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Biomechanical exposure of industrial workers – Influence of automation process

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ABSTRACT

Automated processes in industry have been implemented in order to get higher production rates, but our knowledge about their effects on physical exposure of the workers is still limited. Muscular load, postures, and movements of the head, neck/shoulders, upper arms, and wrists were recorded in 19 operators from two different car clutch disc production lines (manual and semi-automated). Higher angular velocities of the head, upper back, and upper arms were found on the manual production line (on average 20% higher than the semi-automated). Upper trapezius, and forearm extensor rest (% time), as well as hand kept still (% time) were also higher on the manual production line. No difference was found regarding posture, muscular activities, and repetitiveness. The manual line had more rest, but more vigorous movements considering angular velocities. The semi-automated line, therefore, implied a higher production rate with lower angular velocities but fewer opportunities for rest than the manual line. While different physical exposures were found when comparing these two production lines with different levels of automation, the health effects derived from industrial automation ought to be investigated with a larger sample size.

Relevance to industry: The reduction of rest opportunities observed on a semi-automated production line requires the attention of ergonomists when planning or redesigning tasks in such production lines. Lack of rest is considered a risk factor for the development of musculoskeletal disorders.

1. Introduction

Modern production systems have increased production rates by introducing new technology. This has been possible with the combination of skilled human operators and the introduction of automated production processes, which ensures higher production efficiency. However, the introduction of more complex mechanization and automation may include new biomechanical and psychological demands (Coury et al., 2000; Garde et al., 2003).

According to Frohm (2008), the concept of levels of automation can be described as "the allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic". The automated processes are often described as manual, semi-automated and/or automated (Duncheon, 2002; Johansson et al., 2009). Manual systems are those in which human operators are responsible for conducting the tasks. Semi-automated systems are those in which material handling is still conducted by human operators, but there is a higher level of automation regarding alignment of the materials and the performance of specific tasks on them by robots. In automated systems, material handling is also automated and involves less interference by human operators (Duncheon, 2002). The need for human intervention on those different automation levels may influence the physical and/or psychological demands to which workers are exposed. Previous studies have identified that manual production systems are usually characterized by having more diverse work, more exposure variation, and higher levels of alertness and psychological activation when compared to semi-automated or automated production systems (Balogh et al., 2006; Coury et al., 2000; Garde et al., 2003; Juul-Kristensen et al., 2002; Stål et al., 2003).

Automated production systems are frequently followed by

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rationalization of the manufacturing process, generating more constrained and repetitive work with less opportunity for short breaks during work (Mathiassen, 2006; Palmerud et al., 2012; Srinivasan and Mathiassen, 2012). This is of great concern as those characteristics are assumed to be risk factors for the development of musculoskeletal disorders (MSDs), especially in the neck, shoulder, hands, and upper back (Barbieri et al., 2012; Buckle and Devereux, 2002; Kilbom, 1994; Sluiter et al., 2001).

Balogh et al. (2006) pointed out that decreasing the biomechanical workload is one goal of the automation and, consequently, it might reduce the risk of MSDs. However, studies focusing on the introduction of new technology or mechanization/automation of production systems have conflicting results regarding its effect on the biomechanical exposure measurements (Arvidsson et al., 2012, 2006; Balogh et al., 2006; Coury et al., 2000; Juul-Kristensen et al., 2002; Stål et al., 2000). In general, muscular load decreased with the implementation of new technology while muscular rest (% time) increased for wooden board production (Balogh et al., 2006) and meat cutters (Arvidsson et al., 2012) but decreased for milk tethering (Stål et al., 2000). More narrow posture range and lower movements velocity of the head, neck, upper arms, and wrists were observed in air traffic controllers (Arvidsson et al., 2006) and meat cutters (Arvidsson et al., 2012) after introducing new technology. On the other hand, Balogh et al. (2006) observed a more varied and less constrained movement pattern in an automated wooden board production line compared to both manual and semi-automated lines. The literature shows that the effects of automation are complex, and the conflicting results found cannot support synthesized evidence on this issue.

Investigation of the biomechanical workload from manual and automated process requires direct comparison between the two processes. However, most studies have not been able to do so because: (1) the automation of a work process often influences both the automated and manual production processes, which hampers direct comparison, and (2) the workers need to be experienced performing the automatized and the manual work tasks before it can allow for direct comparison. Thus, in this study, the biomechanical load investigated is made upon a situation in which the automation process is investigated in two simultaneously active production lines with different levels of automation.

This study aims to investigate potential differences in biomechanical workload between manual and semi-automated production systems of automotive components. We hypothesized that: (1) the manual production system comprises higher peak load than the semi-automated production system; (2) the semi-automated system has more repetitive work and less opportunity for hand kept still and of muscular rest.

2. Methods

2.1. Production lines and subjects

The study was conducted in an automotive parts production facility situated in the state of São Paulo, Brazil. Two production lines, one manual and one semi-automated, were studied. Both production lines produce identical car clutch discs, with an average weight of 1.2 kg and a diameter of 200 mm. The two teams of operators from the two production lines both work eight-hour shifts.

All 43 operators (all male) currently employed at the company and working on the manual or the semi-automated lines were invited to and participated in an information meeting. All operators worked exclusively on one of the lines, and all of them were experienced (minimum 6 months). Forty-one operators volunteered for an interview and physical examination. Twenty-seven volunteered to wear the measurement equipment for recording physical workload during one workday. Valid measurements were obtained for 19 right-handed operators (nine from the manual, and ten from the semi-automated line). Due to technical issues, the measurements from eight operators (four from each production line) were excluded.

The subjects were interviewed about demographic data and musculoskeletal complaints according to the Brazilian version of the Nordic Questionnaire (Barros and Alexandre, 2003). The operators were also physically examined regarding neck, shoulders, elbows, wrists, and hands (Ohlsson et al., 1994) and diagnoses were made by the examiner according to predefined criteria (Nordander et al., 2009). All subjects were examined by the same examiner, a physiotherapist experienced in occupational health assessments. The study is in accordance with the Declaration of Helsinki and has also been previously approved by the local Ethics Committee. All participants signed an informed consent form before entering the study.

2.2. Work tasks

On the days of the measurements, recordings were made for about seven hours during normal work, including breaks and a mealtime. Each production line had a certain number of distinct tasks and all operators performed all tasks at their production line, taking turns. That meant that, for the manual line, the duration of each work task was approximately one hour, and, for the semi-automated line, each task's duration was approximately 45 min. In total, the measurements were conducted in a three-month period and were performed by the same researcher. The order of measurements was random between the two production lines and the two work shifts.

The tasks performed in each production line are described in Figs. 1 and 2. The manual line was organized into five different workstations with one operator for each (Fig. 1). Approximately 140 clutch discs were produced per hour. On this production line, the operators had to manually handle the clutch disc, position different component parts on the disc, manually activate the machinery of the production system, and manually move the disc to the next workstation. The work at the semi-automated line was organized as a conveyor belt with seven workstations plus one additional workstation located apart from the conveyor belt (Fig. 2). Eight operators worked at the conveyor belt, with two operators in one of the workstations (Task 6 – Fig. 2). The operators at the conveyor belt manually positioned different component parts on the disc that was passing through on the conveyor. Different machinery allowed the work on the semi-automated line to be performed with no need for manual activation of the machinery. The separate workstation was operated by three operators manually pre-molding one of the clutch's parts. The automated apparatus of this production line, apart from the conveyor belt, were composed of automatic robots responsible for processes such as pressing and screwing between workstations. The production rate for the semi-automated line was 260 clutch discs per hour. The only identical task in the two production lines was the visual inspection, which was the final task in both lines.

The main difference between the production lines is the need for manual handling the clutch discs and manually pressing the components (tasks 2–3) on the manual line. On the semi-automated line, the manual handling and pressing processes were replaced by the conveyor belt and robots between workstations. Take note that the manufacturing processes performed in tasks 1–4 on the manual line were equivalent to those performed in tasks 1–6 on the semi-automated line.

On both production lines, the facility implemented a two-hour rotation in which the operators could change tasks according to a predefined scheduled (i.e.: moving from task 1 to task 2, moving from task 2 to task 3, etc.). In this way, the operators, on a regular working day, would perform four different tasks. With the aim of getting representative measurements in a one-day recording, the task rotation schedule was changed in order to ensure a minimum of 40-min recording of each task on each production line. It meant that, on the measurement day, each operator performed all tasks from his production line. This procedure was previously authorized by the facility since this new arrangement would not interfere with the production process.

Both production lines had mobile operators supporting the overall