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Pedro Arezes *Editor*

Advances in Safety Management and Human Factors

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7th International Conference on Applied Human Factors and Ergonomics

Proceedings of the AHFE 2016 International Conference on Safety Management and Human Factors, July 27–31, 2016, Walt Disney World®, Florida, USA

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Preface

Injury prevention is a common thread throughout every workplace, yet keeping employee safety and health knowledge consistently is a continual challenge for all employers. The discipline of Safety Management and Human Factors is cross-disciplinary concerning safety, health and welfare of the people engaged in work or employment. The book offers a platform to showcase research and for the exchange of information in safety management and human factors. Mastering safety management and human factors concepts is fundamental to both the creation of products and systems that people use and the design of work systems to avoid stresses and minimize the risk for accidents.

This book focuses on the advances in the safety management and its relationship with human factors, which are critical in the design of any human-centered technological system. The ideas and practical solutions described in the book are the outcome of dedicated research by academics and practitioners aiming to advance theory and practice in this dynamic and all-encompassing discipline.

A total of six sections are presented in this book. Each section contains research papers that have been reviewed by members of the International Editorial Board. Our sincere thanks and appreciation to the following Board members:

Defining the Angles' Range in Ergonomics Assessment Using 3D Cameras and Surface EMG

Jose Moar, Delfina Ramos and Pedro Arezes

Abstract Work-related Musculoskeletal Disorders (WMSDs) are pathologies of great impact in the working population. The main risk factor in the onset of these diseases are the postures adopted and held by the workers or, in other words, the critical joint angles adopted by them during significant time periods. Large exposure periods usually occur in the workplace. The influence of the postures adopted at the workplace has been studied by several authors who have developed different methodologies for the corresponding risk assessment (e.g., OWAS, RULA, REBA, LUBA, PATH, etc.). There is also a European standard, the EN 1005-4:2005 that is applied to the evaluation of working postures and movements in relation to machinery. The main problem while using these methodologies is the difficulty of knowing the specific angle adopted at a given joint. Currently, this is not a problem since some new technology enables accurate position sensing of any body part. Nowadays, 3D cameras can recreate the specific body segment in the three planes of space with high accuracy by using passive markers that are placed in different anatomical references, allowing to obtain the speed, trajectory, and angles variation data. Additionally, through the use of surface electromyography (sEMG) it is also possible to obtain data about different muscle activation patterns. This paper intends to present a comparative analysis of the angles used by major research methodologies in the field of WMSDs. It tries to establish the reference ranges of angles with their corresponding score for a later ergonomics assessment. The idea is to use that reference with new technologies as 3D cameras and surface EMG, in order to accurately assess and score postures adopted in every workplace.

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1 Introduction

WMSDs are the most prevalent occupational diseases in Europe. Exposure to awkward postures is one of the major physical risks in the workplace [1] and is one of the most important factors related to WMSDs [2, 3]. Several authors have proposed methodologies in this area including: "Ovako Working Posture Analyzing System"(OWAS) [4], a practical method designed to identify and evaluate postures encountered in the workplace; "Rapid Upper Limb Assessment" (RULA) [5], a method used in ergonomics research focusing on the assessment of the upper limbs; "Rapid Entire Body Analysis"; (REBA) [6], a tool for analyzing posture; "Loading on the Upper Body Assessment" (LUBA) [7], an assessment technique used to evaluate and re-design static work stations in industry, "Posture, Activity, Tools and Handling"; (PATH) [8], a sampling based approach to ergonomic job analysis for non-repetitive work; "Portable Ergonomic Observation"(PEO) [9], a method for analyzing postures at work; "Portable Ergonomic Observation Method for Computerized On-Line Recording of Postures and Manual Handling" (SWAT) [10], a method used in ergonomic observation.

Apart from a variety of published methods to assess risk, it is also important to refer that there is a European standard, the EN 1005-4: 2005 + A1: 2008 "Safety of machinery. Human physical performance. Part.4: Evaluation of working postures and movements in relation to machinery".

Based on these methods, one of the most important data is the information about the angles of the workers' relevant joints. The purpose of this paper is to analyze the results, in terms of angles' measurement, provided by some of these observational methods in order to exploit them by using some new technologies available for ergonomic evaluation. This will allow to achieve greater reliability in the results of evaluations of static jobs without repeated movements, by using techniques such as photogrammetry and surface electromyography.

2 Materials and Methods

This paper has considered observational methods of ergonomic evaluation in which forced posture was used as a risk factor.

Of the many existing methods, only those with a valid link or association with WRMSD's or which have a potential for researchers were used [11, 12].

Five general methods were selected and applied: (1) OWAS; (2) REBA; (3) PATH; (4) PEO; and (5) RULA. They have been applied by following the

Table 1 Body areas considered by each considered method

Method	Wrist	Elbow	Shoulder	Cervical	Lumbar
OWAS			X		X
REBA	X	X	X	X	X
PATH			X	X	X
PEO				X	X
RULA	X	X	X	X	X

European standard regarding working postures and movements, the EN 1005-4: 2005.

The muscle groups used in the research methods were different as there are differences within each group. The body areas and the associated major muscle groups that are overloaded in the workplace were selected for this analysis, namely: wrist, elbow, the upper extremity of the shoulder, the vertebral and lumbar parts of the back. Table 1 shows the muscle groups that were used in the various methods in the sample.

3 Results

The selected methods use different intervals of joint angles, and each of them provides a specific score for each position analyzed. A given posture is assigned to a specific working position and it is analyzed with different criteria. The limits of these score intervals are highly variable, since they depend of the evaluation of the angles covered by these intervals which changes the scoring in each method used.

As shown in Tables 2, 3, 4, 5 and 6, the variability in the angular ranges of the various methods is very high and, therefore, the result obtained by applying them can be also very variable.

Table 2 Joint angles considered in wrist flexion

Method	0	−15°	15°
REBA	X		X
RULA	X	X	X

Both REBA and RULA also take into account, without quantifying, if there is radial or ulnar deviation or if pronation or supination are detected

Table 3 Joint angles considered in elbow flexion

Method	0	60º	100°
REBA	X	X	X
RULA	X	X	X

This angles are for the bending posture of the elbows. RULA method also considers whether the arms cross the midline plane of the body or if the forearm is positioned outside the same 45° range

Table 4 Joint angles considered in shoulder flexion

Method	−20°	20°	45°	60°	90°
OWAS					X
RULA	X	X	X		X
REBA	X	X	X		X
PATH					X
PEO					X

The RULA method takes into account, not quantitatively, if the shoulder is raised, if abduction occurs, or if the arms are supported. The REBA method considers, qualitatively, any abduction or rotation that exists

Table 5 Joint angles considered in neck flexion

Method	0°	10°	20°	30°	40°
RULA	X	X	X		
REBA	X		X		
PATH				X	
PEO			X		

The RULA and Reba methods take into account, not quantitatively, if the neck is rotated or tilted sideways. The Path method takes into account the lateral deviation and rotation with limits of 30° and 45°. Finally the PEO method has a limit of 45° for rotation

Table 6 Joint angles considered in back flexion

Method	−20°	0°	20°	45°	60°
RULA		X	X		X
REBA	X	X	X		X
PATH			X	X	
PEO		X	X		X

The RULA, method takes into account, not quantitatively if your back is turned and tilted sideways. The PATH method has limits of 20° to the lateral tilt and rotation. Finally the PEO method has a limit of 45° for rotation

4 Discussion

All observational ergonomic evaluation methods require the determination of the adopted joint angles. For some of them, when analyzing the working day, the analysis of many positions is required for most of the method application. In other cases, during shorter exposure time, only those most demanding postures, from a physical point of view, are analyzed, i.e. those that can originate fatigue.

This entails the need to know the value of the angle of each joint and for each position to be analyzed in all three spatial dimensions.

In practice, while using these methods, ergonomists and/or health and safety professionals or practitioners use photographs and videos and this support involves a more or less important deviation from the real result of each observed angle.

Additionally, in many studies and research programs, conscious that it is impossible to observe postures while working with exactness, limits have been established based not on fatigue produced on the joints, but on the observational limits themselves [4].

A second difficulty in observation must be mentioned too, which is to not consider individual factors, such as those inherent to the individual. Fundamentally it means the characteristics of each individual (age, sex, anthropometrics, habits, fitness, influential chronic diseases such as diabetes, rheumatoid arthritis, etc.). Any of these factors can accelerate a problem and therefore the adoption of joint angles closest to the neutral position. Ultimately, the result of the evaluation of the job would depend on the worker occupying the workplace at a given moment.

As a general principle, which should be analyses carefully for some specific situations, an ergonomic evaluation method must be simple, it should be designed to be used by untrained staff, and must provide clear and specific answers that should offer possibilities for ergonomic correction [13]. The reality is that most of the methods are conditioned by two opposing characteristics, on one hand they have to be easy to use and in the other hand, they should be highly sensitive for be accuracy, which increases difficulty [9].

To achieve higher sensitivity and reliability in the results, some methods have included the possibility to use direct measurement techniques such as electromyography (EMG) or electrogoniometry. Despite that, this application has rarely been used to facilitate any type of recording for several reasons, such as the difficulties associated with worker mobility, and the cost and existence of obstacles in the workplace. Nevertheless, in the future the use of bioinstrumentation will increase [8], since it is the only way to get reliable data in the obtained results.

4.1 Angular Analysis

What is clear, and more than demonstrated in scientific literature, is that the postures adopted by a worker because of the equipment, tools and furniture are one of the most important factors in the development of WMSDs. With respect to the angular values, listed in Tables 2, 3, 4, 5 and 6, the sources are:

- In the case of the wrist, joint ranges ((−15)–0; 0–15) were developed in the publication HSE [14];
- Forearm ranges (0–60, 60–100) were developed by Grandjean [15] and Tichauer [16];
- The ranges of motion of the arm (0–20; 20–45; 45–90) were studied by Tichauer [16], Chaffin [17], Herberts [18], Hagberg [19], Schuldt [20] and Harms

Table 7 Joint angles of flexion considered

Joint	−20°	−15°	0°	10°	15°	20°	30°	40°	45°	60°	90°	100°
Wrist		X	X		X							
Elbow			X							X		X
Shoulder	X					X			X	X	X	
Neck			X	X		X	X	X				
Back	X		X			X			X	X		

Ringdahl [21]. Meanwhile, the value of 60 is included in the European standard EN 1005-4;

- With regard to vertebra flexion ranges (0–10, 10–20) were analyzed by Chaffin [17] and Kilbom [22, 23], the value 30° by Keyserling [24] and the value 40° in the European standard EN 1005-4;
- Finally, the trunk flexion joint has limits of (0–20; 20–60) determined by Drury [25], Grandjean [15, 26] (−20) and included by Hignett [6] and the value (45°) by Keyserling [24].

An ergonomic assessment, from the perspective of the postures taken by the joints involved in the risk of WMSDs, consists in determining an adopted angle and its subsequent inclusion in one of the reference intervals so that it can be assigned a score on a previously established criteria based on epidemiological studies or research.

Angles considered by the methods of the sample are shown in Table 7 and the assigned scores depend on each method and each interval considered, based on studies or previous research.

There are two main issues to consider at this respect: the determination of an adopted posture (angle) and the penalization that is assigned to that angle (score).

4.2 *Performing an Ergonomic Assessment Accurately*

An ergonomic evaluation, to ensure a minimum of reliability, must be based on four separate approaches [27]:

(a) Visual observation, in which an ergonomist, evaluates either in 2D in a sagittal plane or a frontal plane, those relevant aspects of the task analyzed, going beyond frequencies, angles or times;
(b) Quantitative measurement of kinematic parameters: movements, joint angles, times and frequencies;
(c) A biomechanical analysis (strengths and its effects on the task);
(d) A muscle EMG study to determine quantitatively the effort or muscle fatigue that is caused by the task.

Therefore, if what is intended is to assess static work looking at frequencies and negative forces regarding the effect of postures, the assessment should be based on two main actions, a quantitative measurement of joints, and the objective assessment of muscle fatigue.

Using 3D Photogrammetry. Photogrammetry is a science that obtains information from physical objects using the processes of recording, measuring and interpreting photographic images. From the perspective of biomechanics, the human body can be represented as a system of articulated segments and photogrammetry allows, during movement thereof, us to estimate the kinematic variables (mass, center of mass position, moments of inertia [28]), and place them continuously in space.

The Standardization and Terminology Committee (STC) of the International Society of Biomechanics (ISB) has developed a set of rules to correctly report the movement of each joint. In 1993 the Joint Coordinate System (JCS) was approved as a rule, initially proposed by Grood and Suntay [29]. This standard refers some anatomic markers to be used on the spine, full body, shoulder, elbow, wrist and [30] and [31].

By using photogrammetry, scientific evidence obtained from the markers that define each muscle group can give us, in a precise way, the angle of each joint.

Currently, 3D scanning of the human body is used in many fields of knowledge [32], including but not limited to: ergonomics, medicine, clothing sizes, industry, etc. There are many examples that have used photogrammetry to perform a biomechanical analysis of a joint [33] for a particular task, but for the moment its use is more widespread in injury recovery, improving athletic performance and prosthesis design or other sports items.

In any case, once the movement of muscle groups has been recorded, we have all the necessary data for calculating the kinematic variables and to produce a graphical representation. Some software currently available can provide kinematic point data (position, velocity, acceleration, angle angular velocity, and angular acceleration), distances, and rigid body dynamics (translation and rotation), based on previous records of the task. With great accuracy, it is possible to determine the movement and position of a rigid body defined by the applied body markers.

Using EMG. Surface electromyography (sEMG) is a technique that quantifies the physical demands on the body and detects both the effort expended and muscle fatigue. It is a sensitive and specific reproducible diagnostic technique, [34, 35]. Many researchers use it to detect muscle hyperactivity/hypoactivity, muscle imbalances and generally any responses by the muscles to performing mechanical work.

All values obtained from the sEMG require standardization comparison: angle if static test, range of motion in the case of dynamic test speed, applied load, duration, previous state muscle and, of course, electrode placement. On this last point, the SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscles) is used by researchers in Europe as it establishes a series of recommendations on the location of the sensors to evaluate electrical response of the major joints (shoulder, neck, trunk, elbow, wrist, knee and ankle).

Therefore, with the application of this technique it is possible to determine the correlation between the load and the muscle fatigue or in other words, between their spatial positions, if there is no existence of external load, and fatigue. This shows that sEMG can be considered as a very important tool in ergonomic research [36–38].

5 Conclusions

Traditional methods of postures' evaluating at the workplace have always been limited by the type of observation made (visual, photographs, video, etc.).

Most of the methods rely on a score assignment to each posture of the body zone and these evaluations are mostly established based on angular intervals. In some cases, it is necessary to take into account the limits of human observation.

Photogrammetry allows the spatial location of any muscle group and therefore it can be a reliable technique to determine the angle taken by a joint. On the other hand, regarding the assessment of posture, sEMG allows a quantitative analysis of muscle activity and thus an objective determination of muscle fatigue.

With the combination of both previous mentioned tools, it is possible to define a joint posture with great accuracy and the muscle response can be objectively assessed. With this scenario, there will be no need to use ranks or scores that penalize unfavorable situations. At this respect, it is important to mention that, as indicated in previous studies, it has been shown that it is necessary to have a synchronization unit for the digital signal photogrammetry. This must be aligned with the wave of the potential provided by the sEMG. Thus, there will be a muscular response value for each position, i.e. a continuous assessment over time.

Ideally, an ergonomic evaluation should be performed on the field, in the workplace. Even though the operational difficulties of making EMG studies during a work activity are great, they may open a line of research in finding a relationship between posture and muscular effort. This would avoid the necessity for EMG testing on the workplace by just filming the worker with simple portable wireless cameras.

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