

## Technological advances in rebar tying jobs: a comparative analysis of the associated yields and illnesses

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### Abstract

Workers who carry out manual rebar tying tasks are exposed to muscular-skeletal injuries associated with the use of manual tools and the movements associated with them (force, repetitiveness and awkward wrist postures). This paper presents a background on musculoskeletal injuries directly linked to manual and mechanical rebar tying method is conducted.

The objective of this study is to compare the traditional manual rebar tying method to the innovative mechanical technique. The methodology carried out follows a qualitative and a quantitative analysis of both processes. Firstly, a qualitative analysis is performed by semi-structured interviews to workers. Secondly, a quantitative study is carried out in the region of Andalusia (Spain). This field study includes on-site measurements of lengths of time activities. According to the methodology developed by the International Labour Organization, the work timing is calculated and a comparison is given.

Results state that the operators adapt without difficulty to the mechanical method and it could result in better performance, whilst reducing some of the risks deriving from the manual tying technique.

**Keywords:** Rebar, Musculoskeletal risk, Yield, Production costs.

### 1. Introduction

It is in the construction sector where exposure to all types of risks (relating to noise, vibration, ergonomic risks and those caused by exposure to chemical or biological agents) is at its highest [1]. The problems associated with a lack of adequate ergonomic working conditions are of growing importance. There is an increase in the number of musculoskeletal disorders among workers due principally to inadequate ergonomic conditions [2].

Accidents, musculoskeletal disorders (MSDs) and work-related stress are the principal Occupational Safety and Health (OSH) concerns for European enterprises. By country, and starting with the 'traditional risks', accidents are more frequently reported to be of some or major concern by establishments in the Czech Republic, Turkey, Portugal and France, as is the case for dangerous substances and noise and vibration, while MSDs appear to represent a higher concern in Norway, Spain and France [2].

Musculoskeletal injuries are an important cause of absenteeism and disability in many working populations; they encompass a group of conditions concerning nerves, tendons, muscles and support structures of the locomotor system [3, 4].

The musculoskeletal injuries associated with the workplace are those caused or aggravated by the working environment, being by nature multifaceted. These can cause severe and debilitating symptoms such as pain, numbness, paraesthesia and discomfort, in one or more area of the body, as well as loss of time at work, temporary or permanent disability, difficulty in performing work tasks and increased compensation costs [4, 5, 6, 7].

According to the Occupational Safety and Health Administration hereinafter OSHA (Organization that assure safe and healthful working conditions for working men and women) [8, 9], the risks relating to inadequate body mechanics originate from the application of brute force in the workplace, the repetition of tasks, postures, whether forced or static, rapid movements, compression or contact stress, vibrations and low temperatures. The global results of the VII National Survey of Working Conditions [10] show that data referring to physical exertion in the workplace and its associated health problems are on the increase, as are those indicators relating to mental exertion: level of care required, work rate imposed, deadlines to meet and monotony of a job.

One of the indicators of greatest impact on the risk exposure of workers, due to its magnitude and associated consequences, relates to the physical requirements of a job. The most common physical demands include: awkward postures, manual material handling, and back accidents as risk factors for the occurrence of back pain [11]. In concrete, repetition of the same movements of the hand or arm (59%) and adopting painful or tiring postures

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(36%). In both of these circumstances the frequency of exposure is higher among women than men. All in all, 84% of workers claim they feel some level of discomfort which can be blamed on postures and forces deriving from the work they do. Furthermore, in general, the frequency of complaints for musculoskeletal discomfort is markedly higher among women [10].

By sector, workers in the construction sector are exposed to the highest percentage of vibrations (29.8% in the hand-arm, 6.1% in the whole body and 5.2% in both types) followed by the industrial sector (16.4% in the hand-arm, 5.3% in the whole body and 2.5% in both types). Meanwhile, most noteworthy in hand-arm and both types vibrations are: Construction and mining workers and Mechanics and workshop employees [10].

According to [12] properly designed powered tying tool may be the best ergonomic solution.

A study made in Andalusia (Spain) in construction works is made with the aim to obtain advantages and disadvantages of the hand versus mechanics tying methods for workers.

## 2. Background

### 2.1. General causes of ergonomic problems in the construction sector

Epidemiological studies have reported risk factors which can encourage the development of musculoskeletal problems. Among these are repetitive movements, prolonged exertion, frequent or heavy lifting, pushing, pulling or moving heavy objects, prolonged and awkward postures, high work demands, jobs with inadequate scope, cold, vibration, local pressure on the skin or nerve tissue, musculoskeletal load, static load, monotony and cognitive demands, organizational and psychosocial factors associated with work, smoking and vigorous exercise [4, 13, 14, 15, 16].

The most recent data offered by OSHA [17] indicates that workers in the Construction sector have greater exposure to biological, chemical, musculoskeletal and noise and temperature changes; among these, 45% of workers claim that their work affects their health. In the same way, the data shows that musculoskeletal disorders in the back over time lead to permanent injuries among between 60 and 90% of these workers whilst in every day terms this is between 15 and 42%. In the VII Survey of Working Conditions [10] 84% of the workers interviewed claimed to be exposed, "always or usually" or "often", to some deficient aspect related to the physical demands of their workplace. The most common physical demands are: repetition of the same hand or arm movements (58.9%) and adopting painful or tiring postures (35.8%).

Discomfort in *arms/forearms* is most common in Agriculture, forestry and fishing (19.1%) and Construction (18.7%); in *shoulders* in Health and social care (18.7%) and Metal (17.8%); and discomfort in the *legs* is most common in Hospitality (27.3%).

The most influential factors in musculoskeletal problems are: age, length of working day, time of accident,

size of company and day of the week [18], although other determining factors exist [19] such as:

- Environmental conditions in the workplace.
- Handling of tools and equipment.
- Handling of machinery.
- Manual handling of loads.
- Order and cleanliness in the workplace.
- Psychosocial risks [20].

Furthermore, the importance of the risks inherent to the absence of good habits used when adopting adequate body mechanics through implementing a convenient ergonomic strategy in jobs carried out by the Construction Sector is on the increase [21] given that physical overexertion is the leading cause of accidents requiring leave in the sector (more than 25% of the total number of accidents), followed at some distance by accidents caused by blows from blunt objects or tools and falls. These findings highlight the comparison of the results obtained during the Survey 2007 where it was proved that, in general, studies dealing with the majority of occupational risks have increased. The studies which have shown a most significant increase on 2007 are those relating to: organizational and psychosocial aspects, increasing 15 percentage points, work postures, physical strain and repetitive movements, increasing 11.8, and workplace design which have increased 10.7 percentage points.

According to the VII National Survey of Working Conditions [10], on those aspects relating to workplace design analysed in the construction sector the workers state that:

They have insufficient space at their disposal to be able to work comfortably (18.1%).

They must reach for work tools, elements or objects which are situated either very high or very low, or whose positioning means they must stretch their arms a lot (25.2%).

They have an inadequate illumination at their disposal to carry out their tasks (scarce, excessive, with glare, etc.) (12.4%).

They work on unstable or irregular surfaces (24.7%).

Of all the Construction Sector workers, this paper focuses on rebar workers and, specifically, on the ergonomic problems deriving from rebar tying.

### 2.2. Ergonomic analysis of the job of a rebar worker

The tasks to be performed by a rebar worker consist of making the metal reinforcements necessary to be able to carry out the construction elements of reinforced concrete in buildings. They must also organize and prepare the pit and material resources necessary to carry out said reinforcements in optimum performance conditions while respecting the conditions of health and safety at work [22].

This group of workers are subject to the following ergonomic risk factors [22, 23, 24]:

- Forced positions of their trunk and arms
- Manual handling of loads
- Force, repetitiveness and forced postures on the wrist associated with the use of hand tools.
- Working on unstable and irregular surfaces.

With regards to the ergonomic problems, many publications point to the use of fastening tools that reduce stooping positions and the use of tools to tie reinforcing bars and rods as examples of good practice [24, 25]. At the same time, the manufacturers themselves highlight the ergonomic benefits of using rebar tying machines.

### 2.2.1. Rebar tying jobs

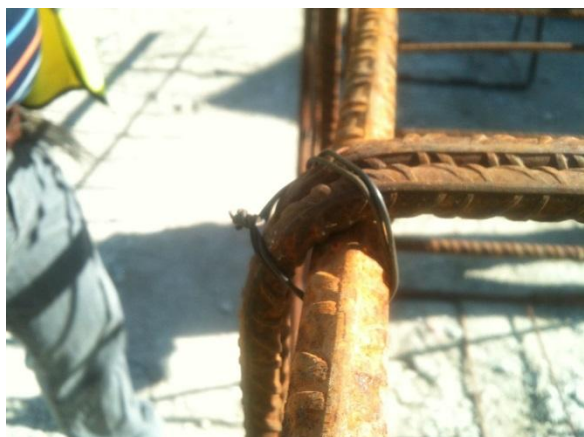
During this study, the tying of bars during the making of beams on-site was evaluated (see Fig. 1). In the tying stage, bars of different diameters, lengths and positions are fastened using wire so as to form the rebar element and assure that its configuration will be maintained during the site work period and for the duration of the lifespan of the structure to be upheld. The tying process can be done manually or mechanically.



**Fig. 1** Activity analyzed

The characteristics of each method applied to the structural element previously mentioned are as follows:

**Manual tying:** the operator, using a double wire, fastens the corners of the stirrups to the main bars of the beam, making a double turn on both bars. The wire used is annealed wire, 0.8mm. Finally, it is tied off with a double loop or double twist, and the excess wire is cut (see Fig. 2). Manual tying is carried out with pliers of 300mm. weighing 490 gr. (see Fig. 3).



**Fig. 2** Close-up of manual tying



**Fig. 3** Pliers

**Mechanic tying:** The different tying machines which exist on the market execute double or triple ties. The machine allows for the adjustments of the pick to fit the diameter of the bars to be tied (see Fig. 4) and can be manipulated with one hand. The rolls of wire have similar characteristics to those used in manual tying (0.8mm.) and each roll performs on average 120 triple ties or 160 double ties.



**Fig. 4** Close-up of the adjustable pick

The mechanical tying performed holds similar characteristics to the manual tying, double mechanical tying (see Fig. 5). The rebar tying employed for the purposes of this study holds similar characteristics to those available on the market. The dimensions of the machine are 277 x 100 x 290 mm. with an approximate weight of 2 kg. (see Fig. 6).



**Fig. 5** Close-up of mechanical tying





Fig. 6 Battery powered rebar tier

### 3. Experimental Procedure

Any ergonomic study of a job is usually carried out using a combination of methods of analysis, resulting in a final evaluation which consists of a conjunction of the results of the different tests. Before the experimental phase, relevant information must be collected of manuals, articles, previous studies on the same topic, and any other useful document. Once this process is complete, the method or methods which best meet the objectives of the study are selected, in concordance with the means available, the time, population size, etc.

Following the classification criteria laid out by Lehto and Buck "guided tour of ergonomics design. Introduction to human factors and ergonomics for engineers" [26], these methods can be physical, quantitative and they include mixed subjective or objective aspects, given that they are based on subjective observations which become objective once the results are correlated in pre-established tables or qualitative analyses.

Before carrying out on-site measurements, the subjects of the study are given a document informing them of the objectives and implications of the study, from the institution carrying out the study and of the methodology followed. In accordance with the *Organic Law 15/1999, of 13 December, on the protection of personal data*, the participants are informed that any information obtained will be treated with the upmost responsibility and total confidentiality, guaranteeing its exclusive use by authorised personnel. Along the same lines, and in accordance with the *Organic Law 1/1982, of 5 May, on civil protection of the right to honor, personal and family privacy and personal image*, the consent of each participant is sought for the taking of pictures or videos and their possible subsequent disclosure for the purposes of the development of the investigation. In this way, informed consent is sought to report the findings at the end of the activity.

#### 3.1. Qualitative analysis

The most suitable methodology applicable to achieve the objectives set consists on implementing the quantitative studies with some kind of qualitative

technique, including among these the semi-structured interview technique, focussing principally on opinions and experiences relating to the use of mechanical tools in rebar tying. Broadly speaking, the interview could be defined as a conversation between two people, interviewer and interviewee, led and recorded by the interviewer, whose objective is to promote the production of a discourse on the part of the interviewee on a topic defined within the framework of an investigation. The subject of the study is then analysed based on the experiences of a certain profile of individuals, individuals who are both part and product of the action studied.

During this stage and before the start of the interview, the interviewees will again be informed about the objectives of the study and about the methodology to be applied, and their informed consent will be sought for the recording of the interviews, guaranteeing the confidentiality of the transcripts and of any personal information, and underlining that the material will only be handled by authorized personnel.

#### 3.2. Quantitative analysis

The methodology employed to measure work times is as recommended by the International Labour Organization hereinafter ILO [27] whose objective is to obtain the lengths of time activities last through observation of their execution. For this, various on-site measurements were taken of the time needed to make a tying knot of a stirrup in a beam (see Image 1), both manually and mechanically (Times Observed). The starting point of the measurement is the moment when the operator touches the rebar tie in order to place the stirrup in its correct position, and ends when the tying tool is taken away.

Although the ILOs method indicates that the Times Observed must be revised through the attribution of a Rhythm type (Performance obtained naturally and without effort by qualified workers on an average workday, provided they know and respect the specified method, and agree with its application. For a correct comparison of work rhythm observed over rhythm type, a numeric scale is necessary and will serve as a measure of calculation, namely a scale of evaluation of the rhythm. Numerous scales exist to calculate rhythm: each of these awards a value to the rhythm defined as rhythm type and, from this, the actions of a worker can be evaluated using the rhythm observed.), by employing a rhythm scale, in this study said correction has not been adhered, given that the rhythm of a machine is always constant and besides the activity time constitutes less than one second.

To obtain the Normal time (According to the UNE 52003 it is the time necessary to carry out a job by a normal operator, working at normal speed, under typical conditions. No kind of tolerance or supplement is to be included.) ( $T_N$ ) of execution of the activity through both methods, qualified workers were observed (He who holds the experience, knowledge and other qualities necessary to be able to carry out the job at hand, whilst satisfactorily following the norms of security, quantity and quality). A sequence of 5 observations was made. In each observation, according to the methodology developed by the International Labour Organization to calculate the work timing [27], the authors have recorded the workers during the rebar tying job, afterward the videos have been

edited in order to obtained the results. Then, on completion of each observation, the arithmetic average accumulated at the origin was calculated.

At the same time a graph for each type of tying (manual and mechanical) was drawn up (see appendix 4).

According to the ILO [27], all workers need additional time to that strictly used for the realization of any activity. This fact must be taken into consideration, as a consequence of various factors and conditions external to the actual job. These are:

- Factors relating to the individual.
- Factors relating to the nature of the work itself.
- Factors relating to the environment.

In this way, Time Type ( $T_T$ ) is defined as the time necessary to carry out a job by a normal operator, working at normal speed, under typical conditions, plus the time necessary to compensate for fatigue, personal needs and inevitable delays (Supplements) (UNE 52003). So,

$$T_T = T_N + Supplements$$

These supplements can be classified as follows:

For rest. These are necessary to enable the worker to recuperate from the physiological, physical and psychological consequences of work.

For personal needs and for basic fatigue, which constitute between 5-7% and 4% of the time, respectively, dedicated to actual work.

Special: cleaning, training, implantation, rejection etc.

For contingencies (<5%): a small supplement which is included, or added, to compensate for small losses which may appear and which do not merit the consideration of being measured, for example when the employee approaches, observes, makes a suggestion or give some instruction.

In this paper the following fixed supplements have been considered for both types of tying:

For personal needs: 6%

For basic fatigue: 4%

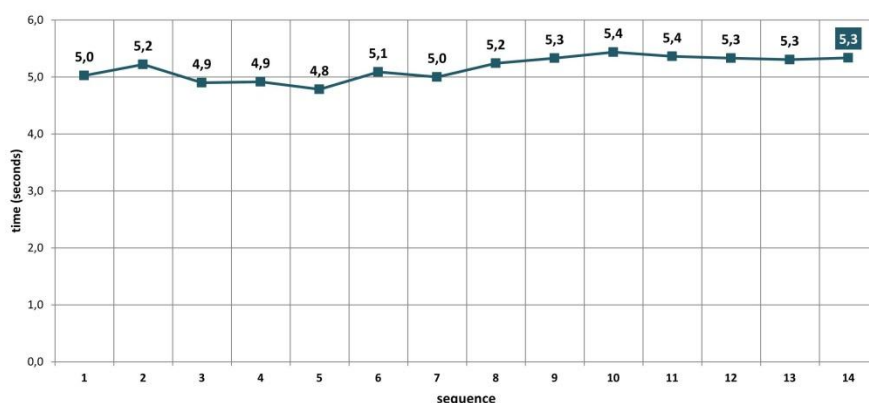
Furthermore, the following contingencies must be considered. These have been estimated at 5%:

In manual tying: small movements to fetch the wire and the preparation of the wire.

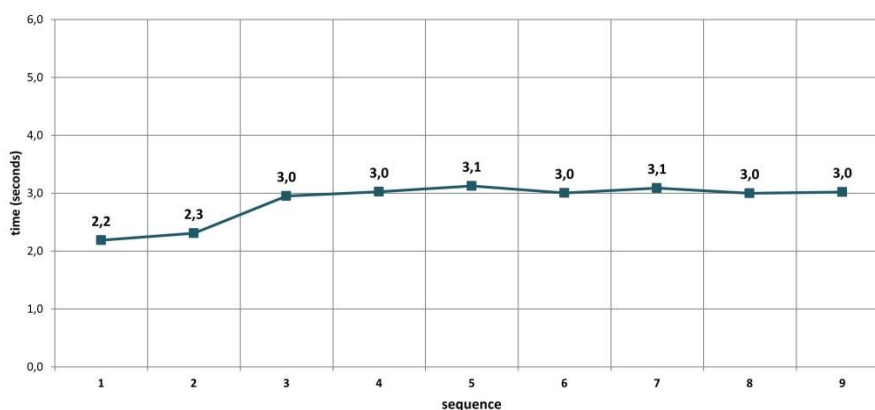
In mechanical tying: jams in the machinery and changing of the roll of wire.

## 4. Results

In graph one, on the ordinate axis, the accumulated  $T_N$  is plotted, and on the abscissa axis, the number of accumulated sequences (see Fig. 7). When the corresponding graph is established horizontally it is not necessary to make further observations and this value will be established as the  $T_N$  of the activity for manual tying. Along the same lines, in Fig. 8 the data referring to mechanical tying is recorded.



**Fig. 7** Accumulated time (in seconds) for each sequence assessed, in the case of manual tying



**Fig. 8** Accumulated time (in seconds) for each sequence assessed, in the case of mechanical tying

Through analysing the graphs the following values have been obtained:

$$T_{N\text{manual}} = 5.3 \text{ seconds y } T_{N\text{mechanical}} = 3.0 \text{ seconds.}$$

If the corresponding supplements and contingencies are added to these values, the  $T_T$  becomes 6.1 seconds in the manual tying of a stirrup and 3.5 seconds for mechanical tying. Therefore, the conclusion is that the time of mechanical tying is the **57%** of the time of manual tying.

The performance variation results in a decrease in costs in the case of tying manual. if we analyze the cost of the tying unit, using price basic prices based in the Data Base Cost of Andalusia and, considering only the elements that differentiate a bundle of another, namely, wire length, diameter and time bound (Data Base Construction Costs of Andalusia, 2010), we obtain that in the case of the

mechanical cost, the use of the tool results in a reduction in cost of knot unit tying 15.38% less.

**Table 1** Cost of the tied unit

TIED UNIT	Unitary Price	Hand Tying	Mechanical Tying
T(s) Rebar	18.33 €/h	0.026 €	0.015 €
Wire (Kg.)	1.23 €/kg	0.101 €	0.0054 €
TOTAL/KNOT		0.130 €	0.02 €

In the qualitative analysis phase, of the interviews carried out on-site with the operators, the following responses were recorded (see Table 2):

**Table 2** Summary of the semi-structured interview

Question	Operator 1	Operator 2
1.- Are you familiar with the machine and how it works?	He had never used it before.	He had previously worked with the tying machine. He affirmed that he had only used the machine in the tying of slabs and walls, never in an element such as a pillar.
2.- Do you suffer from any kind of disorder related to the activities you perform?	He stated that at the end of the day he did not notice any pains in the superior articulations, although the new workers did complain of pains in the wrist at the end of the working day.	He did not complain of pains at the end of the working day.
3.- (After using the machine) What stands out after using the machine?	He complained of the heavy weight of the machine in comparison to the pliers which are much lighter and more manageable.	He underlined the heavy weight of the machine. No problems were noted in the adaptation to using the tying machine.
4.- What are the advantages and disadvantages in using the machine?	He pointed out that the joint made by the machine is much less stable than that made manually.	The joint made using the mechanical method is less secure than the manual joint.
5.- Observations	He suggested that the tool could be useful in other kinds of elements, not in a pillar.	

Through analysing the data recorded in the table above (Table 2), it can be said that the operators adapted without difficulty to the work tool used in the study ("it is faster"). However, when made to use the machine, they doubted the joints achieved ("the knot is less stable"), and even noted the heightened consequences on the health of the worker ("it weighs more").

## 5. Discussion

On completion of the study, the following advantages and disadvantages of mechanical tying have been drawn up.

Advantages:

- The risk of repetitive strain caused by wrist turning is reduced when using the tying machine
- Faster tying when the conditions are adequate.
- The machine allows for the addition of an extendible rod to avoid stooping postures of the operators.

Disadvantages:

- Heavy weight of the tool (2 kg.).
- Difficulty of access for tying of unsupported bars at a short distance, it does not allow for tying of bars of

large diameters (ø16, ø20, etc.).

- Less stable joints than with manual tying
- Higher number of contingencies (jamming of the machine, need to change the roll of wire or the battery...).

As for manual tying, the following advantages and disadvantages have been recorded.

Advantages:

- Higher tying speeds resulting in better performance in the activity, especially among specialized workers.
- Allows entry of the hand between bars situated very close together.
- Reduction in the use of wire.
- Use of pliers as the main tool, whose approximate weight is 490 gr.
- More secure, stable joints.

Disadvantages:

- Ergonomic risks which produce serious damage in the long term. This necessitates the search for alternative methods or systems.

After observing work times, the conclusion reached is that the manual tying time needs a higher number of

sequences before stabilising. Although true, this fact can be explained given that the fluctuations of time in manual tasks are greater in general than those observed in mechanical tasks, taking up ever more time until it becomes a repetitive task for the operator.

On evaluating the usefulness of this tool, not only the technical aspects previously evaluated but also the results of the qualitative analysis must be taken into consideration, through an assessment of the worker's opinions, with the purpose of drawing up a plan of the tasks and measurements which is as effective as possible.

## 6. Conclusions

This investigation calls for further research on the convenience of the mechanical method, with evaluations carried out under more optimal working conditions than those outlined in this study.

Following the evaluation of the authors, the mechanical method evaluated under other more favourable conditions and using other elements (such as meshes or walls) could result in better performance, whilst reducing some of the risks deriving from the manual tying technique. It is therefore necessary to analyse in greater detail the effectiveness of mechanical tying compared to manual tying in different conditions.

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