

Development of a Biomechanical Method for Ergonomic Evaluation: Comparison with Observational Methods

M. Zare, S. Biau, M. Croq, Y. Roquelaure

Abstract—A wide variety of observational methods have been developed to evaluate the ergonomic workloads in manufacturing. However, the precision and accuracy of these methods remain a subject of debate. The aims of this study were to develop biomechanical methods to evaluate ergonomic workloads and to compare them with observational methods.

Two observational methods, i.e. SCANIA Ergonomic Standard (SES) and Rapid Upper Limb Assessment (RULA), were used to assess ergonomic workloads at two simulated workstations. They included four tasks such as tightening & loosening, attachment of tubes and strapping as well as other actions. Sensors were also used to measure biomechanical data (Inclinometers, Accelerometers, and Goniometers).

Our findings showed that in assessment of some risk factors both RULA & SES were in agreement with the results of biomechanical methods. However, there was disagreement on neck and wrist postures. In conclusion, the biomechanical approach was more precise than observational methods, but some risk factors evaluated with observational methods were not measurable with the biomechanical techniques developed.

Keywords—Ergonomic, Observational Method, Biomechanical method, Workload.

I. INTRODUCTION

As discussed in various studies, work-related musculoskeletal disorders are widespread in the manufacturing industries and they are known as multi-factorial occupational diseases for which physical workload, psychosocial, organizational and individual factors are the most important causes [1], [2]. Physical ergonomic risk factors, including forceful exertion, awkward postures, lifting, manual material handling and vibrations are considered to be the obvious risk factors contributing to Work Musculoskeletal Disorders (WMSDs) [3]-[5]. To manage and control physical ergonomic risks, several methods have been developed for assessment of exposure and estimation of risks of injury in various occupations [1]. Paper-based observational methods such as RULA, OCRA, REBA, etc, are the techniques most commonly applied by ergonomists for posture assessments

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[6]. Strain Index and ACGIH hand level activity are the methods for measuring forceful exertion. Manual material handling is evaluated by the NIOSH equation, MAC (UK), ManTRA (Australia), and New Zealand code [7]. Although many studies have applied these methods to analyze job stations, their validity is still a matter of debate. Furthermore, many industrial companies have developed their own internal methods for ergonomic analysis, and a few research articles have addressed the efficacy of using in-housing methods [6]. It is essential for ergonomists and manufacturers that the accuracy and precision of the methods should be applicable for workplace analysis. Risk management policies related to WMSDs are unsuccessful without accurate ergonomic risk assessment [1].

In addition to observational methods, biomechanical methods (direct measurement) have been developed that rely on sensors for recording body movement [8]. Goniometry, inclinometry, accelerometry, and electromyography are the most popular straightforward methods to measure postures, movements and force exertion. A large quantity of precise data related to exposure variables can be provided by biomechanical procedures, and developing the right protocol for applying them is vital. Comparing the results of straightforward methods with observational techniques would provide the opportunity to improve the validity of observational methods. Developing an accurate protocol showing which sensors should be used and how the measurements should be performed is necessary before workplace analysis with biomechanical methods.

The aim of this study was therefore to develop an appropriate protocol for biomechanical measurement in manufacturing assembly. Testing this protocol and comparing it with two observational methods, i.e. SCANIA Ergonomic Standard (SES) and RULA, were the other aims of our study. SES is an in-house observational method that is used for measuring posture, force, lifting and repetition, and RULA is a common method for posture assessment.

II. METHODS

A. Biomechanical Measurements

The first step in our study was selection of sensors to measure the repetition, movements and postures of body regions.

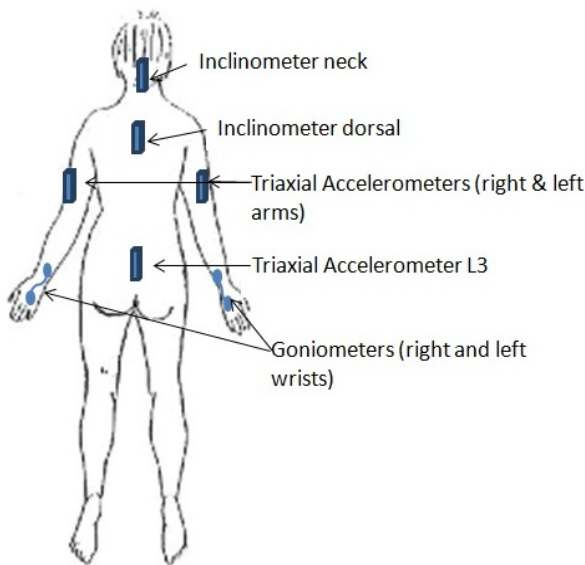


Fig. 1 Sensor placement for measurement of body movements

Inclinometers were used to measure the inclination of body regions such as the head and upper back in a recent study [8]. To measure neck posture, information was sampled using loggers as well as two inclinometers placed on the occipital bone (a saucer-shaped membrane bone situated at the lower back of the cranium) and on the cervico-thoracic spine at the C7-Th1 level. The total number of times when the head posture was more than 10° forward or backward compared to the upper back were characterized as head postures.

Two triaxial accelerometers were placed along the upper arms in the middle of the humerus. The line from the rounded head of the acromion to the lateral epicondyle was measured and divided into two for the placement of accelerometers on the humerus. They were fixed laterally on both hands with their Y-axes on the vertical. Arm elevations as well as hand repetitions were therefore calculated. Another accelerometer was placed on L3 of the lumbar spine to assess back posture. Recordings were performed between $+1g$ and $-1g$.

Biaxial electro-goniometers were used to measure flexion and extension deviations of the right and left wrists, the flexion and extension of the wrist being characterized in this study as hand postures. All sensors were small and placed on the body with double-sided adhesive tape (Fig. 1).

The zero positions for the head and upper back were defined at the first data recording when the subjects were standing upright in their usual postures and looking at a point of eye level. The reference positions for the upper arms and lower back were established when the subjects stood upright with their arms hanging at the side of the body. Once the wrists were relaxed alongside the body, this was taken as the reference position of the wrist.

All the postures and movements were recorded by data logger and camera recorder either in reference positions or while performing four simulated tasks. All the data were then transferred to the computer and actions were synchronized between movie and logger data. The two job stations selected

were Air Component & Tie Wrapping which are simulated job stations in truck manufacturing for operator training. They include following tasks:

1. Tightening with hand and tool (duration 296 seconds)
2. Placing tubes and wrapping with Plastic Strap (duration 462.5 seconds)
3. Loosening with hand and tool (duration 148 seconds)
4. Other actions to test limits of sensor (duration 70 seconds)

B. Observational Methods

The first observational method to evaluate the potential ergonomic risk in the simulated job stations was SCANIA in-house Ergonomic Standard method (SES). This method is adapted to the ergonomic risk requirements in assembly manufacturing and designed to evaluate multi-task work stations. SES not only assesses postures but also evaluates force and lifting tasks. Twenty parameters are classified in 5 categories to define its ergonomic criteria. To prioritize the assessments, the results are sorted in the following order: Green or normal zone which shows minimal risk of WMSDs, and these kinds of risk are acceptable. Yellow shows the zone which has moderate risk of WMSDs. Yellow tasks and job stations might need some improvement action in the future. Red is an action zone where there are considerable risks of WMSDs for workers, and changes are required as soon as possible. Finally, double red (DR) shows the potential for excessive ergonomic risk for the tasks assessed as DR, so they should be stopped immediately and the solutions found.

TABLE I
COMPARISON OF ERGONOMIC RISK PRIORITIZATION BY RULA AND SES METHODS

Category	RULA Score	SES Color	Definition
Level 1	1-2	Green	Acceptable
Level 2	3-4	Yellow	More investigation needed
Level 3	5-6	Red	Modification needed soon
Level 4	7	Double Red	Modification needed as soon as possible

The numbers of yellows, reds and DRs are then added and the colors of workstations are determined. The worst color is considered to be the final evaluation of the workstation.

The other observational method used in this study was the Rapid Upper Limb Assessment (RULA). This method is widely used by ergonomists and researchers in various occupations to assess the risk of upper limb disorders. RULA measures ergonomic risk based on postures, weight, duration and frequency, and then provides a score showing the risk of injury for the tasks evaluated. The scale rate for posture assessment varies from one to seven, one showing the best and seven the worst. In RULA the body is divided in two zones, A and B, of which A includes the upper arms, lower arms, and wrist positions, and group B the neck and trunk. The final score generated by RULA shows the postures and ergonomic loads as four levels. Table I shows the categorization of the scores generated by SES and RULA.

The observational methods were undertaken by an experienced ergonomist and were analyzed by Excel.

MATLAB software was used to analyze biomechanical data.

III. RESULTS

Observations and video recordings were performed for all the tasks selected. Our general results showed that posture assessments with the different methods for the tasks evaluated yielded the same results. However, some differences occurred for the neck and wrist postures. Furthermore, direct methods provided a range of information which clearly revealed different aspects of workstations for ergonomists and decision makers. The main advantage of the direct method is observing whether the body movements while performing a task were symmetric.

A. Tightening with Hand and with Tools (Task One)

The neck posture score with the RULA method was 4 ($20^\circ < \text{neck flexion}$) for 73% of the total task time, while the SES method showed that the neck posture for 46% of the task time was red ($45^\circ < \text{neck flexion}$), and for 27% of the time period it was yellow ($20^\circ < \text{neck flexion} < 45^\circ$). The inclinometers showed that for 80% of the time for this task the neck was in flexion between 10° and 20° , although they never record flexion of more than 20° . The results for neck posture for this task with the three methods were therefore rather different.

During 13% of the tightening task period, the trunk score was assessed as 2 with RULA ($10^\circ < \text{back flexion} < 20^\circ$). SES yielded green for back posture, as bending forward was less than 20° during this task. The accelerometer that was used as inclinometer for the lower back showed back flexion $< 20^\circ$ for 81% of the task time. The direct method results for the trunk were therefore consistent with both the RULA and SES methods.

The upper arm score with RULA for 10% of the tightening task was 2 ($20^\circ < \text{upper arm lifting} < 45^\circ$) and for 90% of the time it was 1 ($\text{upper arm lifting} < 20^\circ$). The lower arm position score with RULA was 1 during this task. The SES assessment for static work posture of the shoulder and arm was green, while the bending movement forward or outward was less than 45° . There are no criteria with the SES method for assessing the lower arms. Two accelerometers on the left and right arms showed that the arms were never in flexion or abduction of more than 40° throughout this task. The methods revealed the same results for assessment of arm postures.

Similarly, the RULA score for wrist postures was 1 (neutral wrist) and the same results were observed by the SES method. However, electro-goniometry of both hands showed that for 30% of task duration wrist postures were more than 15° , results which were inconsistent with observational methods.

Repetition was evaluated with SES as red because the tightening actions with either hands or a tool were repeated more than 3 times per minute (according SES criteria). The numbers of repetitions were calculated with an accelerometer, and four repetitions for tightening with a torque wrench as well as eight repetitions for hand tightening were observed for each action (Fig. 2). In total, 50 repetitions with the hand and 32 repetitions with a tool were recorded over 5 minutes in this

task. Although repetition was assessed as an action zone (red) by the SES method (the same result as the direct method), it is difficult to determine real values of repetition numbers by the observational method. The direct method clearly visualized the number and pattern of repetitions.

The final RULA score for this task was 5, which shows that further investigation and changes are required soon. The overall color of this task with the SES method was green, which is in the normal zone and acceptable.

TABLE II
COMPARISON OF ERGONOMIC RISK ASSESSMENT BY RULA, SES AND DIRECT METHOD

		RULA score	SES color	Direct method
Tightening Task	Neck	4	Red	Neck flexion $< 20^\circ$
	Back	2	Green	Back flexion $< 20^\circ$
	Arm	2	Green	Arm lifting $< 40^\circ$
	Wrist	1	Green	flexion and extension $> 15^\circ$
Wrapping with plastic strap	Neck	4	Red	Neck flexion $< 20^\circ$
	Back	3	Yellow	Back flexion $> 45^\circ$
	Arm	2	Green	Arm lifting $< 40^\circ$
	Wrist	3	Red	flexion and extension $> 15^\circ$
Loosening task	Neck	4	Red	Neck flexion $< 20^\circ$
	Back	2	Green	$20^\circ < \text{Back flexion} < 45^\circ$
	Arm	2	Green	Arm lifting $< 40^\circ$
	Wrist	1	Green	flexion and extension $> 15^\circ$
Other tasks	Neck	1	Green	Neck flexion $< 20^\circ$
	Back	4	Red	Flexion $> 45^\circ$
	Arm	5	Red	Arm lifting $> 40^\circ$
	Wrist	3	Red	flexion and extension $> 15^\circ$

B. Placing a Tube and Wrapping with Plastic Strap

The task duration in which all the different actions were performed was approximately 8 minutes. The RULA score for neck posture for 51% of the task time was 2 ($10^\circ < \text{neck flexion} < 20^\circ$) and for 19% of the task time it was 3 ($20^\circ < \text{neck flexion}$). The overall score for the neck was 4 because sometimes the neck was bending to the side during this task. The SES method showed red ($45^\circ < \text{neck flexion}$ and sideways/rotation $> 30^\circ$) for neck posture for just 10 seconds of the whole task time (2% of task time), while for most of the task duration the neck posture was assessed as yellow. Since the worst color governs the final evaluation in the SES method, the final color for neck posture was red. The direct method showed the neck was in flexion of 10° and 20° for 26% of the task time. In this study side bending of the neck posture was not assessed with the inclinometer. Again, for this task the results of observational methods were in conflict with the inclinometer recording.

The RULA score for 70% of the task time for back posture was 3, defined as back flexion more than 20° and less than 60° . Trunk twisting and side bending were not observed in this task. Trunk posture was assessed by SES as yellow, which shows bending forward between 20° and 45° . The accelerometer at L3 showed lower back flexion between 20° and 45° for 68% of task duration, and for 13% of the task time the trunk posture was more than 45° . The three methods

provided similar results for back posture for this task.

The RULA score for the upper arms was 4 (upper arm lifting $>90^\circ$) for less than 5 seconds of total task time whereas for 95% of the task duration this score was 2 ($20^\circ <$ upper arm lifting $<45^\circ$). Static posture of the shoulders and arms was assessed by SES as green (upper arm lifting $<45^\circ$). The left and right arm positions were evaluated at more than 40° by the direct methods for only 1% of the task time, and this was consistent with the other methods.

Wrist postures were assessed as 3 by RULA, showing flexion or extension of more than 15° , and the result on SES for this task was red. Electro-goniometry demonstrated that the wrist postures were more than 15° for 65% of the task period.

The overall RULA score in this task was 5 and the final color for the SES method was green, as for the tightening task.

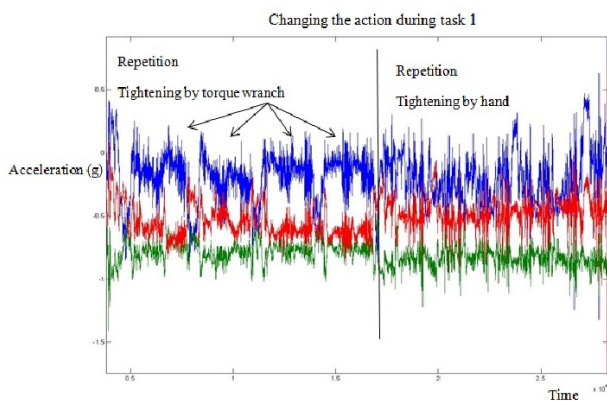


Fig. 2 Cyclic accelerations of the arm for two consecutive tasks: vertical accelerations (green), longitudinal accelerations (blue) and lateral acceleration (red)

C. Loosening with Hand/Tools and Other Actions

The results of posture assessments during the loosening task were the same as the tightening task, especially for the neck, back and upper arms. However, the duration of awkward postures was shorter for the tightening task and the numbers of repetitions were also different. Table II shows the results of observational methods and the direct method for these tasks.

The two accelerations with the left and right arms provided further information about hand movements and the symmetry of the body movements. As shown in Table III, although the tightening task involved the same amount of work, with both tools and hands, acceleration between the two hands for these actions was not the same. Tightening with a tool was more symmetric for both arms compared to tightening by hand.

TABLE III
ASYMMETRIC MOVEMENTS OF THE ARM DURING MANUAL TIGHTENING COMPARE TO TIGHTENING WITH A TOOL CALCULATED BY ACCELERATION (G)

Action type	Arm	RMS	RMS
Manual	Right Arm	0.77	1.34
	Left Arm	0.57	
	Right Arm	0.95	1.23
	Left Arm	0.3	
Tool	Right Arm	0.82	1.31
	Left Arm	0.49	
	Right Arm	0.93	1.26
	Left Arm	0.33	

IV. DISCUSSION

This study was undertaken to develop a biomechanical method which allows measurement and calculation of movements and positions in assembly and manufacturing plants. We compared the results of biomechanical measurements with two observational methods. Overall, we did not find a great difference between the three methods. For most parts of the body all methods demonstrated the same results, although the biomechanical method provided more precise information. However, some inconsistencies were observed, especially in assessment of the neck and wrists. As explained, for tightening and loosening tasks the results of both observational methods for the neck were in the action zone and further changes should be proposed as soon as possible, whereas the inclinometer measured neck angles of less than 20° in these tasks which is in the normal zone and acceptable. One reason for this conflict is probably that the observers looked at the neck in terms of an anatomical straight line while the inclinometer provided the neck angles in relation to upper back position. Evidently, neck bending accompanies upper back bending.

Furthermore, some differences were found between the methods for assessing wrist postures. In contrast to neck posture, the electro-goniometer provided angle values for both wrists that were much worse than the results of observational methods. The reference positions for the wrist when measuring with the goniometer might be the reason for these differences. Goniometers measure the flexion and extension of a functional position of the hands.

The direct method would provide the possibility of measuring exactly how many repetitions occurred during an individual task. In addition, symmetry of movement is another criterion which we could never assess with the observational method. However, further investigations are required, particularly in real workplaces, to confirm the results of this study.

V. CONCLUSION

In conclusion, our results showed that sensors were more precise than observational methods as they decrease raters' errors. Accelerometers on the arms and back should be sufficient to assess postures instead of inclinometers which also provide complementary information about movement speeds, symmetry and repetitions.

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