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PROCESS ENGINEERING

Ergonomic assessment of natural rubber processing in plantations and small enterprises

INGENIERÍA DE PROCESOS

Evaluación ergonómica del procesamiento del caucho natural en plantaciones y pequeñas empresas

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Abstract
This exploratory study used OWAS (Ovako Working Posture Analysing System) to analyze the working postures of natural rubber tappers and rubber industry workers. A community of natural rubber farmers of Tarazá and five small companies of Medellín and Itagüí, all of them allocated in Antioquia-Colombia, participated in this study. Processes were analyzed in-situ and videotapes of activities were recorded for carrying out a movement study. For an overall distribution of trunk postures, OWAS identified that a bent and twisted trunk posture which fell into action category 4, was the major poor posture for rubber tappers and rubber industry workers. This study also identified that latex tapping, latex collection, mixing in two roll mills and metallic molds operation were the four activities in which the major working posture risks were observed. It was found that reduction of posture risks in natural rubber production chain requires designing and implementing plans considering organizational culture, socio-economic and socio-demographic factors of natural rubber farmers and small rubber manufacturing industries, besides the use of some useful tools that reduce the handling of heavy loads.

Keywords: *Ergonomic assessment, natural rubber industry, OWAS, posture.*

Resumen
Este trabajo presenta un estudio exploratorio que usa la metodología OWAS (Ovako Working Posture Analysing System, por sus siglas en inglés) para analizar las posturas de heveicultores y operarios de la industria del caucho durante sus actividades laborales. El estudio se realizó en pequeñas plantaciones de una asociación de cultivadores de caucho en Tarazá, y en cinco pequeñas empresas de Medellín e Itagüí, en Antioquia-Colombia. Se analizaron los procesos in-situ, tomando registros mediante videos para posteriormente efectuar un análisis de los movimientos. Se encontró que los mayores riesgos ergonómicos para los heveicultores y los operarios de pequeñas y medianas industrias de caucho son la generación de trastornos musculoesqueléticos (TME) en la columna vertebral y la Back, con un nivel de riesgo 4. Se encontró también que el sangrado de los árboles, la recolección del látex, el mezclado en molino abierto de rodillos y la manipulación de moldes fueron las cuatro actividades en las cuales se presentan los principales riesgos de postura. Al final del trabajo se proponen recomendaciones para evaluar y reducir los riesgos de postura en pequeñas empresas de la cadena productiva del caucho natural. Se identificó que la reducción de los riesgos de postura in la cadena productiva del caucho natural requiere diseñar e implementar planes que consideren la cultura organizacional y factores socioeconómicos y sociodemográficos de los cultivadores de caucho natural y pequeñas industrias fabricantes de artículos en caucho, además de la utilización de algunas herramientas que reducen la manipulación de cargas pesadas.

Palabras clave: *Evaluación ergonómica, industria del caucho natural, OWAS, postura.*

1. Introduction

Work-related ergonomic risks are a major problem in public health (Stock et al., 2011). Physical/ergonomic factors during working time such as combination of mechanical loading and postures (Butler & Kozey, 2003), discomfort of the lower extremities of workers in occupational environments, (Reid et al., 2010), awkward postures during work time (Burdorf et al., 1993; Choobineh et al., 2007; Scuffham et al., 2010), lifting loads (Andersen et al., 2007), manual material handling (Meksawi et al., 2012), standing or walking prolonged periods (Andersen et al., 2007; Balasubramanian et al., 2009), long working hours (Raanaas & Anderson, 2008), torsion of the trunk (Sbriccoli et al., 2004; Hartman et al., 2005), repetitive or monotonous work (Guo, 2002; Juul-Kristensen & Jensen, 2005), are associated to some work-related musculoskeletal disorders (WMSDs), specially to lower back pain (Petit et al., 2016).

Prevalence of WMSDs varies by occupation, gender and country, being higher among unskilled workers like farmers (Holmberg et al., 2003; Punnett et al., 2005; Singh et al., 2015), forestry workers (Gallis, 2006), construction workers (Savinainen & Nyberg, 2012) and manufacturing processes operators (Punnett et al., 2005).

While natural rubber is grown and processed for industrial purposes since the late XIX century, there are still ergonomic issues without addressing with regard to heveiculture, as it is called this economic activity consistent in harvesting, tapping, collecting and processing natural rubber. In Thailand, having the largest natural rubber production in the world (Meksawi et al., 2012) found that natural rubber processing includes activities with high risk of developing WMSDs. (Bensa-ard et al., 2004) stated that natural rubber farmers had high risk of developing back pain and to a lesser degree carpal tunnel syndrome, possibly as an effect of awkward and highly repetitive postures.

Natural rubber production and consumption exhibit constant growth, and some projections estimate that this will continue for at least the next decade, so it is appropriate to consider associated occupational health risks to begin mitigate them (Warren-Thomas et al., 2015). In the case of Colombia, heveiculture has increased significantly in the last decade but it is estimated that 90 % of farmers have crops of 5 hectares or less, that is small plantations (Confederación Cauchera Colombiana, 2015). These natural rubber-producing areas are located in regions with unsatisfied basic needs in infrastructure, education and health which make relevant an intervention with regard to ergonomic risks associated with their work.

Natural rubber production chain ends with its transformation in industries generally located in urban centers, where rubber is mixed with chemical additives and/or synthetic rubbers and vulcanization process takes place for obtaining parts with the elastic properties and chemical resistance that characterize rubber products (Confederación Cauchera Colombiana, 2015). 61% of companies dedicated to manufacture rubber parts in Colombia have technology ranked among poor and regular, 32% have technology fair to low, and only 7% have technologies considered between normal and excellent (Cámara de Comercio de Medellin, 2014). This study also indicates that approximately 80% of these enterprises are micro and small enterprises, recalling that these organizations are more likely to operate in ergonomic risk conditions (Unnikrishnan et al., 2015). Musculoskeletal problems among workers of rubber factories were reported in the lower back, knees and upper back due to awkward postures and manual material handling (Choobinehi et al., 2007). Risks related to exposure to the chemicals substances used in rubber industry have been reported by Andjelkovich et al. (1988), but this work is focused on working postures and posture risks of workers in Antioquia (Colombia) who perform operational tasks in small plantations of natural rubber and small rubber factories. Postural hygiene for these activities is analyzed by OWAS method (Ovako Working Posture Analysing System) and some improvement actions to mitigate them are proposed.

2. Methodology

Processes characterization in plantations and small industries was carried out at first. Processing of rubber latex was analyzed in small plantations of ASCULTICAUCHO (Asociación Comité de Cultivadores de Caucho) in Santa Clara, municipality of Tarazá (Antioquia). This region represents 8 % of the cultivated area in Colombia, recalling that is the area of Antioquia with the highest amount of cultivated land and natural rubber workers. Characterization of natural rubber processing was carried out by analyzing the working postures of three workers separately during four visits every three months, regarding this work is aimed to identify working postures. Workers are males between 17 and 26 years old, they received some type of training in natural rubber processing in the last five years and have worked for at least three years in those activities.

Mixing and vulcanization processes were characterized in five small businesses in the Valle de Aburrá, industrial capital of Antioquia and the second most industrialized area of Colombia, considering that 80 % of rubber factories in Colombia are micro and small businesses. All the workers included in this study were males between 23 and 34 years old, without any type of training in natural rubber manufacturing. In all the cases they learned its skills by working in rubber industries.

According to interviews and Confederación Cauchera Colombiana (2015), in Colombia all rubber workers of small plantations and small rubber factories perform its activities in the same way that was observed in this work.

Information was collected through direct observation (*in situ*), photographs and videos were useful recording in detail each activity, with special attention to the operator's movements. Each process was recorded four times, analyzing the movements from the videos and images using the open source software Kinovea®.

Activities involving ergonomic risks were identified and aspects related to postural hygiene for theseactivities were analyzed by OWAS method, because this method is of easy implementation by small companies and does not requires specialized instructions to be used. OWAS method allows a simple analysis of the posture based only on the observation of the activity (Wahyudi et al., 2015), seeking to reduce musculoskeletal loads during activities in the workplace and make it safer and more productive (Lee & Han, 2013). Wintachai & Charoenchai (2012) used OWAS method finding that working postures in rubber sheet manufacturing contained high OWAS scores. Positions codes used in this work and description of risks that were observed are presented in Table 1.

To analyze control and handling of loads the methodology developed by the National Institute for Occupational Safety and Health of the United States (NIOSH) was used, because it has been demonstrated that it is reliable in several manufacturing activities (Hafeezah et al., 2013). NIOSH Lift Index® application for Apple was used for obtaining the risk level for each activity in rubber processing. Potential WMSD that can be generated if the ergonomic hazards are not evaluated properly were identified. Then, preventive and corrective measures to minimize the probability of occurrence of MSDs were established.

Table 1. *Posture codes and risks description of OWAS method.*

Body area	Assigned posture code 1	2	3	4	5	6	7
Legs	Sated	Standing with both-legs straight	Stand with the weight on one leg	Stand with the knees bent	Standing or crouched with one knee bent	Kneeling on one or both knees	Walking
Back	Erect	Leaning forward or backward	Rotated or tilted laterally	Leaning back with twist			
Arms	Both arms below shoulder level	One arm above and one below the shoulder level	Both arms above shoulder level				
Load	< 10Kg	Between 10Kg and 20Kg	> 10Kg				

Risk Description

Risk	Description	Action
1	Normal and natural posture without harmful effects on the musculoskeletal system	No action is required
2	Posture with harmful effects on the musculoskeletal system.	Corrective actions are required in the near future.
3	Posture with harmful effects on the musculoskeletal system.	Corrective actions are required as soon as possible.
4	The burden caused by this posture has extremely harmful effects on the musculoskeletal system.	Corrective actions are required immediately.

3. Results and discussion

In this section, the characterization of activities is presented as the first set of results. Then, the identification of postural risks and finally the OWAS scores are calculated.

3.1 Characterization of processes

3.1.1 Natural rubber processing at plantations

Once Heveas brasiliensis plantation has been established and it is suitable for exploitation, tapping takes place; this activity consists in make an incision in the tree's bark with a knife, letting the latex flow from the lactiferous vessels of the tree to a gatherer cup. The worker performs this action during between 12 and 20 seconds for each tree in the plantation. This procedure was carried out between 400 and 600 times a day according to the crop size that the worker had in charge that day.

Farmers reported that tapping usually began when the circumference of the tree trunk reached 50 cm, and then divided the circumference in two or three sections. A single section can bleed for 6 years and then the next section can start be tapped. The cuts started at a height of 150 cm from the base of the tree and continued down until nearly ground level, as shown in Figure 1. The first cut is carried out from the left to the right in a downward direction, along a path that forms an angle of 30° to the horizontal by using a pattern made of a plastic film. When the cut of section reaches the base of the tree, it is necessary starts to bleed a new section, beginning again at a level of 150 cm above ground level.

It was observed that when performing the incision, worker’s forearms and wrists must maintain a degree of flexion while the trunk was leaning forward and lateral rotated. The level of flexion or rotation depended on the height of the level of bleeding. After finished the tapping of all the trees on the plantation and when latex stopped to drop into the cups, the worker collected the latex of each cup located on each tree and gather the latex in drums to facilitate their transport to the latex treatment area where next activity is carried out, as shown in Figure 1.

Activity 1: *Tapping. In this image the cut is performed near the ground*

Activity 2: *Latex collection in drums*

Activity 3: *Filtering and dilution of latex*

Activity 4: *Rolling*

Figure 1. *Natural rubber processing for obtaining sheets.*

During this study, each worker transported 15 to 25 Kg drums by walking between 1 and 2 Km from the plantation to a zone where rubber sheets are manufactured. The distance that was traveled by the worker depended of the location of the plantation where he ended the collection of latex. Collected latex was filtered to remove impurities and subjected to dilution using an aqueous solution of acetic or formic acid.

After a coagulation period of one day, rolling of rubber until transformation to rubber sheets on manually operated equipment took place. The worker passed the coagulated material 7 to 10 times between two metal rollers in which the worker diminished gradually the gap until sheets of 1.5 to 2 mm thick are obtained.

After a drying period of seven to ten days, dried sheets of natural rubber were obtained. These sheets are raw materials for rubber industries.

3.1.2 Rubber articles manufacturing

Natural rubber sheets were mixed with the ingredients selected by the manufacturer according to the desired properties for the product, by passing the materials by an open roll mill. The mixture was cut in pieces that were incorporated to a mold, where parts were manufactured by applying heat and pressure in a molding press. Mixing and molding are shown in Figure 2.

In the case of micro and small rubber factories from Antioquia, their mills, molding presses and molds varied in structural configuration and automation level but broadly have low and old automated technologies, which increase the level of ergonomic risk.

Activity 1: *Incorporation of ingredients to the mill*

Activities 2 and 3: *Mixing–extraction of the mixture*

Activity 4: *Mill cleaning*

a) *Mixing in the open rolls mill*

b) *Types of open roll mills used for mixing*

c) *Molds handling for compression molding*

d) *Types of molding presses used for compression molding*

Figure 2. *Rubber parts manufacturing processes* ***a)*** *y* ***b)*** *Mixing in open rolls mill,* ***c)*** *and* ***d)*** *compression molding*

Tables 2 and 3 describe ergonomic risks identified during in-situ work and analysis of the videos, for the natural rubber processing at plantations and small industries, respectively. It can be seen that the main risks are associated with awkward postures in activities like rubber tapping, latex collection, filtering and dilution, rolling of rubber to obtain sheets, mixing, and molding; manual handling of heavy loads in activities like latex collection, mixing and molding; repetitive movements during latex tapping, latex collection and mixing, and mechanical entrapment risk during rolling of rubber to obtain sheets.

Table 2. *Postural risks in natural rubber processing for obtaining sheets.*

Activity	Postural risk
Tapping	*Awkward postures* • Mechanical loading is not symmetrically applied due to the slope of the incision, because the worker must cut the tree's bark using its deft hand. • The height above the floor at which the incision is done varies with the time of exploitation of the tree and tree diameter. Often the worker must perform the activity in a squatting position, with constant bending of the knees and trunk tilt with sporadic rotations. The level of stress generated also depends on the height of the worker. The activity is executed taking the knife with both hands, but the deft hand applies the most demanding force that is required by the tool. *Repetitive movements* • The worker repeats the activity between 400 and 600 times every day. The activity takes between 2 and 4 hours, according to the slope of the terrain and the size of the plantation.
Latex collection	*Risks associated with manual handling of loads in the workplace* • Unbalanced lifting that increases the load to the back. Once filled, buckets weigh between 10 and 15 kilograms; the worker carry one bucket with an arm. Drums filled weigh between 15 and 25 kilograms; the worker can carry one drum with an arm or with each arm when transportation of two drums is needed. *Awkward postures* • The height above the floor at which the incision is done varies with the time of exploitation of the tree and tree diameter. Sometimes the worker must squat to perform the activity, i.e. bending the knees is frequent. The level of stress generated also depends on the height of the worker. *Repetitive movements* • The worker collects between 400 and 600 cups every day. The activity takes between 1 and 1.5 hours, according to the slope of the terrain and the size of the plantation.
Manufacturing of rubber sheets	*Awkward postures* • Filtering and dilution are carried out at ground level. Sometimes the worker must squat to perform the activity and bending of the knees occurs, but sometimes the activity is carried out by tilting the trunk, with or without twisting of the trunk. Mechanical loading is not symmetrically applied. *Mechanical entrapment risk* • Mechanical entrapment of fingers can occur at the open rolls or at the gears that generates the movement of the rolls.

Table 3. *Postural risks in manufacturing of rubber parts in small factories.*

Activity	Postural risk
Mixing at open rolls mill	*Awkward postures* • Mechanical loading is not symmetrically applied due to the height of the space where rubber enters for rolling. • The level of stress depends on the size of the mixtures, the height of the mill and the height of the worker. *Repetitive movements* Two repetitive movements were observed: • When ingredients enter to the space betwwen rolls, an overload is applied on hands and the back. Mixtures weight varies between 1 and 13 Kg. • During the collection of ingredients that fall into the tray the worker must bend down to pick up the materials, and rise again to incorporate them into the mix at the top of the mill. *Risks associated with manual handling of loads in the workplace* • The level of stress depends on the size and the weight of the mixtures, which varies between 1 Kg and 13 Kg, and the height of the mill.
Molding	*Awkward postures* • The worker must carry the molds from the working tables to the molding press, and then transport them back to extract the finished product. The activity is carried out by twisting of the trunk. Occasionally, tilting of the trunk is required. The tables were molds are handled are also used for placing tools, polishing products, preparing pieces of the mixture to be incorporated to the molds or temporarily placing finished products, then the height and position of the table vary into the company. For this reason, mechanical loading on the back is unbalanced. *Risks associated with manual handling of loads in the workplace* • For manufacturing small pieces, it was observed that molds of 500 gr are handled every five minutes. Molds of 40 Kg were handled every 30 minutes during the *in situ* work. Adequate apparatus for handling molds were not used at the small industries, and the workers indicated that those devices are not available.

Table 4. *OWAS analysis for natural rubber processing for obtaining sheets.*

Process	Activity	Postural risk		Risk level	Possible WMSDs s
		Aspect	Code		
Tapping and latex collection	I. (Tapping)	Back	4	4	• Back symptoms
		Arms	1		• Deviation of the spine (lordosis or scoliosis)
		Legs	6		• Muscle contractures, sciatalgia, frequent muscle spasms
		Load	1		• Tendinitis, tenosynovitis, and carpal tunnel syndrome
	II. (Collection)	Back	4	4	• Pain associated with the compression of the lumbar vertebrae (lower back pain)
		Arms	1		• Deviation of the spine (lordosis or scoliosis)
		Legs	5		• Cervical tension syndrome
		Load	1		• Rotator cuff tendinitis • Muscular fatigue
Sheet manufacturing	I. (Filtering and dilution)	Back	3	3	• Back symptoms
		Arms	1		• Deviation of the spine (lordosis or scoliosis)
		Legs	5		• Muscle contractures, sciatalgia, frequent muscle spasms
		Load	1		• Pain associated with the compression of the lumbar vertebrae (lower back pain)
	II. (Rolling for obtaining rubber sheets)	Back	2	2	• Hand sprain or hand fracture
		Arms	1		• Amputation of fingers or hand
		Legs	4		
		Load	1		

Table 5. *OWAS analysis for rubber mixing and molding*

Process	Activity	Postural risk Aspect	Code	Risk level	Possible WMSDs s
Mixing in open rolls mill	I. (Incorporation of ingredients to the mill)	Back	2	2	• Back symptoms • Deviation of the spine (lordosis or scoliosis) • Muscle contractures, sciatalgia, frequent muscle spasms
		Arms	1		
		Legs	2		
		Load	2		
	II. (Mixing until ingredients are dispersed in the rubber matrix)	Back	2	3	• Pain associated with the compression of the lumbar vertebrae (lower back pain) • Deviation of the spine (lordosis or scoliosis) • Muscle contractures, sciatalgia, frequent muscle spasms
		Arms	1		
		Legs	4		
		Load	2		
	III. (Extraction of the mixture)	Back	2	3	• Pain associated with the compression of the lumbar vertebrae (lower back pain) • Deviation of the spine (lordosis or scoliosis)
		Arms	1		
		Legs	4		
		Load	2		
	IV. (Mill cleaning)	Back	4	4	• Pain associated with the compression of the lumbar vertebrae (lower back pain) • Deviation of the spine (lordosis or scoliosis) • Cervical tension syndrome • Rotator cuff tendinitis • Muscular fatigue
		Arms	2		
		Legs	4		
		Load	1		
Molding	I. (Molds handling)	Back	4	3	• Back symptoms • Deviation of the spine (lordosis or scoliosis) • Muscle contractures, sciatalgia, frequent muscle spasms • Pain associated with the compression of the lumbar vertebrae (lower back pain)
		Arms	1		
		Legs	2		
		Load	3		

3.1.3 OWAS analysis

Table 4 presents OWAS analysis natural rubber processing at plantations and Table 5 presents the same type of analysis for manufacturing rubber parts. In both processes it can be seen that there are level 4 risk activities, such as bleeding and collecting cups in the case of work in plantations, and mill cleaning in the case of rubber articles manufacturing. WMSDs like musculoskeletal injuries at back level, spine deviation and cramps can occur in both processes. Other activities have lower risk levels, creating risks of WMSD as described above, but also with the possibility of causing upper limb and muscle fatigue.

According to the risk levels that were identified, OWAS method establishes that it is necessary to perform corrective action immediately for activities such as tapping, latex collecting and handling of molds because its OWAS codes were 4, and for other activities such as filtering and dilution, mixing and mold handling is relevant implement corrective actions as soon as possible because its OWAS codes were 3.

According to OWAS analysis and literature review, it is recommended to carry out some actions seeking to reduce work-related ergonomic risks:

Design and implement improvement plans specifically aimed to reduce the ergonomic risks in natural rubber production chain, considering organizational culture, socio-economic and socio-demographic factors of natural rubber farmers and small rubber manufacturing industries. To create awareness between workers and employers is a key component of these plans, as was stated in the studies of Singh et al. (2012) and Unnikrishnan et al. (2015).

Since latex tapping and collection cannot be automated, it is inevitable trunk tilting and leg bending when workers perform those activities. It is required to design and implement an active pauses program at appropriate intervals during workday.

For mixing in open rolls mills it is recommended that the worker uses a bench according to the height of the mill, reducing the lifting of the arms above the shoulder level. Frequent stretching and active pauses are also necessary.

A redistribution of workplaces and the use of height adjustable tables in molding process areas could reduce postural risks in rubber industries. Furthermore, handling molds closer to the center of gravity of the worker could reduce posture risks related to musculoskeletal disorders mainly in the spine, and in the low back area.

It is recommended the use of mechanical aids such as carts for lifting and transportation of drums in plantations and molds in rubber industries. In the case of rubber industries, wheeled tables or to seek help from co-workers could decrease ergonomical risks related to manual handling of loads in the workplace.

4. Conclusions

In this exploratory study, ergonomic risks in small plantations and small industries belonging to the natural rubber production chain were identified by using the OWAS method. It was observed that several activities of natural rubber processing required movements that can cause work-related musculoskeletal disorders in back and legs. The risks arise in awkward postures, repetitive movements, manual handling of loads and mechanical entrapment of hands. OWAS analysis identified level 4 risks for two activities in plantations, i.e. latex tapping and collection, and two activities in small rubber industries, i.e. mixing in open rolls mills and mold handling.

According to OWAS analysis and literature review, it is recommended to carry out some corrective and other preventive actions seeking to reduce work-related ergonomic risks. Since few ergonomic studies are available on the natural rubber chain production, it is appropriate to carry out new studies involving other ergonomic evaluation techniques to complete the results found in this work. It is important to note that small plantations and rubber industries are more exposed to posture risks because the lack of education in ergonomic issues.

It was identified that workers are unaware of the risks associated with their tasks, so some education in ergonomic aspects could avoid habits that are potentially harmful to their health and welfare. Considering that physiological disorders caused by ergonomic risks do not appear immediately, which hinders further analysis and control implementation to minimize the consequences of those risks, it is appropriate to act preventively in the case of a growing economic activity like is the case of natural rubber exploitation in Colombia and other regions where heveiculture is important for the economy of smallholders and small rubber industries.

The assessment presented in this work can help mitigating the ergonomic risks in production chains similar to natural rubber.

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