not the conditions of the health and safety of workers. Some advantages is the increase of workers:

- Flexibility;
- Responsibility and engagement;
- Learning opportunity (offer workers greater potential for self-direction and confidence);
- Skill development;
- Career growth (leads to reduced stress and increase satisfaction and wellbeing);

On the other hand it may increase the a) biomechanical workload; b) repetitive movements; c) work pace and decrease the job control. Those factors can be potentially stressful or hazardous leading to high levels of emotional exhaustion. (NIOSH, 2003). Arezes *et al*, (2010), provided a brief list of some advantages and disadvantages of the implementation of a LPS (Table 4).

Table 4 Advantages and disadvantages of the implementation of a LPS (Arezes, Dinis-carvalho, & Alves C, 2010)

Advantages	Disadvantages
<b>Hierarchical level decrease</b>	Decrease of workers' autonomy
<b>High qualification of the workforce</b>	Increased risk of WMSD development
<b>Worker's participation and engagement</b>	Individual pressure/surveillance
<b>Less Human effort</b>	Job enlargement
<b>Team work increase</b>	Stress increase
<b>Worker's autonomy</b>	Inflexible work pattern
<b>Workforce perceived as central element</b>	Work pace increase
	Work intensification
	LPS Perceived as "modern" Taylorism

Even technology has evolved and provides solutions to reduce biomechanical load nowadays engineers still are more directed to the production systems efficiency than the ergonomic aspects of work. Thus, the major challenge for ergonomics is to design the work in order to prevent WMSD and with no negative impact on production quality and productivity.

Currently assembly lines remain the production system chosen by companies. Assembly line consists of several stations organized along mechanical structures were machines and equipment's are placed. Materials and pieces are moved throw conveyor systems. At each station, certain operations are repeatedly performed regarding cycle time. In the development of assembly lines several conditions have to be taken in account:

- The number of stations necessary to produce the final product;
- Tasks (the total amount of work necessary to assemble a workpiece and is also indivisible referred as task time);
  - The set of tasks assigned to a station (constitutes the station load or work content);
- The cycle time that can be described as the time duration between two entries in a station.

The factors above are taken in consideration in early phase of development in order to improve efficiency and optimize the production system – assembly line balancing (ALB). The ALB consists essentially in all the decisions before workstations are manufacture (Becker & Scholl, 2006). Due to the diverse conditions of the industrial companies and the products characteristics there is a wide range of assembly lines and ALB’s (Table 5) (Boysen, Fliedner, & Scholl, 2008).

Table 5 Different assembly lines production systems (Boysen et al., 2008)

	<b>Assembly Line Model</b>	<b>Characteristics</b>
<b>Number of models</b>	Single-model assembly lines	Traditional form (high-volume production of a single commodity) Negligible set-up times and costs Shorter cycles times
	Mixed-model assembly lines	Mixed-model production Set-up times reduced Homogeneous production processes Same base product Higher cycle times than single model
	Multi-model assembly lines	Multi-model production Heterogeneous production processes The different models are manufactured by use of the same resources Increased set-up times and/or costs Lower specialization of labour Increased training costs
<b>Line control</b>	Paced line	Common cycle time at all stations Pace kept by handling devices that forces the operators to finish the operations before the workpiece has reached Pace by intermittent transport where the workpiece stops at very station and its transferred as soon the time is elapsed
	Unpaced asynchronous line	Workpieces are transferred whenever the required operations are completed Workpiece is moved as soon as all required operations at a station are completed and the successive station is not blocked by another workpiece In order minimize waiting times, buffers are installed in-between stations, which can temporarily store workpieces The use of a global cycle time not used, instead is used a station-specific local cycle times
	Unpaced synchronous line	Stations wait for the slowest station to finish all operations before workpieces are transferred at the same point in time No buffers needed Treated just like a paced line with intermittent transport, as the cycle time is determined by the slowest station Higher output
<b>Level of automation</b>	Manual	Rely on manual labor Especially common where workpieces are fragile or need to be gripped frequently Assignment of packages of cohesive tasks to workers Operators of adjacent stations support each other in case of an overload wage costs constitute the highest cost factor if manual labor is used extensively quality often suffers if operators are overloaded with work and thus need to work faster
	Automated	Wherever the work environment is hostile to human beings, or where industrial robots are able to perform tasks More economically and with a higher precision Flexible transfer lines - multi-purpose machines with automated tool swaps can perform a number of different tasks at varying speed. High investment Breakdowns of machinery become a relevant planning issue

Automated production systems consist of automated workstations connected by a material handling system whose actuation is coordinated with the stations. In the ideal, no human workers are needed except to perform auxiliary functions such as tool changing, loading and unloading

parts, repair and maintenance activities. Even though the initial investment is higher companies rapidly recover it due to the savings in power/energy saving, less manpower usage and security.

Production systems have been described as “sociotechnical” systems with both equipment (technical) and human (social) subsystems (Neumann et al., 2010).

The automation of stations, specialization and repetition of tasks 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).

### 2.4.1 Production System Design

The production system of the company in study consists in the manufacture of mechanical cables to the automotive industry and has the Lean Production System implemented.

The company essentially has two main production areas; a) manufacture of parts, b) assembly lines area. To produce the final product, assembly lines are supplied by the parts produced in manufacture area and external suppliers. Assembly line have *andon* and *poke-yoke* systems, so all the problems are instantly communicated (maintenance, quality and components supply). When the *andon* system is activated in seconds a team attempts to solve the problem. All the workstations have a limit number of quality problems that can be detected (this depends directly of the cable reference that is being produced), when this number is exceeded the operator has to stop the equipment and activate the *andon* system.

In the beginning of the each shift the operator responsible carries a full verification of major points of the cable quality. Every two hours is also performed a quality verification in order to guarantee the process has not modified throw the hours. Other controls are also made by each operator such as: a) safety items, i.e., all the equipment have the safety protections placed and are operative; b) 5S (workplace organization), i.e., cleaning and organization of the workstation.

To this field study it was selected two assembly lines, a manual line and a semi-automated line. The selected assembly line produces the same type of family product – automotive door cables.

Of the two assembly lines, the manual is the oldest one. The six workstations are organized along two parallel frameworks (Figure 5). In each workstation is an operator which places the components and activates the equipment so the components can be assemble.

Figure 5 Manual Assembly Line Layout

In this line the same operator works on the workstation 100 and 101 given the short time that takes to make one subset of the final cable. The subsets are transported throw each workstation by a drag mat. The task 106 (packing) was not considered in this study.

The semi-automated line was built after the manual and the main purpose of the construction was to produce the same amount of cables reducing the workforce.

The shape of the line is distinct from the manual line (Figure 6) due to the automatic workstations (102 and 105).

Figure 6 Semi-automated Assembly Line Layout

Similar to the manual line, the same operator works in the workstation 100 and 101 due to the short time of production. In this case only three operators assemble the cable, being the rest of the production system automatized. The manual workstations have the same type of the working method and equipment's of the manual line.

The subsets are transported by a mat with pallets where the subsets are placed and are transported through each workstation with the exception of the transport since the workstation 104 to 105 that is made manually by the operator. Both the assembly line's work by the same Lean guidelines (Table 6).

Table 6 Assembly lines characteristics

<b>Production Characteristic</b>	<b>Manual Line</b>	<b>Semi-automated Line</b>
<b>Production Average</b>	540	540
<b>Average time per final product (seconds)</b>	29,2	28,7
<b>Average time per subset (seconds)</b>	4,9	4,8
<b>Team structure</b>	5 operators 1 responsible operator	3 operators 1 responsible operator
<b>Job rotation/flexibility</b>	Rotation every two hours	Rotation only by the operators that are not in the critical workstations
<b>Quality System</b>	<i>Andon</i> <i>Poke-yoke</i>	<i>Andon</i> <i>Poke-yoke</i>

## 2.5 Motion Capture Systems

A major challenge constitutes to engineers when developing or reconfiguring production systems due to all the characteristics that have to be included (i.e., work conditions and production characteristics). Thus, human factors have to be taken in account in early phase of workstations development as: a) ergonomics; b) kinematics; c) safety; d) accessibility of materials; e) lighting

placement and f) cycle time. When health and safety aspects are considered the amount of production can increase for the reason that the performance of workers is tightly linked to their work environment.

A multidisciplinary team has to be included in all the phases of the production system development (i.e., ergonomists, mechanical engineers, supply chain engineers and worker's). Methods and studies are now available to help identify potential risks associated with WMSDs, hazardous jobs or risk factors. The methods can be divided under three main headings:

- Self-reports can be used to collect data on workplace exposure to both physical and psychosocial factors by using methods that include worker diaries, interviews and questionnaires;
- Observational methods that may be further subdivided between:
  - Simpler techniques developed for systematically recording workplace exposure that enable an observer to assess and record data on a number of factors using specifically designed pro-forma sheets for establishing priorities for workplace intervention;
  - Advanced techniques developed for the assessment of postural variation for highly dynamic activities that record data either on videotape or are computer analyzed using dedicated software;
- Direct measurements using monitoring instruments that rely on sensors attached directly to the subject for the measurement of exposure variables at work (David, 2005; Li & Buckle, 1999).

Advanced observational methods are being mostly used by companies in order to improve production system and ergonomics. Virtual reality based methods can analyze postures, biomechanical load and the workstation ergonomic conditions. Using this type of software designers can carry out in a rapid, cost-less and safe way virtual experiments for assembly processes.

In this kind of method the virtual space is approximated to the real situation approximating the physical and intuitive movements of the operators. It can also be included all the characteristics of the workplace such as working environment, human subjects, product components, jigs, workbenches and tools (Chryssolouris, Mavrikios, Fragos, & Karabatsou, 2000). Other type of systems are now being used to evaluate the risk development of WMSDs. Motion Capture Systems (Mo-Cop) has the ability of recording a live motion event and translating it into a 3D recreation. MO-Cop allows by a visual interpretation the human behavior from images sequences providing biomechanical data. Several fields of study utilizes this type of systems such as: a) Ergonomists, b) Medicine; c) Engineering; d) Sports; e) Video Games and Entertainment, among others.

These type of systems were early developed in the 19<sup>th</sup> century and then used by cinematographic companies. In nowadays is being widely used by doctors and scientists to better understand pathologies. Due to the need of the use of these systems a wide range of technologies were developed along the years (Table 7).

Inertial measurement systems (portable 3-D Motion Capture Systems) are also being used providing human biomechanical data. These type of systems can be used indoors or outside and are easily transported (Dutta, 2012). Examples of these type of systems can be:

- *Xsens (MVN BIOMECH; MVN AWINDA)*<sup>1</sup>: full body inertial kinematic measurement system, with the incorporation of video data; uses miniature inertial sensors and wireless communication; easy to use and cost efficient system;

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<sup>1</sup> <http://www.xsens.com/products/mvn-biomech/> accessed at 28/08/2014

- Outputs: position, velocity, acceleration, orientation, angular velocity and angular acceleration;
- *MyoMotion, Velamed*<sup>2</sup> is a 3D kinematic system that enables the capture of human motion completely Portable for use indoors or outside; expandable from 2 to 36 IMU sensors
  - Outputs: Orientation data and linear acceleration data, angular velocities available post hoc, models of all major body joints.

Table 7 Motion Caption technologies

Traditional Marker-based Optical Motion Capture Systems	Computer Vision Optical motion capture software and systems use computer vision	Digital images are processed by software to identify objects in order to track motion. An array of video cameras are connected to a computer running specialized software.
	Special Markers	Markers are either highly reflective balls or else small bright lights that stand out from the background and are simpler for computer vision algorithms to identify.
Drawbacks	Having to wear special suits with markers or have the markers applied to clothing or body. Precise application of the markers is essential, as the software is estimating the position of the subject.	
Modern Markerless Motion Capture Technology	No Markers	Uses advanced computer vision technology to identify and track subjects without the need for any special suits or markers. Advanced algorithms are required

For the development of this field study (data collection outside of a laboratory, library or workplace setting) it was carried out a survey of the scientific data using several scientific data bases as *Web of Science*, *PubMed* and *Academic Search Complete* using several key-words: *Kinematics; Upper Limb; Musculoskeletal Disorders; Assemble Work; Work Design*. A compilation of the scientific papers with most relevant impact were chosen through the analysis of the abstract, results and journal impact. In order to organize all the scientific papers it was used *Mendeley*, a free reference manager.

<sup>2</sup><http://www.velamed.com/englisch/products/kinematics/noraxon/myomotion/myomotion.html> accessed at 28/08/2014

### **3 OBJECTIVES, MATERIALS AND METHODS**

#### **3.1 Objectives**

In the past few years is being a growing interest of the relationship between workplace factors and the development of the disorders of muscles, tendons, and peripheral nerves in the neck and upper limbs.

The statistics indicates that WMSDs are increasing among workers of the EU members states and is believed that are associated with the advance of automation and specialization in work. Automatized production systems requires that workers performs a single task or a very limited number of tasks repeatedly during the day (Stock, 1991). Repetitive exertions have been among the most widely studied stressors to the development of WMSDs (Latko et al., 1997). Nowadays, repetitiveness and monotonous work are common in industries with automated work processes.

According to Baraldi & Kaminski (2011), the ergonomic improvements of the workstations can increase the benefits to the workers (by providing a better quality of life and avoiding long-term injuries and professional diseases) and to the company (by creating competitive advantages in the manufacturing area with the increase of the productivity and avoiding expenses and legal reparations).

The aim of this study is to make a comparative ergonomic evaluation of operators of two types of assembly lines in a Manufacture company of parts and accessories for automotive industry.

For that purpose it will be evaluated the right upper limb movements adopted by the operator's in manual assembly line and in a semi-automatized line. The biomechanical data collection will be made by a portable inertial measurement system *Xsens MVN BIOMECH*.

The final purpose of this study is to compare the angular data of the right elbow, shoulder and wrist articulations of the operators of the two assembly lines and propose improvements measures in order to enhance the health and well-being of worker's in assemble work.

#### **3.2 Materials and Methods**

##### **3.2.1 Operators**

Seven healthy female subjects without any health complaints were included in this study. All the subjects gave written informed consent.

The average ages was 37,3 years (range 24-55) and the mean employment time 5,7 years (range 1-14), all 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 at the middle of the term.

The female employees have been physical evaluated by a bioimpedance analysis to determinate the body composition and the anthropometric data of the upper limb was also collected.

Due to the physical characteristics of one of the subject the kinematics measurements will not be considered in the results of this study.

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. A characterization of the movements performed by the operators (work method) was made (Table 8 and 9). In the data collection was asked to the

operators to follow the working method defined by the process engineer department in the development of the both assembly lines.

Table 8 Characterization of the movements of the upper limb's operators of Semi-automated line

Semi-Automated Line					
Workstation	Task	Work Method	Movement Image	Movement Characterization	Takt Time (Seconds)
100				Elbow flexed at 90° Slight internal rotation and adduction of the forearm (near the medial line of the body) Hand in semi-pronation Cylindrical grip	1
				Shoulder flexion Elbow flexed at 90° Slight internal rotation and adduction of the forearm (near the medial line of the body) Wrist abduction Hand in semi-pronation Cylindrical grip	
101				Shoulder flexion Wrist abduction Hand pronation Tip grip	5,5
				Shoulder flexion Elbow flexed Internal rotation of the forearm Wrist in abduction Tip grip	
				Shoulder in extension and abduction Elbow flexed 90° Slight internal rotation of the forearm Hand in pronation Palm grip	
				Shoulder abduction Elbow flexed 90°	

				Slight internal rotation of the forearm Hand in pronation Palm grip	
				Shoulder abduction Slight internal rotation of the forearm Hand in pronation Cylindrical grip	
				Shoulder abduction Internal rotation of the forearm Wrist in extension Hand in pronation Cylindrical grip	
				Shoulder extension Hand pronation Palm grip	
103				Shoulder flexion Wrist abduction Hand in semi pronation Tip grip	5,5
				Elbow flexed 90° Wrist abduction Hand in semi pronation Tip grip	
				Shoulder abduction Elbow flexed Hand in semi pronation Tip Grip	
				Elbow flexed 90° Wrist abduction Hand in semi pronation Tip Grip	
				Shoulders flexion Hand pronation Wrist abduction with internal rotation Tip grip	
				Shoulder abduction Elbow flexed	

				Wrist in abduction Hand pronation Fingertip grip	
104				Shoulder abduction Wrist abduction Hand in semi pronation Tip Grip	6,7
				Shoulder abduction and extension Wrist adduction Hand in semi pronation Tip grip	
				Elbow flexed Forearm in the medial line of the body Wrist in abduction Hand in semi pronation Tip Grip	
				Left shoulder in abduction Internal rotation of the forearm (near the medial line of the body) Left hand in pronation Cylindrical handgrip Right elbow flexed at 90 <sup>a</sup> Slight External rotation of the forearm Right hand in semi-pronation Tip grip	
				Flexed elbow Wrist in adduction Hand in pronation Tip grip	
				Shoulder flexion Elbow flexed Wrist extension Hand pronation Fingertip Grip	

Table 9 Characterization of the movements of the upper limbs operators of the Manual line

Manual Line					
Workstation	Task	Work method	Movement Image	Movement Characterization	Takt Time (Seconds)
100				Elbow flexed 90° Forearm near the medial line of the body Wrist adduction Hand in semi pronation Cylindrical grip	1
				Elbow flexed 90° Forearm near the medial line of the body Wrist abduction Hand in semi pronation Cylindrical grip	
101				Elbow flexed 90° Wrist in adduction and flexed Hand in pronation Tip Grip	5
				Shoulder abduction with slight extension Elbow flexed Wrist in reference position Tip Grip	
				Shoulder flexion Elbow flexed Hand in pronation Wrist in extension Tip Grip	
				Shoulder flexion and abduction Internal rotation of the forearm Wrist in flexion Hand in pronation Tip Grip	
				Elbow flexed 90° Wrist flexion and abduction Palm grip	

102				Shoulder abduction Hand in semi pronation Tip grip	5,5
				Elbow flexed 90° Hand in semi pronation Tip Grip	
				Shoulders flexion Hands pronation Wrist abduction Tip grip	
				Shoulder abduction in slight extension Hand in semi pronation Tip grip	
				Shoulder flexion Hand in semi pronation Tip Grip	
				Elbow flexed 90 <sup>a</sup> Wrist extension with radial deviation Hand in pronation Finger push	
103				Shoulder in flexion Hand in pronation Wrist in flexion with radial deviation Tip Grip	5
				Shoulder in abduction and flexion Shoulder flexed Hand in pronation Tip Grip	
				Shoulder flexed Hand in semi pronation Tip Grip	

				<p>Medial rotation of the arm</p> <p>Hand in pronation</p> <p>Finger push</p>	
104				<p>Shoulder abduction</p> <p>Elbow flexed with medial rotation</p> <p>Hand in pronation</p> <p>Tip Grip</p>	6,7
				<p>Elbow flexed</p> <p>Wrist in neutral position</p> <p>Hand in semi pronation</p> <p>Tip grip</p>	
				<p>Shoulder in abduction</p> <p>Shoulder flexed</p> <p>Wrist extension</p> <p>Hand in pronation</p> <p>Finger push</p>	
105				<p>Elbow Flexed</p> <p>Left wrist in neutral position with flexion with tip grip</p> <p>Right hand in pronation with cylindrical grip</p>	6
				<p>Shoulder flexion</p> <p>Elbow flexion</p> <p>Wrist in radial deviation</p> <p>Hand in pronation</p> <p>Index finger push</p>	
				<p>Shoulder flexion</p> <p>Elbow flexion</p> <p>Wrist in radial deviation</p> <p>Hand in pronation</p> <p>Thumb push</p>	
				<p>Elbow flexion</p> <p>Wrist extension with radial deviation</p> <p>Index finger push</p>	

### 3.2.2 Instrumentation and Data Collection Procedure

Anthropometric data was collected by the traditional method using two anthropometric rulers, (one sliding ruler fixed at two meters in the wall to measure the stature and other to collect the upper limbs data). For the data collection was requested the operators to adopt the position for standing height (look straight ahead, shoulders relaxed, arms at sides, legs straight and knees together, feet flat, heels almost together and to place the shoulders blades, buttocks and heels touching the measurement surface) and maintain the posture along the measurements. Before the data collection it was asked to operators to remove the working uniform, shoes, socks and all the electric equipment's so it couldn't interfere with the measurements.

It was used a check-list (Appendix 1) to register the values. The following measures were recorded:

- Stature Height: the vertical distance from the floor to the vertex, i.e., crown of the head;
- Eye height, standing: vertical distance from the floor to the inner canthus (corner) of the eye;
- Shoulder height, standing: vertical distance from the floor to the acromion i.e., the bony tip of the shoulder;
- Elbow Height, Standing: vertical distance from the floor to the radial bone; the bony landmark formed by the upper end of the radius bone which is palpable on the outer surface of the elbow);
- Knuckle height: vertical distance from the floor to metacarpal III, i.e., the knuckle of the middle finger;
- Shoulder breadth (bi-deltoid): the maximum horizontal breadth across the shoulders, measured to the protrusions of the deltoid muscles;
- Elbow-fingertip length: distance from the back of the elbow to the tip of the middle finger in a standard sitting position;
- Vertical Grip reach (standing): distance from the acromion to the center of an object gripped in the hand, with the elbow and wrist straight (Pheseant, Stephen; Haslegrave, 2006).

Bioimpedance data collection was made using the *In Body 230 – Body composition analyzer*, a precision scale that provides precision body composition as weight, lean body mass, body fat mass, total body water, dry lean mass, body mass index (BMI), percent of body fat, basal metabolic rate, segmental lean mass (right arm, left arm, trunk, right leg, left leg) and impedance of each segments.

The scale uses a bioelectrical impedance ( $Z$ ) that measures ten impedance measurements using two different frequencies (20 KHz, 100 KHz) at each five segments (right arm, left arm, trunk, right leg and left leg). The measurement duration was 30 seconds.

The bioimpedance examination was made at the medical office of the company at the ambient temperature (20-26 °C) after the anthropometric data collection. The scale *In Body230* was installed following the user manual instructions. In order to provide a correct data and to reduce errors it was introduced the gender, height and age of subject.

To achieve reliable results and high reproducibility was important to adopt a proper posture when placed in the scale (Appendix 2). The output of each measurement was saved in the computer to posterior analysis.

Throw each weighting the hand and foot electrodes were cleaned using disinfectants wipes.

For the angular kinematic data collection was used *Xsens MVN BIOMECH*, an Inertial Measurement system. The system can estimate body segment orientation and position changes by integration of gyroscope and accelerometer signals which are continuously updated by using a biomechanical model of the human body, This allows the tracking of dynamic motion.

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. The sensors are connected by wires to the Xbus Masters (only one cable leading to each limb). The Xbus Masters synchronizes all sensor sampling, provides sensors with power and handles the wireless communication with the laptop.

Before the measurements the equipment was assembled and tested in a mannequin.

The data collection was made in the plant floor, on workstations of the assembly lines selected after two hours of the beginning of the shift so subjects were already adapted to work.

The sensors modules were placed on the feet, lower legs, upper legs, pelvis, shoulders, sternum, head, upper arms, forearms and hands (Figure 7). The setup time in the studied subjects was less than ten minutes.



Figure 7 Sensor Modules Localization

Although the sensors modules were all placed in order to optimize the calibration it is going to be analyzed the ROM of the right upper limb articulations due to the dominance in the performance of the tasks (Table 10).

Table 10 Range of Motions and Degrees of freedom analyzed

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

One degree of freedom of the elbow is going to be examined due to his anatomical particularity. Anatomically the elbow has only one articulation but physiologically has two separate functions: a) pronation/supination and b) flexion/extension (Kapandji, 1987). Pronation/supination movement is also evaluated on the wrist, so the elbow ROM further studied is flexion/extension.

After the placement of *Xsens MVN BIOMECH* on subjects it was performed the calibration. For the correct procedure, subject's foot length was measured using an anthropometric ruler and introduced in the software. For the basic calibration was asked to the operators to adopt the N-

Pose (Figure 8). The aim of the calibration is to determinate the body alignment and body dimensions. Through each measurement the equipment was calibrated.



Figure 8 N-Pose for calibration procedure

### 3.2.3 Statistical Data Analysis

*Microsoft Excel (Office 2013)* was used for the anthropometric and bioimpedance data analysis. For the angular kinematics statistics analysis was used *R*, version 3.1.1., a free software environment for statistical computing and graphics, executing the following procedure:

1. The values that were not considered of the normal assemble work cycles (*outliers*) were rejected (i.e., route of the calibration area until the workstation and *vice-versa*);
2. Due to the high number of values of the data collection it was carried out a *downsampling* of the *datasets* (reduce of the number of samples – 0,01 to 0,1);
3. Graphics development of the articulations ranges (x, y, z) of all subjects in the several workstations;
4. Descriptive Statistics variables of *downsampled* angular kinematic data of the articulation in study (mean; SD; maximum; minimum for each subject in workstation);
5. It was verified that the samples follows a normal distribution in accordance to the Central limit theorem;
6. As the samples are in time series, a cross correlation analysis was made; Cross-correlation and significance level of the data was calculated in the following cases:
  - 6.1. Between subjects in the same workstations in both assembly line (Manual vs. Semi-automated);
  - 6.2. Maximum cross correlation between subjects of the workstations 100, 102 vs. 103 and 103 vs. 104 of the two assembly lines in study (Manual vs. Semi-automated).

The correlation values  $r$  ranges between 1 and -1.  $r > 0$  indicates positive relationship,  $r < 0$  indicates negative relationship and  $r = 0$  indicates no relationship. In general when values are closer to absolute values (-1 and 1) indicates a perfect positive or negative correlation. In accordance to the values achieved correlation can be none to strong (Table 11) (DeGroot, 2011).

Table 11 Strength of relationship of r values

Value of r	Strength of relationship
-1 to -0,5 or 1 to 0,5	Strong
-0,5 to -0,3 or 0,3 to 0,5	Moderate
0,3 to -0,1 or 0,1 to 0,3	Weak
-0,1 to 0,1	None or Very Weak

Descriptive statistic was calculated to all subjects, workstations and assembly lines. Thus, is going to be further analyzed the statistics of the similar workstations (100; 102 vs. 103 and 103 vs. 104) between lines in study.

# **PART 2**



## 4 RESULTS AND DISCUSSION

### 4.1 Anthropometric and Bioimpedance Data

Eight body standing dimensions were chosen due to their importance in workstations design (Table 12). In addition, five other anthropometric indices were calculated: weight; Skeletal Muscle Mass (SM), Body Fat Mass Body Fat Percentage and the Body Mass Index (BMI) (Table 11).

Manual line operators are taller than the semi-automated line (161.55 SD 6.36 cm vs. 155 SD 3.91 cm). It was possible to verify that manual operators were also the heavier (59.68 SD 9.76 vs. 52.75 SD 11.10). In regard of these two anthropometric data it was possible to verify even that the semi-automated subjects were smaller and slimmer the BMI (21,45 SD 3,04) is in accordance to the standard values recommended (18, 5 – 24, 9) (WHO, 2000). It was also verified the same fact in manual line subjects (59.68 SD 9.76). Even though the manual subjects are heavier the Skeletal Muscle Mass (22.35 SD 1.69) is higher than the Body Fat Mass (17.98 SD 1.44). The same occurs in the semi-automated operators (21.40 SD 2.83 vs. 16.85 SD 1.20). Due of the bioimpedance data of one operator the kinematic data collection was not taken in account and rejected the anthropometric data analysis.

Regarding the dimensions (reach, length and depth dimension) manual line operator's data indicates also different in relation to the semi-automated line operators:

- Eye Height (149.54 SD 6.17 vs. 145.02 SD 4.50);
- Shoulder Height (134.14 SD 5.31 vs. 129.08 SD 3.75);
- Elbow Height (103.25 SD 5.15 vs. 98.02 SD 2.05);
- Knuckle Height (71.09 SD 3.62 vs. 68.95 SD 2.86);
- Vertical grip reach (66.19 SD 2.78 vs. 63.73 SD 1.34);
- Elbow-fingertip length (31.11 SD 1.90 vs. 29.85 SD 0.46);
- Shoulder breadth (bi-deltoid) (42.75 SD 2.98 vs. 41.77 SD 3.72).

Table 12 Anthropometric and Bioimpedance Data

	<b>Manual Line</b>	<b>Semi-automated Line</b>		
<b>Anthropometric Data (Standing)</b>	Stature height (cm)	161.55 SD 6.36	155 SD 3.91	
	Eye height (cm)	149.54 SD 6.17	145.02 SD 4.50	
	Shoulder height (cm)	134.14 SD 5.31	129.08 SD 3.75	
	Elbow Height (cm)	103.25 SD 5.15	98.02 SD 2.05	
	Knuckle height (cm)	71.09 SD 3.62	68.95 SD 2.86	
	Shoulder breadth (bi-deltoid) (cm)	42.75 SD 2.98	41.77 SD 3.72	
	Elbow-fingertip length (cm)	31.11 SD 1.90	29.85 SD 0.46	
	Vertical Grip reach (cm)	66.19 SD 2.78	63.73 SD 1.34	
	<b>Bioimpedance Data</b>	Weight (Kg)	59.68 SD 9.76	52.75 SD 11.10
		Skeletal Muscle Mass (Kg)	22.35 SD 1.69	21.40 SD 2.83
Body Fat Mass (Kg)		17.98 SD 1.44	16.85 SD 1.20	
Body Fat Percentage (%)		29.83 SD 8,78	24.75 SD 6.01	
Body Mass Index (BMI)		22.95 SD 4,18	21.45 SD 3.04	

### 4.2 Angular Kinematic Range of Motion – Manual Assembly Line

Several differences between subjects were detected in same workstation. In order to distinguish some of the differences it was discussed the most ROM dissimilarities among subjects.

In workstation 100 the minimum value achieved in shoulder abduction was 5.01° in subject 1 and 0.76° in subject 2.

The maximum value of the shoulder internal rotation are also slightly dissimilar ( $46.32^\circ$  vs.  $52.15^\circ$ ). Minimum values were in extension movement ( $-5.71^\circ$  vs.  $-12.29^\circ$ ) and maximum values in flexion movement ( $37.85^\circ$  vs.  $43.90^\circ$ ) (Figure 9; Table 15).

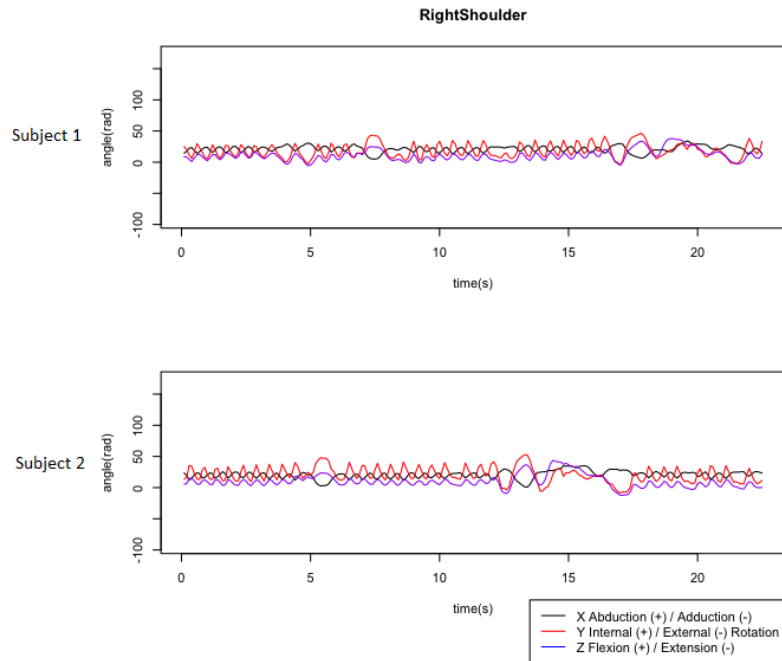


Figure 9 Right Shoulder ROM of studied subjects in workstation 100 - Manual Assembly Line

In the wrist pronation it was likewise found differences between the maximum values of the subjects in workstation 100 ( $45.33^\circ$  vs.  $50.62^\circ$ ). The elbow flexion/extension minimum values obtained were  $28.87^\circ$  and  $14.86^\circ$  respectively on subjects, presenting only values in flexion movements (Figure 10; Table 15).

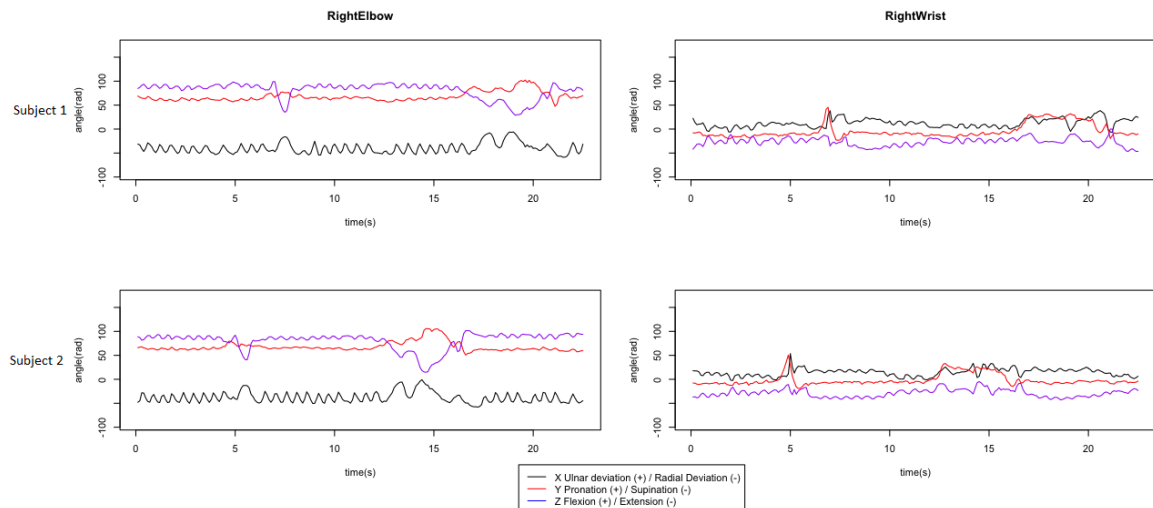


Figure 10 Right elbow and wrist ROM of studied subjects in workstation 100 - Manual Assembly Line

In workstation 102 less significant differences were detected among subjects. It was found maximum values of shoulder flexion of  $62.56^\circ$  to  $56.16^\circ$ . It was not found high variability on the other ROM of shoulder between subjects (Figure 11; Table 16).

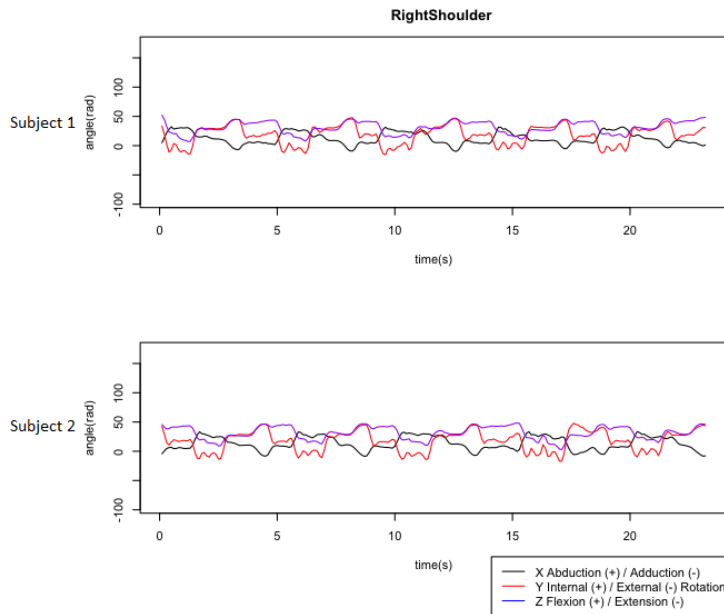
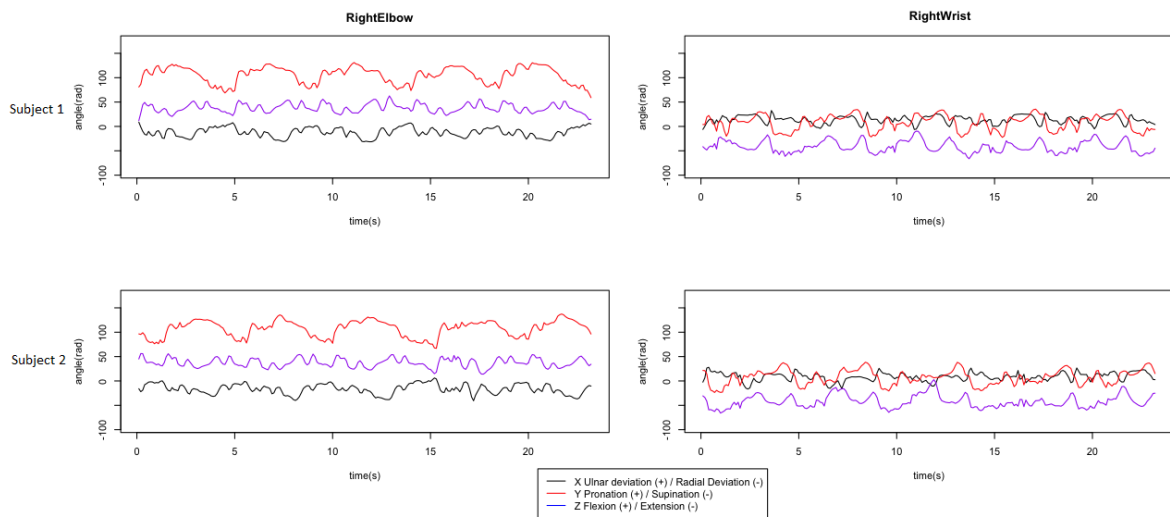


Figure 11 Right Shoulder ROM of studied subjects in workstation 102 - Manual Assembly Line

More significant variability was found in the maximum values achieved of the wrist. Subject 1 achieved the maximum in extension ( $-9.70^\circ$ ) and in subject 2 in flexion ( $2.66^\circ$ ) (Figure 12; Table 13).

Figure 12 Right elbow and wrist ROM of studied subjects in workstation 102 - Manual Assembly Line



In workstation 103 the maximum and minimum values of the ROM of the shoulder are in abduction (+). Although, the movement performed is the same, there is a significant difference ( $\pm 12^\circ$ ) of the values between subjects (minimum:  $7.68^\circ$  vs.  $19.07^\circ$ ; maximum:  $27.06^\circ$  vs.  $40.34^\circ$ ). In flexion/extension ROM it was also found a high dissimilarity among subjects. In subject 1 the minimum value is in flexion ( $2.49^\circ$ ) and subject 2 in extension ( $18.60^\circ$ ) (Figure 13; Table 14).

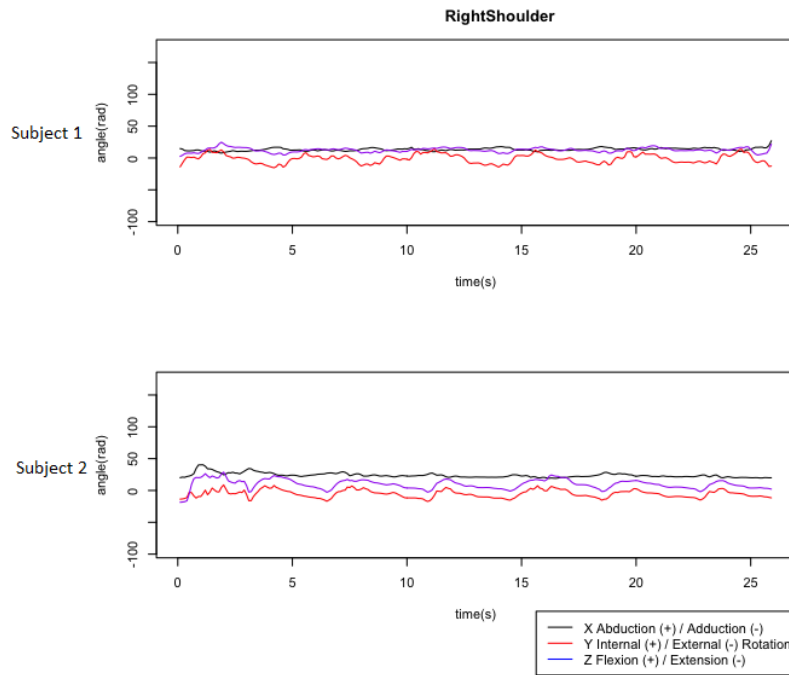


Figure 13 Right Shoulder ROM of studied subjects in workstation 103 - Manual Assembly Line

Maximum values of the elbow flexion was also different among subjects ( $71.95^\circ$  vs.  $124.32^\circ$ ).

At the three DOF of the wrist was also identified diverse dissimilarities. In the *x* axis, the minimum ROM of both subjects were in radial deviation ( $15.98^\circ$  vs.  $44.78^\circ$ ). In the ulnar deviation was not found significant variances. In the *y* axis the minimum values were in supination and the maximum in pronation. The same occurs in the flexion/ extension movement (Figure 14; Table 16).

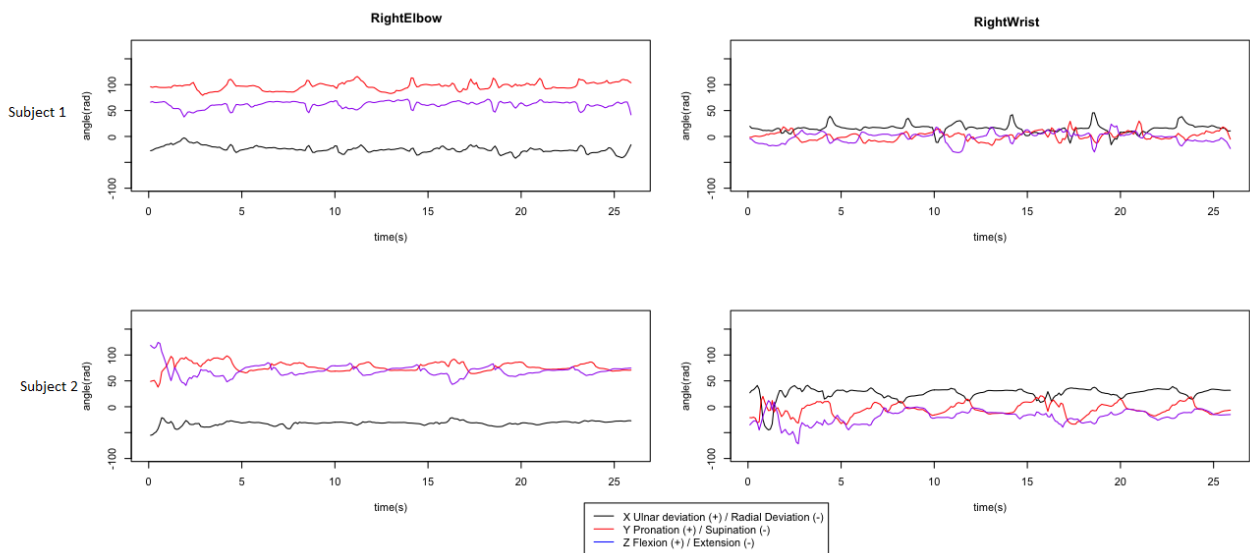


Figure 14 Right Elbow and Wrist ROM of studied subjects in workstation 103 - Manual Assembly Line

As it was expected due to similarities in descriptive statistics most of correlation values between subjects in same workstation are strong (Table 13). 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 of shoulder ROM:

- Abduction/adduction:
  - Workstation 101:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 102:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 104:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 103:  $r= 0.6$ ;  $p=1.05E-02$ ;
  - Workstation 105:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 100:  $r= 0.5$ ;  $p=6.72E-13$ .
- Internal/external shoulder rotation
  - Workstation 104:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 105:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 102:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 103:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 100:  $r= 0.5$ ;  $p=1.31E-10$ ;
  - Workstation 101:  $r= 0.5$ ;  $p=3.57E-14$ .
- Shoulder Flexion/Extension
  - Workstation 100:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 104:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 105:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 101:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 102:  $r= 0.6$ ;  $p=0$ ;
- Elbow flexion/extension
  - Workstation 100:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 104:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 105:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 101:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 102:  $r= 0.6$ ;  $p=0$ ;
- Wrist Ulnar/Radial Deviation
  - Workstation 101:  $r= 0.8$ ;  $p=0$ ;
  - Workstation 100:  $r= 0.5$ ;  $p=2.18E-14$ ;
  - Workstation 105:  $r= 0.5$ ;  $p=0$ ;
- Wrist Pronation/Supination
  - Workstation 100:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 101:  $r= 0.6$ ;  $p=7.52E-12$ ;
  - Workstation 104:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 105:  $r= 0.6$ ;  $p=3.21E-13$ ;
- Wrist flexion/extension
  - Workstation 101:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 105:  $r= 0.6$ ;  $p=2.22E-16$ ;
  - Workstation 102:  $r= 0.5$ ;  $p=2.44E-14$ ;

Moderate correlation (0.3 to 0.5) was detected in:

- Elbow flexion/extension in workstation 104:  $r= 0.4$ ;  $p=4.83E-13$ ;
- Wrist Ulnar and radial deviation in workstation 104:  $r= 0.4$ ;  $p=4.54E-13$ ;
- Wrist extension/flexion in workstation 100:  $r= 0.4$ ;  $p=8.54E-11$ ;
- Wrist extension/flexion in workstation 103:  $r= 0.4$ ;  $p=8.65E-10$ ;
- Shoulder flexion/extension in workstation 103:  $r= 0.3$ ;  $p=2.21E-07$ ;

- Wrist Ulnar and radial deviation in workstation 102:  $r= 0.3$ ;  $p=2.56E-05$ ;
- Wrist Ulnar and radial deviation in workstation 103:  $r= 0.3$ ;  $p=2.69E-06$ ;

Wrist pronation/supination in workstation 103 reached the lower correlation value  $r= 0.2$ ;  $p=7.40E-04$ .

Table 13 Correlation value  $r$  and statistical significance testing  $p$  between subjects in same workstations – Manual Assembly line

Workstation	Subjects Correlation	Shoulder				Elbow				Wrist					
		(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
		$r$	$p$	$r$	$p$	$r$	$p$	$r$	$p$	$r$	$p$	$r$	$p$	$r$	$p$
<b>100</b>	1 vs. 2	0.5	6.72E-13	0.5	1.31E-10	0.7	0.00E+00	0.7	0.00E+00	0.5	2.18E-14	0.7	0.00E+00	0.4	8.54E-11
<b>101</b>	1 vs. 2	0.7	0.00E+00	0.5	3.57E-14	0.6	0.00E+00	0.7	0.00E+00	0.8	0.00E+00	0.6	7.52E-12	0.6	0.00E+00
<b>102</b>	1 vs. 2	0.7	0.00E+00	0.6	0.00E+00	0.6	0.00E+00	0.6	2.01E-11	0.3	2,56E-05	0.5	4.44E-16	0.5	2.44E-14
<b>103</b>	1 vs. 2	0.6	1.05E-02	0.6	0.00E+00	0.3	2.21E-07	0.5	1.83E-12	0.3	2.69E-06	0.2	7.40E-04	0.4	8.65E-10
<b>104</b>	1 vs. 2	0.7	0.00E+00	0.7	0.00E+00	0.7	0.00E+00	0.4	4.83E-13	0.4	4,54E-13	0.6	0.00E+00	0.5	0.00E+00
<b>105</b>	1 vs. 2	0.6	0.00E+00	0.7	0.00E+00	0.7	0.00E+00	0.6	0.00E+00	0.5	0.00E+00	0.6	3.21E-13	0.6	2.22E-16

### 4.3 Angular Kinematic Range of Motion – Semi-Automated Assembly Line

In respect of the Semi-automated assembly line it was detected further significant differences in ROM of articulations among subjects.

In workstation 100 was found a 9° degree dissimilarity in the maximum value of shoulder abduction (30.34° vs. 49.74°). The minimum values achieved in rotation of the shoulder were in external rotation (-22.09° vs. -15.93°) and maximum values in internal rotation (31.81° vs. 38.05°). In the shoulder flexion/extension in subject 1 minimum value (-13.72°) was in extension, in the other hand the minimum value of subject 2 was in flexion (7.94°). The maximum values were both in flexion (25.27° vs. 64.06°) (Figure15; Table 18).

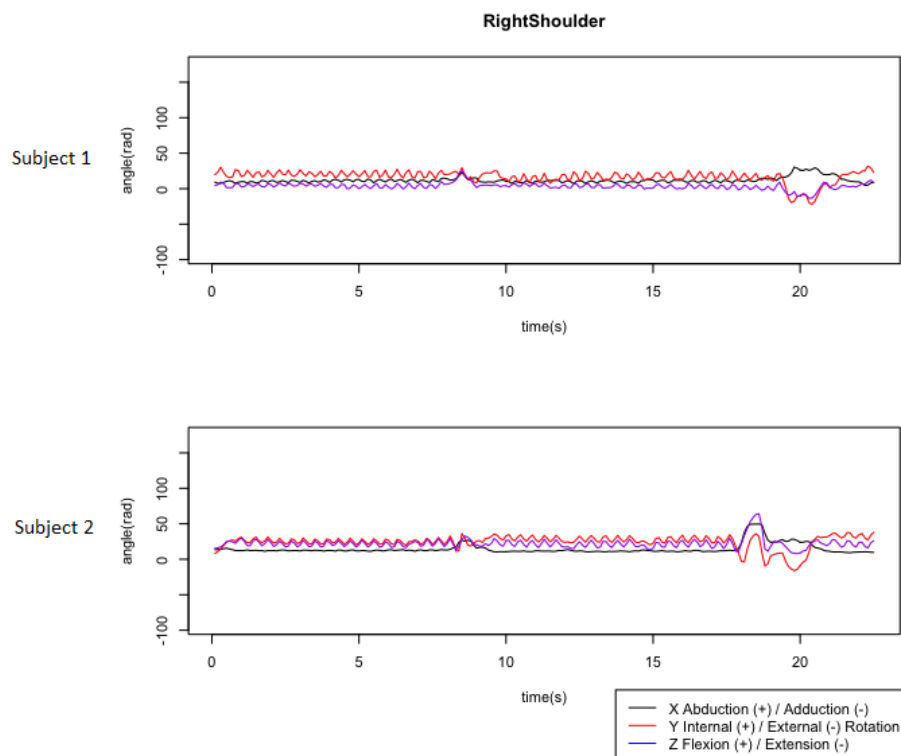


Figure 15 Right Shoulder ROM of studied subjects in workstation 100 – Semi-automated Assembly Line

The maximum and minimum values of the elbow in flexion (minimum: 31.6° vs. 2.88°; Maximum: 112.27° vs. 90.45°) (Figure 16; Table 18).

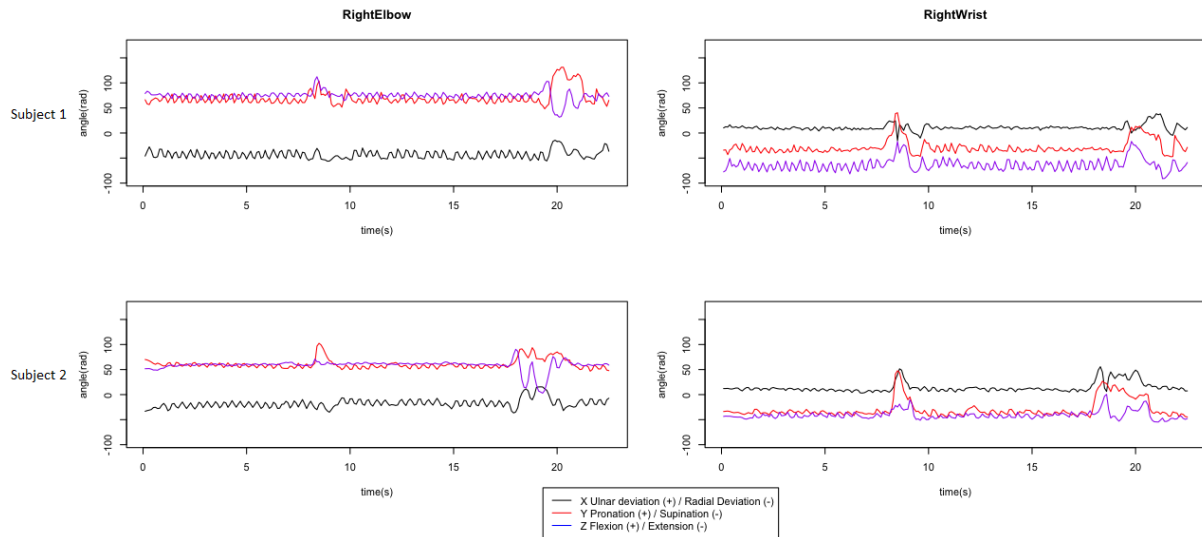


Figure 16 ROM of the Right Elbow and Wrist of the subjects studied in workstation 100 - Semi-automated Assembly Line

The minimum values reached in ulnar/radial deviation in subject 1 was in radial deviation ( $-15.35^\circ$ ), on the other hand in subject 2 was in ulnar deviation ( $3.12^\circ$ ). The maximum values reached were both in ulnar deviation ( $38.51^\circ$  vs.  $55.71^\circ$ ). In wrist pronation the maximum values were disparate ( $40.41^\circ$  vs.  $47.67^\circ$ ). The both minimum values of the wrist flexion/extension were achieved in extension movements ( $-91.03^\circ$  vs.  $-54.73^\circ$ ). It was also verified that the maximum value of the subject one and 2 were in extension ( $-16.80^\circ$  vs.  $0.50^\circ$ ) (Figure 16; Table 18).

In workstation 103 values continue different among subjects. The minimum value of shoulder adduction in subject 1 achieved  $-8.99^\circ$  and subject 2 in abduction  $5.14^\circ$ . The maximum value, as expected were in abduction ( $31.62^\circ$  vs.  $42.33^\circ$ ). In the internal/external rotation of the shoulder maximum value was reached in internal rotation among subjects ( $44.52^\circ$  vs.  $37.63^\circ$ ) (Figure 17; Table 19).

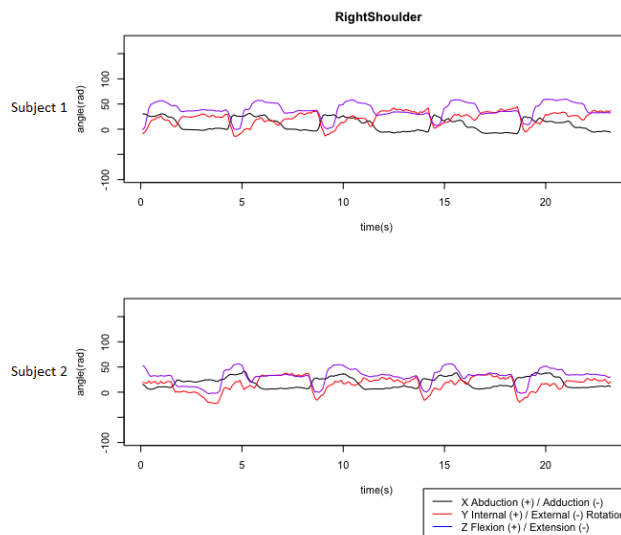
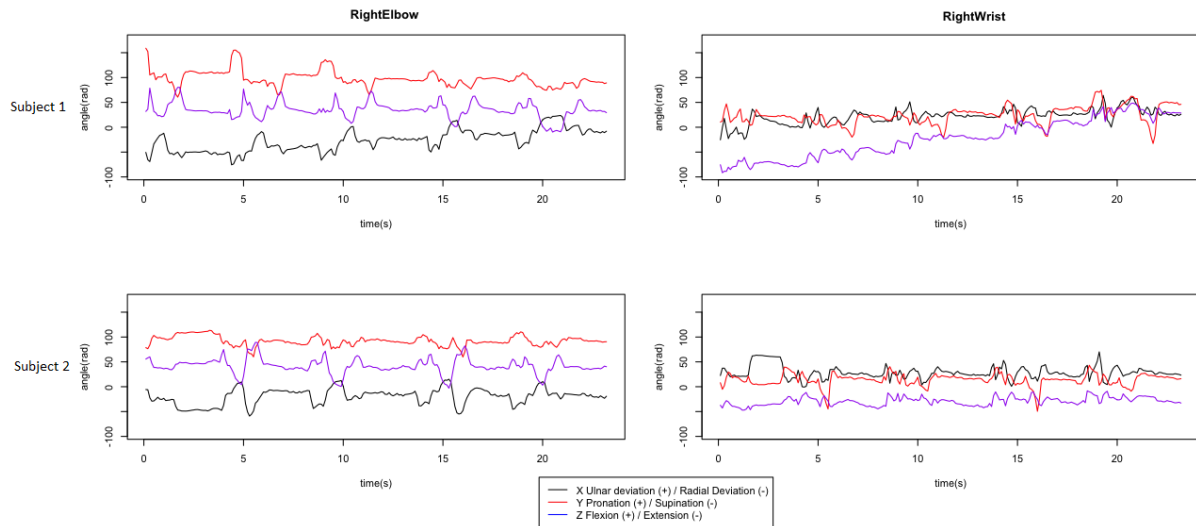


Figure 17 Right Shoulder ROM of studied subjects in workstation 103 - Semi-automated Assembly Line

Elbow flexion/extension movement it was only detected dissimilarities in maximum values reached in flexion movement ( $80.26^\circ$  vs.  $89.24^\circ$ ) (Figure 18; Table 19).

In ulnar/radial deviation was found a slight dissimilarity in maximum value of ulnar deviation ( $64.05^\circ$  vs.  $70.16^\circ$ ). Even more significant differences between subjects were detected in pronation/supination movement. Both the minimum values were in supination ( $-31.72^\circ$  vs.  $49.47^\circ$ ), on the contrary the maximum values were in pronation ( $43.24^\circ$  vs.  $48.59^\circ$ ). In wrist flexion/extension it was also found dissimilarities, minimum values ( $-91.53^\circ$  vs.  $-47.19^\circ$ ) were in extension and maximum in flexion ( $48.59^\circ$  vs.  $-8.30^\circ$ ) (Figure 18; Table 19).



In workstation 104 the shoulder abduction/adduction movement also shown a slight difference in the minimum value between subjects although in same movement (adduction):  $-6.29^\circ$  vs.  $-13.38^\circ$  (Figure 19; Table 20).

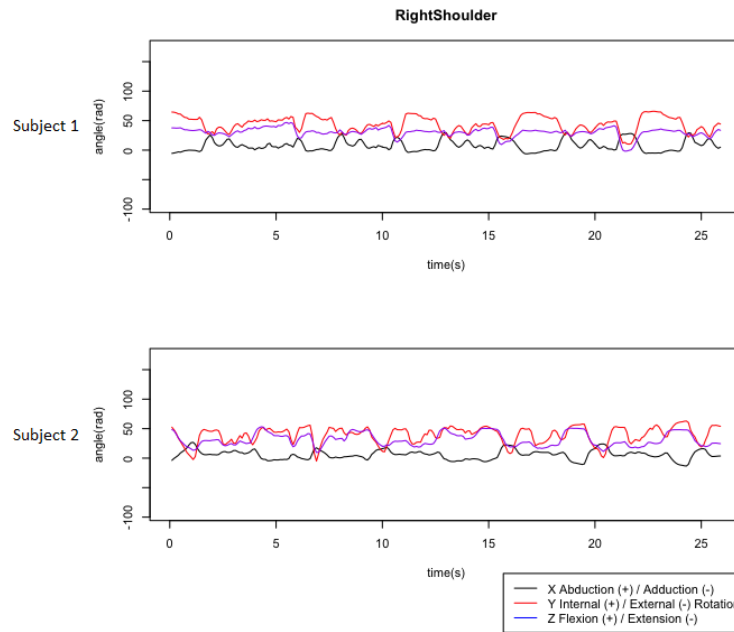


Figure 19 Right Shoulder ROM of studied subjects studied in workstation 104 - Semi-automated Assembly Line

In elbow flexion the maximum values (Figure 20; Table 20) were slightly different ( $84.52^\circ$  vs  $78.15^\circ$ ).

In wrist ROM it was found high dissimilarities on three DOF. The minimum values were ( $-32.28^\circ$  vs.  $-17.41^\circ$ ) in radial deviation. The maximum values achieved were ( $28.28^\circ$  vs.  $56.18^\circ$ ) in ulnar deviation. More significant differences were detected on the wrist pronation/supination movement. Both the minimum values were in supination ( $-22.08^\circ$  vs.  $-60.33^\circ$ ), on the contrary the maximum values were in pronation ( $6.67^\circ$  vs.  $43.60^\circ$ ). In wrist flexion/extension it was found high variation of extension minimum values ( $-51.37^\circ$  vs.  $-62.67^\circ$ ) (Figure 20; Table 20).

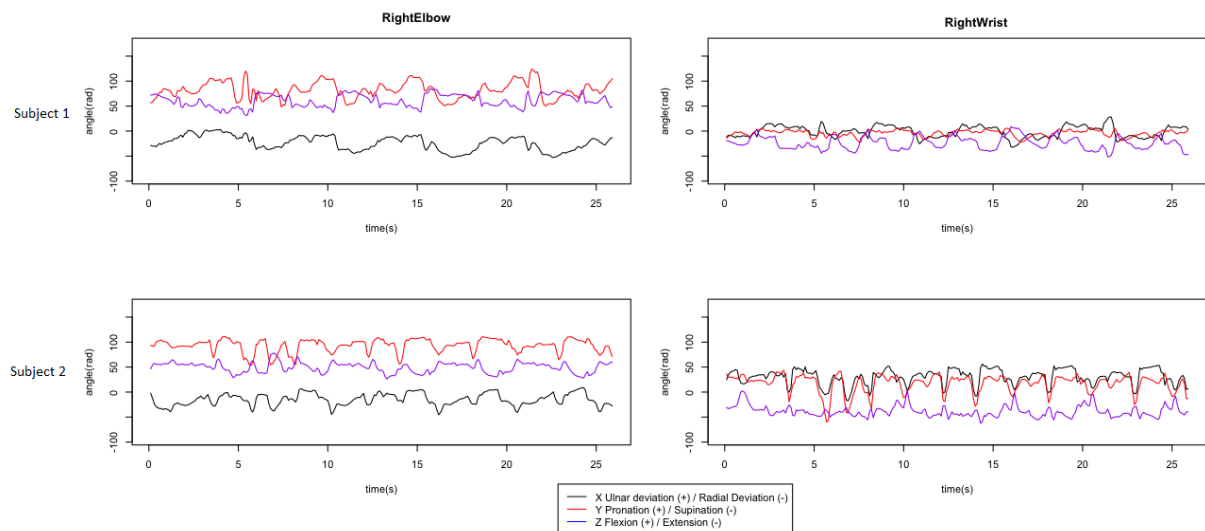


Figure 20 Right Elbow and Wrist ROM of studied subjects in workstation 104 - Semi-automated Assembly Line

As the descriptive statistics suggested, in semi-automated assembly line were encountered less strong correlations between subjects. Even though no relation between the variables in study was

detected. Of the 28  $r$  values, 16 were strong:  $r$  (1 to 0.5) and 12  $r$  (0.3 to 0.5). No weak correlation were also encountered (Table 14).

The stronger correlation values were on shoulder ROM:

- Abduction/adduction:
  - Workstation 100:  $r= 0.7$ ;  $p=0$ ;
  - Workstation 103:  $r=0.7$ ;  $p=0$ ;
  - Workstation 101:  $r= 0.5$ ;  $p=0$ ;
- Internal/External rotation:
  - Workstation 100:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 103:  $r= 0.6$ ;  $p=0$ ;
  - Workstation 104:  $r= 0.5$ ;  $p=3.93E-07$ ;
- Flexion/Extension:
  - Workstation 100:  $r= 0.6$ ;  $p=2.22E-13$ ;
  - Workstation 103:  $r= 0.5$ ;  $p=0$ ;
  - Workstation 104:  $r= 0.5$ ;  $p=8.29E-13$ ;

Among the four workstations studied in elbow flexion/extension was found three strong correlations:

- Workstation 104:  $r=0.6$ ;  $p=6.44E-15$ ;
- Workstation 101:  $r= 0.5$ ;  $p=6.66E-16$ ;
- Workstation 102:  $r=0.5$ ;  $p=7.46E-12$ ;

Overall, on wrist ROM was found only 4 strong correlation values among subjects and workstations:

- Ulnar/Radial Deviation, in workstation 103:  $r=0.6$ ;  $p=2.17E-05$ ;
- Pronation/Supination, in workstation 100:  $r=0.5$ ;  $p=3.51E-14$ ;
- Flexion/Extension, in workstation 100:  $r=0.5$ ;  $p=3.44E-12$ ;
- Flexion/Extension, in workstation 104:  $r= 0.5$ ;  $p=8.18E-08$ ;

Moderate correlation (0.3 to 0.5) of shoulder and elbow was identified:

- Shoulder abduction/adduction in workstation 104:  $r= 0.3$ ;  $p=1.83E-05$ ;
- Shoulder Internal/external rotation in workstation 101:  $r= 0.4$ ;  $p=4.38E-07$ ;
- Shoulder Flexion/Extension in workstation 101:  $r=0.4$ ;  $p=1.35E-07$ ;
- Elbow flexion/extension in workstation 101:  $r= 0.4$ ;  $p=1.90E-09$ ;

The higher number of moderate correlation values were in the wrist ROM:

- Ulnar and radial deviation in workstation 100:  $r= 0.4$ ;  $p=2.30E-11$ ;
- Ulnar and radial deviation in workstation 101:  $r= 0.3$ ;  $p=3.37E-05$ ;
- Ulnar and radial deviation in workstation 104:  $r=0.3$ ;  $p=1.90E-05$ ;
- Pronation/Supination in workstation 101:  $r= 0.4$ ;  $p=1.67E-08$ ;
- Pronation/Supination in workstation 103:  $r= 0.4$ ;  $p=1.13E-08$ ;
- Pronation/Supination in workstation 104:  $r= 0.3$ ;  $p=2.47E-04$ ;
- Flexion/Extension in workstation 103:  $r= 0.4$ ;  $p=7.99E-15$ ;
- Flexion/Extension in workstation 101:  $r= 0.3$ ;  $p=7.86E-06$ ;

Overall the workstation 101 has the lowest correlation values between subjects (Table 14).

Table 14 Correlation value  $r$  and statistical significance testing  $p$  between subjects in the same workstations – Semi-Automated Assembly Line

		Shoulder						Elbow				Wrist			
		(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
Workstation	Subjects Correlation	$r$	$p$	$r$	$p$	$r$	$p$	$r$	$p$	$r$	$p$	$r$	$p$	$r$	$p$
<b>100</b>	1 vs. 2	0.7	0.00E+00	0.6	0.00E+00	0.6	2.22E-13	0.5	6.66E-16	0.4	2.30E-11	0.5	3.51E-14	0.5	3.44E-12
<b>101</b>	1 vs. 2	0.5	0.00E+00	0.4	4.38E-07	0.4	1.35E-07	0.4	1.90E-09	0.3	3.37E-05	0.4	1.67E-08	0.3	7.86E-06
<b>103</b>	1 vs. 2	0.7	0.00E+00	0.6	0.00E+00	0.5	0.00E+00	0.5	7.46E-12	0.6	2.17E-05	0.4	1.13E-08	0.4	7.99E-15
<b>104</b>	1 vs. 2	0.3	1.83E-05	0.5	3.93E-07	0.5	8.29E-13	0.6	6.44E-15	0.3	1.09E-05	0.3	2.47E-04	0.5	8.18E-08

Table 14 Statistics variables between subjects in workstation 100 – Manual Assembly Line

Workstation 100														
	Shoulder				Elbow				Wrist					
	(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
<b>Mean</b>	20.92	20.66	18.48	21.07	10.86	10.10	80.61	80.49	12.18	14.24	-4.02	-1.52	-26.47	-28.85
<b>SD</b>	5.36	6.31	11.07	12.20	8.87	10.35	16.35	17.55	9.15	8.10	14.57	11.80	8.61	8.37
<b>Min.</b>	5.01	0.76	-5.15	-8.55	-5.71	-12.29	28.87	14.86	-6.86	-2.55	-23.32	-19.24	-46.74	-43.00
<b>Max.</b>	34.12	35.00	46.32	52.75	37.85	43.80	99.02	101.47	38.43	53.70	45.33	50.62	-0.02	-4.70

Table 15 Statistics variables between subjects in workstation 102 – Manual Assembly Line

Workstation 102														
	Shoulder				Elbow				Wrist					
	(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
<b>Mean</b>	12.41	13.37	17.79	17.40	30.88	31.42	37.93	37.35	13.80	8.59	8.08	7.60	-41.22	-41.85
<b>SD</b>	10.70	11.67	16.46	17.21	10.75	11.20	9.32	9.27	8.20	8.73	15.52	15.02	12.00	13.15
<b>Min.</b>	-9.81	-8.48	-15.54	-17.15	6.94	2.78	11.89	14.01	-6.24	-16.55	-22.40	-23.66	-66.25	-65.90
<b>Max.</b>	32.31	33.46	47.78	47.79	52.22	48.06	62.56	56.16	32.59	28.04	35.43	38.36	-9.70	2.66

Table 16 Statistics variables between subjects in workstation 103 – Manual Assembly Line

Workstation 103														
	Shoulder				Elbow				Wrist					
	(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
<b>Mean</b>	13.46	23.84	-1.08	-5.29	12.47	9.77	61.60	69.34	15.32	26.11	1.22	-5.04	-1.32	-19.26
<b>SD</b>	2.27	3.69	7.00	5.94	3.49	7.62	6.50	11.64	8.70	12.23	8.27	12.26	10.10	12.94
<b>Min.</b>	7.68	19.07	-15.33	-17.23	2.49	-18.60	37.66	41.19	-15.98	-44.78	-17.35	-34.33	-31.15	-71.64
<b>Max.</b>	27.06	40.34	14.72	8.70	24.79	28.86	71.95	124.32	45.69	41.32	29.75	20.96	23.80	11.83

Table 17 Statistics variables between subjects in workstation 100 – Semi-Automated Assembly Line

Workstation 100														
	Shoulder				Elbow				Wrist					
	(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
<b>Mean</b>	11.86	14.63	16.75	24.50	3.46	22.19	74.31	58.57	10.80	14.11	-28.53	-28.94	-63.49	-40.89
<b>SD</b>	4.31	7.39	8.87	9.78	4.61	7.18	9.44	10.77	6.46	10.16	13.91	17.99	12.28	8.40
<b>Min.</b>	4.72	9.25	-22.09	-15.93	-13.72	7.94	31.66	2.88	-15.35	3.12	-47.30	-45.99	-91.03	-54.73
<b>Max.</b>	30.34	49.74	31.81	38.05	25.27	64.06	112.27	90.45	38.51	55.71	40.41	47.67	-16.80	0.50

Table 18 Statistics variables between subjects in workstation 103 – Semi-Automated Assembly Line

Workstation 103														
	Shoulder				Elbow				Wrist					
	(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
<b>Mean</b>	9.15	18.59	22.11	15.98	38.21	31.32	34.71	41.55	21.60	28.45	23.86	13.81	-22.11	-28.96
<b>SD</b>	12.82	10.69	13.24	14.63	14.76	14.69	16.29	15.44	14.97	13.08	17.94	12.61	38.25	8.46
<b>Min.</b>	-8.99	5.14	-14.41	-22.19	-0.84	-3.12	-9.72	-2.92	-25.32	-0.74	-32.72	-49.47	-91.53	-47.19
<b>Max.</b>	31.62	42.33	44.52	37.63	59.89	56.54	80.26	89.24	64.05	70.16	74.36	43.24	48.59	-8.30

Table 19 Statistics variables between subjects in workstation 104 – Semi-Automated Assembly Line

Workstation 104														
	Shoulder				Elbow				Wrist					
	(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
<b>Mean</b>	7.75	5.65	43.58	39.29	30.34	31.49	60.67	49.39	-1.09	30.20	-4.23	16.94	-23.69	-38.49
<b>SD</b>	9.35	7.91	13.34	14.01	7.80	11.15	12.63	10.34	11.79	15.78	6.40	18.35	12.95	11.49
<b>Min.</b>	-6.29	-13.38	10.07	-4.98	-1.74	9.66	31.51	26.19	-32.28	-17.41	-22.08	-60.33	-51.37	-62.67
<b>Max.</b>	29.82	26.77	65.84	62.90	46.84	53.15	84.52	78.15	28.28	56.18	6.67	43.60	9.00	4.18

#### 4.4 Maximum Cross Correlation - Semi-Automated vs. Manual Assembly Line

It was achieved 84 maximum cross correlation: 23 strong; 54 moderate and 7 weak. Values with no correlation wasn't achieved (Table 21).

Table 20 Correlation values distribution among workstations

Strength of relationship	Workstation		
	100	102 vs. 103	103 vs. 104
<b>-1 to -0,5 or 1 to 0,5</b> <b>Strong</b>	8	9	6
<b>-0,5 to -0,3 or 0,3 to 0,5</b> <b>Moderate</b>	19	18	17
<b>0,3 to -0,1 or 0,1 to 0,3</b> <b>Weak</b>	1	1	5
<b>-0,1 to 0,1</b> <b>None or Very Weak</b>	0	0	0

In workstation 102 vs. 103 was achieved the largest number of strong values (9). In second place was workstation 100 with 8 strong values and 103 vs. 104 with 6. The prevalent weak correlation was in workstation 103 vs. 104.

The largest number of stronger correlations (Table 22) were:

- Shoulder Abduction/adduction in workstation 102 vs. 103 (subj. 1 vs. subj.2):  $r=0.8$ ;  $p=0$ ;
- Shoulder Abduction/adduction in workstation 102 vs. 103 (subj. 1 vs. subj.1):  $r=0.7$ ;  $p=0$ ;
- Wrist Pronation/Supination in workstation 100 (subj. 2 vs. subj.1):  $r=0.7$ ;  $p=0$ ;
- Shoulder Abduction/adduction in workstation 102 vs. 103 (subj. 2 vs. subj.1):  $r=0.6$ ;  $p=0$ ;
- Shoulder Abduction/adduction in workstation 102 vs. 103 (subj. 2 vs. subj.2):  $r=0.6$ ;  $p=0$ ;
- Shoulder Abduction/adduction in workstation 102 vs. 103 (subj. 2 vs. subj.2):  $r=0.6$ ;  $p=6.66E-16$ ;
- Elbow Flexion/extension in workstation 100 (subj. 2 vs. subj.2):  $r=0.6$ ;  $p=4.44E-16$ ;

The lowest ROM correlation values of articulations:

- Shoulder Abduction/adduction in workstation 102 vs. 103 (subj. 1 vs. subj.1):  $r=0.2$ ;  $p=5.27E-04$ ;
- Shoulder Internal/External rotation in workstation 100 (subj. 2 vs. subj.1):  $r=0.2$ ;  $p=3.99E-04$ ;
- Shoulder Internal/External rotation in workstation 103 vs. 104 (subj. 2 vs. subj.2):  $r=0.2$ ;  $p=2.92E-03$ ;
- Elbow flexion/Extension in workstation 103 vs. 104 (subj. 1 vs. subj.1):  $r=0.2$ ;  $p=5.29E-04$ ;
- Wrist pronation/supination in workstation 103 vs. 104 (subj. 1 vs. subj.2):  $r=0.2$ ;  $p=3.89E-03$ ;
- Wrist pronation/supination in workstation 103 vs. 104 (subj. 2 vs. subj.1):  $r=0.2$ ;  $p=1.58E-06$ ;
- Wrist flexion/extension in workstation 102 vs. 103 (subj. 1 vs. subj.1):  $r=0.1$ ;  $p=1.02E-01$ ;

The remaining 70 correlations values were between 0.3 and 0.5 showing also articulation ROM relation between subjects in the performance of tasks in several workstations.

Through the data analysis it was possible to verify that the articulations ROM of operators are similar between subjects in study workstations. Even though seven values show a weak correlation, statistical significance testing were all near 0, which proves that the null hypotheses is true - correlation exists between subjects in same workstation.

The graphics indicates a well-defined pattern in ROM performed by the upper-limbs articulations. The patterns between subjects in same workstation proves that operators adopt similar movements in assemble work. Repetitive work and highly dynamic movements are performed. Studies and statistics reports of upper limb disorders determines that repetitive work can be a risk factor to the development of WMSDs (Mohammadi, 2012; WHO, 2003).

Even the semi-automatic assembly line is technological advanced in relation to manual line it was verified that same work methods were used. Balogh *et al* (2006), proven in a study that the technological improvements among workstations can improve workers health. In this study it was not alike.

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 the plant and assembly line conditions.

Due to the assembly line automation high level of automation it requires the use of auxiliary systems for error detection. Machinery has several poke yokes systems that detect quality errors by using electromagnetic radiation. The radiation could influence the correct *Xsens* wireless-sensors reading. Other possible influence is the number of Access Point Wireless that are near the line. Metal physical barriers also influence the reading of the equipment. Semi-automated line is in the middle of the plant near of plastic injection machines and several electrical panels are also near the workstations, this fact could also increase errors in the measurements (Brodie, Walmsley, & Page, 2008).

The lowest correlation values were achieved on wrists ROM. It was not found studies using inertial measurement system to quantity angular kinematic in assemble work: a) short cycle time (inferior to 30 seconds); b) hands mostly used in meticulous tasks; c) high work pace. Angular kinematics analyses are frequently studied in human rehabilitation in daily living activities. This studies determines the normal ROM of the articulations in order to identify disorders or diseases on subjects (Magermans, Chadwick, Veeger, & van der Helm, 2005; Perry, Rosen, & Burns, 2007). Others studies that uses these type of inertial measurement system are Sports in order to collect biomechanical data of lower limbs. In a study made by Zhang, Novak, Brouwer, & Li (2013) were a comparison between systems was performed (*Xsens MVN BIOMECH* vs. camera-based motion capture system) showed an high accuracy of the *Xsens* in the data collection of the lower limb against the motion capture system (Zhang, Novak, Brouwer, & Li, 2013). Those facts can be a limitation of *Xsens* reading due to velocity of the wrists movements in assemble work.

Data analysis provided information that indicates further dissimilarities between subjects in workstations 103 vs. 104. Even both workstations have the same machinery and standard work method the articulation ROM has a weaker correlation between subjects. The possible justification of such dissimilarities can be due working ranges.

The aim of semi-automated line manufacture was to produce the same amount of cables decreasing the workforce. Limitation of space available at the plant was also a challenge for engineers to design it at time. Workstations space were to be significantly reduced. Several conditions can influence articulations ROM such age, gender, BMI, arm and forearm circumferences and physical activity (Chapleau et al., 2013). The reduced space available to perform tasks can influence the articulation ROM because workers have to cringe movements performed. On the other hand, in

manual line the working ranges appears to be more adequate to the comfortable performance of the task.

It was also possible to verify that the work pace of the semi-automated assembly line was higher than in the manual line due to automation level. In semi-automated assembly line operators follows the automatic equipment's pace. If operators are not capable to track the automatic part the production range is highly less. This fact decreases job control and social activities among operators. It also increases the work demand and stress levels. These aspects can lead or contribute to the development of WMSDs (Wells et al., 2007; Womack et al., 2009). On the other hand the work pace of manual line operators were less. The production is controlled by the operator itself. When the work pace is high and break time is low the probability of the development of WMSDs escalates.

Weaker correlation can also be due to the work-method adopted by workers performing the 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.

Table 21 Maximum cross correlation and statistical significance testing p between subjects in similar workstations (Manual vs. Semi-Automated)

Workstation	Subjects Correlation	Shoulder				Elbow				Wrist					
		(x) Abduction(+)/ Adduction (-)		(y) Internal (+)/ External (-) Rotation		(z) Flexion (+)/ Extension (-)		(z) Flexion (+)/ Extension (-)		(x) Ulnar deviation (+)/ Radial deviation (-)		(y) Pronation (+)/ Supination (-)		(z) Flexion (+)/ Extension (-)	
		<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
<b>100</b>	1 vs. 1	0.3	2.34E-07	0.4	2.99E-04	0.4	7.04E-06	0.3	3.30E-05	0.4	1.02E-09	0.5	0.00E+00	0.3	1.46E-04
	1 vs. 2	0.5	3.69E-12	0.4	3.37E-08	0.4	4.89E-08	0.5	1.39E-09	0.3	1.60E-04	0.3	1.89E-04	0.3	1.79E-04
	2 vs. 1	0.4	8.12E-08	0.2	3.99E-04	0.3	1.01E-05	0.4	3.41E-12	0.4	1.12E-11	0.7	0.00E+00	0.3	2.62E-06
	2 vs. 2	0.5	4.98E-11	0.3	3.46E-06	0.4	4.59E-07	0.6	4.44E-16	0.4	3.44E-10	0.5	3.84E-14	0.5	3.77E-15
<b>102 vs. 103</b>	1 vs. 1	0.7	0.00E+00	0.4	3.30E-11	0.5	1.99E-13	0.3	5.69E-06	0.3	4.88E-04	0.4	8.03E-09	0.1	1.02E-01
	1 vs. 2	0.8	0.00E+00	0.5	5.77E-15	0.4	1.17E-11	0.3	6.90E-06	0.4	5.97E-09	0.4	5.97E-06	0.3	2.44E-04
	2 vs. 1	0.6	0.00E+00	0.5	8.44E-15	0.4	3.29E-09	0.5	3.49E-06	0.3	4.30E-05	0.3	8.09E-06	0.5	1.09E-08
	2 vs. 2	0.6	0.00E+00	0.4	5.94E-08	0.4	2.57E-08	0.3	1.08E-04	0.3	3.40E-06	0.4	7.71E-07	0.3	3.65E-07
<b>103 vs. 104</b>	1 vs. 1	0.2	5.27E-04	0.4	5.19E-06	0.4	6.36E-10	0.2	5.29E-04	0.4	8.31E-09	0.3	4.51E-07	0.4	4.40E-09
	1 vs. 2	0.5	1.47E-06	0.5	2.17E-09	0.3	1.95E-06	0.3	1.47E-05	0.5	4.08E-09	0.2	3.89E-03	0.3	1.77E-05
	2 vs. 1	0.6	6.66E-16	0.3	4.34E-07	0.5	7.11E-15	0.3	1.52E-05	0.4	3.28E-07	0.2	1.66E-04	0.4	5.94E-06
	2 vs. 2	0.5	4.27E-07	0.2	2.92E-03	0.4	5.56E-08	0.4	1.27E-08	0.4	2.32E-08	0.3	1.58E-06	0.3	2.54E-04

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## 5 CONCLUSIONS AND FUTURE PERSPECTIVES

### 5.1 Conclusions

As the global economy and competition accelerates the working demands are also increasing. The complexity of work combined by individual and psychosocial conditions can lead to the development of work-related musculoskeletal disorders. The musculoskeletal system appears to be particularly vulnerable to these multiple factors given the extent of occupational musculoskeletal injuries and illnesses relative to other occupational health problems.

Even with the technological advantages in production and manufacture systems that companies nowadays tend to implement is not totally certain that human factors are taken in account.

By the comparison angular kinematics analysis of upper-limbs articulations in assemble work it was possible to verify that 27.4% of correlation are strong (1 to 0.5); 64.3% have moderated correlation (0.3 to 0.5) and 8.3% weak correlation (0.1 to 0.3). No relation between subjects articulations studied was verified. This values probable means that even with the improvement of the assembly line in technological aspects the movements and range of motion of the upper limb articulation are the identical. Apparently proves that human factor weren't taken in account in the workstation design and manufacture.

Due to the few similar studies and limited information of upper-limb articulations ROM in assemble work it wasn't possible to determinate if the range of motion performed by the subjects are a risk factor to the development of WMSDs.

In order to improve ergonomics aspects of workstations it would be important to increase the training of engineers in these field so they gain awareness of ergonomics risk factors when developing workstations.

The implementation of a simulating systems in company would also provide a wider analysis of workstations in relation to the production system, working reaches, ergonomic and safety risks.

Due to the structure of the semi-automated line little can be done in the aspect of reconfiguration workstations. Thus, organizational changes can be improved such as the increase of breaks during day-work, the implementation of activity plans and the rotation of workers between assembly lines.

### 5.2 Future Perspectives

Due to the impact on the production of the assembly line in study it wasn't possible to increase the sample. As future perspectives for this type of study is proposed to increase the sample of the operators studied.

In order to understand if the assembly line workstations dimensions follows the existent work design guidelines, it would be reasonable to evaluate the workstation ergonomic measures to verify if is adapted to the workers anthropometrics measures.

Even if it was asked to the operators to perform the task in accordance to work method defined it as possible that the workers adopted their own working method during the data collection. This fact can lead to a significant difference in the ROM of the articulations. One possibility would be to perform the measures with operators performing the task by the working method defined and others in their own way and verify the differences.

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It would be also important to utilize other type of data collection systems such as goniometers in order to achieve comparable results between equipment's.

The postures adopted by workers in the performance of the tasks can also influence the angular kinematics of the articulations. A postural analysis of the operators would be an improvement in this type of study.

In order to investigate if operators have upper limb disorders it would be interesting to perform a study were assemble work operators perform daily living activities and compare the results with the several studies that are already made in this field in healthy subjects.

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## Correct Posture to Adopt - *InBody 230*

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### Posture

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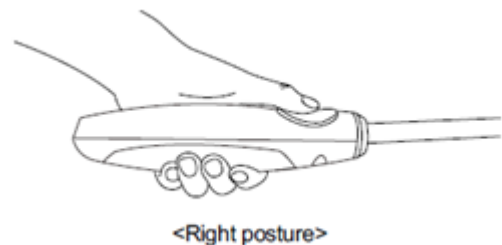
Normal standing position with the arms and legs extended



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### Hold the Hand Electrodes

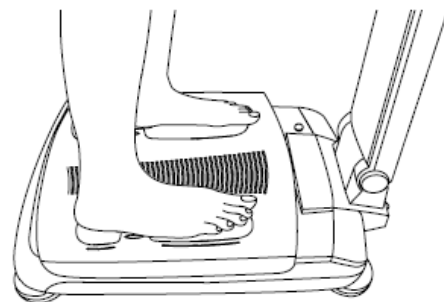
1. Make parallel, flat contact with four fingers on the surface of the electrode
2. Place thumb on the electrode pad on the top surface of the handle. Touch lightly, do not press with nails and do not press down too hard
3. When holding the grips, make sure your thumbs are covering the circular electrodes and hold them with the rest of your hands



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### Foot Electrodes

1. Bare feet must be in contact with the electrode foot pads
2. First, place the heel on the circular electrode.
3. Place sole on the elliptical electrode surface.



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(Based on the user manual)

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