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Running Title: Ergonomics Interventions in a truck Industry

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Highlights:

- A case of implementing a combination of ergonomic solutions in a real assembly setting.
- Workstation redesign and balancing high-risk tasks implemented over the usual production changes and reduced risk factors.
- Involving stakeholders in the interventions facilitated the acceptance of most changes.

Ergonomic interventions to reduce musculoskeletal risk factors in a truck manufacturing plant

Ergonomic interventions may potentially reduce MSDs, but the context of industries (barriers, ever-changing situations, dialogue processes) might play a significant role in the success of interventions. This study evaluates the effectiveness of ergonomic interventions including engineering/technical and organizational interventions, and the involvement of the stakeholders in reducing musculoskeletal risk factors/symptoms. A pre- post-test experimental study in non-randomized groups was performed over three years in a sector of a truck assembly plant. The mean age of the operators in the sector for the initial and second assessment time was 42.0 (±7.6) years and 39.0 (±8.7), respectively. The mean length of work experience in the current job was 15.2 (±7.2) years and 13.9 (±7.3) for the initial and second assessment times, respectively. Five engineering ergonomic solutions and organizational interventions were implemented after a comprehensive ergonomic analysis. The organizational interventions consisted mostly of transferring and redistributing the tasks, i.e., ergonomically balancing and redesigning of the workstations. Before performing the interventions, the findings of the ergonomic study were presented at several meetings to encourage the involvement of the stakeholders (including managers, engineers, and operators) in the interventions. This study showed that a combination of ergonomic measures—engineering and organizational interventions—could reduce physical workloads. Musculoskeletal symptoms decreased after interventions although the difference was not significant.

Keywords: organizational changing; engineering intervention; stakeholder; musculoskeletal risk factors; automotive assembly plant

Introduction

Work-related musculoskeletal disorders (MSDs) are a significant challenge for the automotive manufacturing industry. MSDs represent a high percentage of all diagnosed work-related diseases across occupations and worker groups, particularly in high-risk tasks (Oranye & Bennett 2018). The costs of MSDs are substantial and include direct costs such as compensation, administrative and medical costs, and indirect costs such as absenteeism, and losses related to product quality and productivity (Landstad et al. 2002; Genaidy et al. 2009; Sultan-Taïeb et al. 2017). Adverse job characteristics such as physical, organizational and psychosocial risk factors have a relationship with the prevalence of MSDs in many occupations, particularly those in truck assembly plants (Driessen et al. 2010; Daniels et al. 2017; Widanarko et al. 2014). Operators in the truck assembly line are exposed to various physical risk factors such as repetition, forceful exertion, awkward postures, manual materials handling, and vibration (Zare et al. 2016; Falck, Örtengren, & Rosenqvist 2014). Furthermore, organizational factors such as un-balanced workstations and insufficient recovery time exist in the truck assembly line workstations (Kazmierczak et al. 2005; Otto & Scholl 2011).

The literature shows that proactive ergonomics and remedial actions are standard approaches to prevent MSDs and increase productivity/quality in the automotive industry (Driessen et al. 2010; Neumann et al. 2010). However, specific factors such as contextual factors, mal-adapted intervention strategies, ineffective contributions of stakeholders, and poor ergonomic analysis can lead to the unsuccessful intervention practices (Stock et al. 2018; Neumann et al. 2010; Driessen et al. 2011; Burgess-Limerick 2018; Winkel et al. 2017; Dasgupta et al. 2017). The automotive industries have not usually published their intervention strategies, and few kinds of literature have described the intervention processes, their success, and particularly the overall impact on MSDs (Driessen et al. 2010; Westgaard & Winkel 1997). Gupta et al. and Driessen et al. showed that the participatory ergonomics interventions were ineffective in reducing physical and psychosocial risk factors (Gupta et al. 2018; Driessen et al. 2011). Westgaard and Winkel showed that intervention programs focusing on identifying and solving specific problems are more successful than generic interventions aimed at reducing exposure to a particular level (Westgaard & Winkel, 1997). Previous studies have suggested that a combination of policies including information, education, both compulsory and voluntary strategies would reduce physical workloads and MSDs risk factors (Burgess-Limerick 2018; Neumann et al. 2010). Van der Molen et al. recommended that ergonomic engineering controls such as lifting tools, combined with a participatory approach and involvement of stakeholders, would efficiently reduce physical work demands and MSDs in the long term (van der Molen et al. 2005).

The effectiveness of ergonomic strategies in real settings such as truck industry is a matter of debate in the previous literature. This study aimed to evaluate the effectiveness of ergonomic interventions to reduce physical risk factors and musculoskeletal symptoms in the truck assembly line.

Materials and Methods

Subjects and Context of Study

A pre- post-test experimental study in non-randomized groups was performed over three years in one sector of a truck assembly plant. Figure 1 shows the conceptual framework applied in this study. This framework is similar to the research framework proposed by van der Beek et al. (2017).

The factory divided the sector under study into smaller groups of workstations to enhance continuous improvement (Liljedahl & Muftic 2012). Three Improvement Groups (IGs) were therefore studied, and each group included various workstations, a team leader, and the operators (Table 1). The typical tasks of this sector were the assembly of truck parts, wiring, hose connection, picking up objects from a pallet, lifting and carrying parts (manually or with devices), tightening with screwdrivers, and pushing/pulling wagons. Table 1 describes the main tasks of each workstation, and the main risk factors were initially identified.

The cycle time for each workstation in the first part of the study (before intervention) was 11 minutes. Seventeen operators worked in the sector during the initial assessment time. We included all the operators in the study, but two operators were excluded due to having musculoskeletal symptoms. Finally, 15 operators participated in the study before the intervention. All the operators were men, and the mean age was 42.0 (±7.6). The mean length of work experience in the current job was 15.2 (±7.2) years.

The cycle time decreased to eight minutes in the second part of the study (after intervention). Twenty-four operators worked in the sector in the new assessment time, but three operators were excluded from the study because of musculoskeletal pain. The sample of 21 participants included after the intervention. The mean age and length of experience for the participants were 39.0 (±8.7) and 13.9 (±7.3) years, respectively, in the second assessment time.

Another sector of the factory was selected as the control group. The operators of this sector mainly carried out similar tasks as the sector under investigation: picking up parts, material handling, lifting, carrying, assembling, pushing/pulling, and tightening. Furthermore, both sectors were similar regarding work conditions, organization, management, and psychosocial factors. All the parameters, such as the worker demographics (ages, gender, and years of experience), environmental conditions, and social conditions, were equivalent between the control and intervention groups in both assessment times.

All the subjects consented to participate in this investigation and gave the written informed consent before including in the study.

Data collection

Before intervention, eleven workstations of the selected sector were analyzed by an in-house ergonomic observational method (Zare et al. 2016) and the NIOSH lifting equation (Waters et al. 1993). Twenty-eight scenarios were assessed (including the most common type of trucks and other variant truck models). The workstations assessed by viewing work in person and on video. The majority of tasks at each workstation were observed several times, either in person or on video for several operators included in the study.

The in-house ergonomic standard method used to analyze the workstations consists of 20 factors classified into four categories, including repetition, work posture, force, and energy consumption (Table 2). The methods prioritized the assessment into three levels. The green level shows the minimal risk of musculoskeletal disorders and is acceptable. Yellow denotes moderate risk of musculoskeletal disorders; tasks and workstations assigned yellow might need some improvement in the future. Red is an action level with considerable risks of musculoskeletal disorders, and changes are required as soon as possible. The number of yellows and reds determines the color of workstations classified in one of three categories, i.e., green, yellow, and red.

The NIOSH lifting equation method considered seven factors (load (LC), Horizontal location of the object relative to the body (HM), Vertical location of the object relative to the floor (VM), Distance the object is moved vertically (DM), Asymmetry angle or twisting requirement (AM), Frequency and duration of lifting activity (FM), and Coupling (CM) or quality of the workers grip on the object) to calculate the recommended weight limit (RWL) for a lifting task. The ratio of weight lifted to the RWL yield lifting index (LI). In this study, the task was considered as green when LI value was less than one, yellow when LI was between 1 to 1.6, and red when LI was more than 1.6.

The operators reported the symptoms of the pain or discomfort for each body region (the neck, arms, elbows/forearms, hands/wrists, and back) at the moment of filling out the questionnaire in a scale of 0-10 (0= No pain or discomfort, 10= Intolerable pain or discomfort) (Ha and Roquelaure, 2007). We used only one question of the Nordic Musculoskeletal Questionnaire about the intensity of musculoskeletal symptoms at the time of responding to the questionnaire.

After the intervention, 34 scenarios were assessed with the same protocol and methods in the 14 workstations. Eleven participants were the same at both assessment times. Ergonomics assessments were only performed for the same participants before and after intervention; however, all the participants responded the musculoskeletal questionnaire. Musculoskeletal symptoms were assessed with the same questionnaire in both parts of the study.

The control sector had nine and 11 workstations in the initial and second assessment times. According to the general ergonomic strategy of the industry, this sector was evaluated by the in-house ergonomic standard method (Zare et al. 2016) and the NIOSH equation for the initial and the new assessment time.

Involvement of Stakeholders

Throughout the study, the research group developed a dialogue processes with the stakeholders, i.e., a factory management steering group, engineers, technicians, and operators. The findings of the study were regularly communicated with them (at least every six months). The dialogue processes aimed to make the stakeholders aware of ergonomic workloads, to develop appropriate interventions according to local circumstances, and to encourage the stakeholders to contribute/implement the required changes.

Five meetings were held with the management committee (including top/middle managers and engineers). The main subjects discussed at these meetings were the results of the ergonomic analysis, possible solutions, the effects of poor ergonomics on the quality of products, and the idea of balancing workload and high-risk tasks in different workstations. Three similar meetings were explicitly organized for the participants in the study. Furthermore, the results of the study were communicated two times for the workers' union. Most of the research group's ideas regarding ergonomic solutions were transferred to the stakeholders during these meetings.

Statistical Analysis

Due to the small sample sizes (n=28 scenarios for the first assessment time, n=34 scenarios for the second assessment time), the non-parametric Kruskal-Wallis rank-sum test was used for interval variables. Mac Nemar exact test was used to compare MSDs symptoms between the same respondents (11 operators) before and after the interventions. The variable associated with the NIOSH score was analyzed using medians. All computations and graphics were performed with the R Software.

Results

The ergonomic analysis in the initial assessment time showed high exposure to wrists risk factors at most of the workstations. We found awkward trunk (lying, kneeling, and squatting) and shoulder postures at approximately 45% of the workstations. The NIOSH equation results for 20 lifting tasks (Table 1) showed a higher LI (red) for 35% of tasks and a moderate LI (yellow) for 20% of tasks. Moderate exposure (yellow) to different risk factors was observed more frequently than excessive exposure (red). The detailed results of this analysis have already been published in another study (Zare et al. 2016). According to the ergonomic analysis findings, the following engineering remedies were proposed and implemented to reduce excessive wrist, trunk, shoulder exposure to risk factors, manual material handlings, and repetitions.

Engineering/technical interventions

Lifting tool unlocking system

The overall risk of the '*Bumper Assembly on truck*' workstation was red (high exposure to physical workload). The unlocking lifting tool task was assessed as an excessive risk. The operators had to unlock the lifting tool for bumper handling toward the truck chassis with their fingers using hand gripping. This action required approximately 200N (measured by mechanical dynamometer) fingertip grip force and was evaluated red by the in-house ergonomic standard method. The thumb and index finger were involved in this task (Figure 2a).

It was therefore decided to change the design of the unlocking system and to develop a new handle to reduce the unlocking force required. A new proposed unlocking system used a cord to unlock the lifting tool. With the new cord handle, the finger-grip was replaced by involving all fingers and the palm (Figure 2b). The workstation was then reevaluated, and the criterion for finger force was assessed as no risk due to the elimination of the thumb and index finger unlocking gesture. The overall workload of the workstation was reduced. However, the new unlocking system imposed another risk factor. The surface area that the palm/several fingers had contacted on the new handle (cord) for the unlocking system was less than 7 cm², and the force was > 10 N, which was assessed as a red risk.

Embedded camera on the hand-held screwdriver machine

Trunk awkward postures (kneeling with bending and rotation of back/neck) were also identified at the '*Bumper Assembly on the truck*' workstation (approximately 11 min/2hours). The majority of awkward postures were related to the operation of tightening several screws below the bumper (hidden access), which required kneeling with awkward back/neck postures (Figure 3a). The solution that was proposed following several working meetings with the sector's manager and engineers was to embed a camera near the nose of the hand-held screwdriver machine and to place a monitor beside the jig (Figure 3b). Operators could then look at the camera in a standing position, identify the location of the hidden screws below the bumper and tighten them without needing to kneel or bend the neck/back. The ergonomic analysis after the intervention showed that exposure time to kneeling and awkward neck/back postures reduced to approximately six min/2hours. The implemented solution did not eliminate all the kneeling and awkward back/neck postures because of the other high-risk tasks such as tightening and repositioning the bumper on the chassis.

Gripping tool for handling air filter

Lifting and carrying the cab tilt cylinder and air filter were the high-risk tasks at '*Air Filter & Cab tilt Cylinder Mounting*' workstation. Lifting the air filter from the trolley was assessed as red by the NIOSH equation. The completed air filter weighed 12 kg, the horizontal location of the object relative to the body (H) was 80 cm (HM=0.31), and the vertical location of the object relative to the floor (V) was 108 cm (VM=0.9). The other coefficients of the equation (including AM, FM, and CM) were 1. The operators had to lift the air filter from a trolley with an awkward back posture and work outside the acceptable reach envelope. The RWL calculated for this task was 6.5 and the LI was 1.9. They must also hold the air filter with one hand to insert the screws during repositioning the air filter on the truck (Figure 4). These tasks involved high-risk factors for the back and hand/wrist.

After presenting the findings to the sector stakeholders, the team decided to use a gripping tool for lifting and carrying air filter. A gripping tool was then selected, the design of the workplace was changed, and a new trolley adapted to the new gripping device was designed. The team chose a vertical gripping tool for lifting a load at its center of gravity with a capacity of 20 kg (Figure 5). Although the solution eliminated lifting, carrying, and mounting the air filter on the chassis, lifting the air filter from the preparation trolley to the newly designed cart was still manual.

Furthermore, another manual lifting task (lifting cab tilt cylinder) was evaluated yellow at this workstation. The intervention reduced the frequency and severity of lifting risk factors, but it did not eliminate the risk of manual material handling, completely. Engineering/technical interventions often involve only one exposure dimension (elevating air filter in this case) while the other exposure dimensions cannot be improved (Westgaard and Winkel 1997). Nevertheless, single technical interventions are practical aspects of ergonomic improvements that provide ongoing positive results.

Lifting tool for handling rear and front mudguards

The main risk factors at the '*Boarding Steps & Mudguards*' workstation were the manual lifting of the rear (12.1kg) and front mudguards (15.2 kg) on both the left and right-side workstations (Figure 6a). The front mudguards weighted 15.2 kg and the operator had to lift the mudguards on the wagon situated beside the production line at floor heights: V= 105 cm and H= 58 (VM= 0.91 and HM=0.43) and then transferred them manually for assembly on the chassis at the height of: V= 90 cm and H= 30 cm (VM= 0.96 and HM= 0.83). The frequency of lifting was 12 times/hour for each side so that the FM coefficient was 1. The other coefficients of the NIOSH equations were also 1 for these tasks. The LI was therfore calculated 1.7 (red) for the origin and 0.8 (green) for destination. The LI was 1.2 (yellow) for the right side of the mudguards handling (V= 104 cm, H= 40; VM= 0.91, HM= 0.31). The reason that LI was different between right and left side was the horizontal distance of mudguards from the body.

The solution was to implement a new lifting tool that would eliminate the lifting and carrying of mudguards (Figure 6b). Safety engineers and technicians tested the new lifting tool and confirmed its operation. The lifting risk factor was eliminated after the intervention. Although using the lifting device eliminated the lifting and carrying task at this workstation, some operators still preferred to carry out this task manually.

Eliminating repeated actions

The most frequently repeated actions were inserting screws and bolts, tightening with a torque wrench and turning the handles of the trolley. Two tasks with repeated movements were identified at the '*Preparation of Selective Catalyst Reduction (SCR) Tank*' workstation, i.e., manually tightening the screws to assemble the SCR tank and manual turning of the handle to change the direction of the SCR assembly wagon (Figure 7a). These tasks were red because the repeated same actions occurred at approximately >400 times per hour (Zare et al. 2016; Schaub et al. 2013).

The working team decided to change the design of the wagon to eliminate the manual handle turning task. An electric screwdriver replaced the manual handle of the wagon, and the wagon direction could be changed just by pushing the screwdriver button (Figure 7b). The manual turning of the wagon handle was thus eliminated. Manual tightening of screws, however, remained at this workstation as repetition risk factors. Although the new intervention design of the wagon reduced the number of repeated actions, this workstation was still assessed as red for repetition criteria because of the other repeated movements for manually tightening the screws.

Organizational interventions and workplace redesign

The sector under study implemented organizational interventions proposed by the research group during the cycle time change (the cycle time reduced from 11 minutes to 8 minutes due to production rate). High-risk tasks were smoothly balanced across the workstations, and the new workstations were created. However, the primary operation of the workstations and sectors remained unchanged. Table 3 and the following paragraphs explain the organizational interventions at different workstations.

Preparation of the SCR tank workstation

The layout of the workplace was changed in this workstation after the intervention, many unnecessary movements related to picking up components were eliminated, and the workstation was transferred nearer to the production line. The engineers designed a new portable wagon for the SCR tank assembly. The tasks to prepare the Euro 5 SCR Tank had a few changes in the second assessment time. The in-house ergonomic method evaluated the overall color of the preparation of the Euro 5 SCR Tank as yellow in both the initial and the second assessment time (Table 3). However, the number of red criteria reduced in the second assessment time. Three ergonomic criteria (hand clearance, wrist posture, and arm/hand force) was red at the initial assessment time, while only one criterion (wrist posture) was evaluated as red in the second assessment time (Table 3). The repetition criterion was green (117 repeated actions per hours) in the initial assessment time, but it was assessed as yellow (180 repeated actions per hours) in the second assessment time. The number of repeated movements increased in a cycle due to the reduction in the cycle time.

A new European standard imposed truck manufacturer to design the Euro 6 Selective Catalyst Reduction (SCR) for reducing air pollution. The operators, therefore, had to prepare in the second assessment time the new generation of SCR tank (Euro 6 SCR) at the '*preparation of the SCR tank*' workstation. Most tasks for the new SCR tank generation were similar to the Euro 5 SCR tank, but hose connecting task that required an excessive hand force (200N hands/arms force measured by a dynamometer) had to implement at this workstation. This task was assessed as red for the hand and arm force criterion. Many screws had to be inserted and tightened manually so that repetition was also evaluated as high risk (440 similar actions per hours). The ergonomic workload for assembling the Euro 6 SCR tank was higher than for assembling the Euro 5 SCR Tank (Table 3).

Mounting SCR Tank on chassis

The final color of this workstation for assembling the Euro 5 SCR tank was green after the intervention (Table 3). Another operator was added to the workstation and performed several high workload tasks such as the hose connecting task (assessed red and required 200N force from hands/arms) and manually lifting the reservoir tank (13 kg) in the second assessment time. The number of red risk factors for assembling the Euro 5 SCR reduced—three red risk factors compared to six red risks in the initial assessment time (Table 3).

The operators assembled the Euro 6 SCR tank on the truck chassis in the second assessment time at this workstation, and its tasks were similar to that of the Euro 5. The final color of the workstation for assembling the Euro 6 SCR Tank was green, and the risk factors were almost the same as the Euro 5 SCR Tank (Table 3). However, manual handling of the Euro 6 SCR tank (8 kg) was eliminated because of assigning a lifting tool for this task. Tightening the Euro 6 SCR support with a manual torque wrench required excessive whole-body force (280 N).

Preparation air filter and cab tilt cylinder

The operators prepared the air filter, SCR Tank, air pipe, heat cover, cab tilt cylinder, and straining cylinder before intervention over three cycles (33 minutes) at this workstation. We evaluated the final color of the ergonomics workload as yellow for performing all these tasks (eight red and five yellow criterions; Table 3). The engineers redesigned the workstation and divided it into two positions in the second assessment time, i.e. '*picking up the SCR tank and cab tilt cylinder*' and '*picking up the air filter, air pipe, and heat cover preparation*.' Furthermore, the physically difficult cylinder task was transferred to another workstation (assembling air filters in the line), but some extra tasks were defined for '*picking up the SCR tank and cab tilt cylinder*' workstation because of the new products. The layout of the workplace was also modified. After the intervention, the '*picking up air filter, air pipe, and heat cover preparation*' workstation was green with just two red criteria (back/wrist posture and lifting/handling of the air filter). However, the '*picking up the SCR tank and cab tilt cylinder*' workstation was red because a non-standard pallet required excessive whole-body force (311 N). The non-standard pallet was, therefore, replaced by the standard one, which only needed 120 N pushing and pulling forces. The final ergonomic color became green (Table 3).

Air filter and cab tilt cylinder mounting on the chassis

This workstation included assembling the air filter, air pipe, cab tilt cylinder, heat cover, and hoses connecting on the chassis in the initial assessment time. The final ergonomic color was yellow with seven red risk factors. In the second assessment time, the engineers transferred the assembly task of heat cover to the right mudguard workstation and added the cylinder-straining task to this position. The final ergonomic color was still yellow after reassessment, and seven red criteria were identified, meaning that the results did not differ between the two assessment times (Table 3). As explained above, a lifting tool was designed for lifting and carrying the air filter at this position, which eliminated manual handling of the air filter (a high-risk action). However, other high-risk tasks such as lifting the cab tilt cylinder, assembling the air pipe and air filter that were similar in both systems resulted in only minor changes in ergonomic risks after interventions (Table 3).

Bumper preparation and mounting on chassis

This zone included three workstations in the initial assessment time: bumper preparation (1 and 2) and mounting bumper on the chassis workstation. The ergonomic workloads for these workstations were yellow, green, and red, respectively (Table 3). Due to merging the preparation tasks of bumper equipment (pump, washer tank, and fog lamp preparation) into this zone in the new organization, five sequential workstations were then designed in which one operator worked for each cycle time (8 minutes). The final ergonomic color for four workstations of the bumper preparation was green, and '*mounting the bumper on chassis*' workstation was yellow (Table 3). This position was red in the initial assessment time. The reorganization and distribution of the tasks (balancing workload) between work positions and technical modifications had positive effects in this zone.

Boarding step and Mudguard Assembly

The duration of exposure to awkward back, shoulder, and wrist postures was high (12 minutes per two hours) due to assembling two main parts of a truck, i.e., mudguards -

front and rear, and boarding steps. In the second assessment time, the engineers distributed the tasks into four workstations (i.e., boarding steps left/right and mudguards left/right). Some tasks such as fitting the air pipe into the inlet pipe task and the assembly task of heat cover (from other workstations) were also assigned to these positions. The final ergonomic color was green for three workstations in the new system, and only the "*right boarding step assembly*" workstation was yellow (Table 3).

Evaluation of ergonomic workload before and after interventions

Table 4 summarizes the results of the ergonomic workload by the workstation and by IG before and after the interventions. The NIOSH lifting index results differed significantly between IGs in the first assessment time ($p=0.006$), while the difference was not significant in the second assessment time. The mean of lifting index in the initial assessment time was 1.0 (±0.88), while it reduced after interventions (0.27 ±0.51). Corrective actions involving lifting tasks reduced the lifting index. The number of yellow ergonomic workloads was the same in both assessment times per workstation and IG. Red ergonomic workloads were significantly different between IGs in the first assessment time ($p=0.001$), but its difference was non-significant in the second assessment time ($p=0.3$). However, the number of red risk factors per workstation was significantly different in both assessment times (Table 4).

Figure 8 illustrates the results of the green, yellow, and red ergonomic evaluations for both assessment times. The mean of ergonomic assessment for minimum risks (green) was 8.0 in the initial assessment time, but it increased to 9.6 after interventions. On the other hand, the moderate ergonomic workload (yellow) was lower in the second assessment time (6.3 vs. 7.0 after interventions). The high-risk (red) ergonomic workload was lower in the second assessment time than in the initial one.

These differences were statistically significant (Kruskal-Wallis rank-sum test, $p < 0.001$; Figure 8).

Figure 9 shows the distribution of high-risk workload between IGs for both assessment times. The distribution of ergonomic workloads was homogeneous in the second assessment time. The red evaluations were significantly more in the first IG than in two other IGs before the intervention, whereas they were almost balanced between IGs in the second assessment time.

Self-reported musculoskeletal symptoms before and after interventions

Table 5 shows the prevalence of musculoskeletal symptoms in both assessment times for the intervention group. The participants reported a higher percentage of symptoms in the upper limbs, back, and lower limbs in the initial assessment time compared to the second assessment time (except for knee symptoms). However, the difference between the percentages of musculoskeletal symptoms was insignificant between assessment times.

Ergonomic evaluation of the control group

The ergonomic assessment for the control group showed that out of 181 ergonomic criteria evaluated by the in-house ergonomic method in the first assessment time, 32.0% were green, 33.7% yellow, and 33.1% red. On the other hand, 223 ergonomic criteria were assessed in the second assessment time, and the percentages of green, yellow, and red risk factors were 38.6%, 33.6%, and 26.9%, respectively. Although the portion of red risk factors reduced by 6%, the difference was not considerable.

Discussion

This intervention study shows that a combination of measures such as dialogue processes with the stakeholders, engineering solutions, and organizational changes could reduce physical workloads. Physical risk factors reduced in most of the workstations after implementing a combination of ergonomic interventions in our study. Many studies have shown that physical risk factors could significantly reduce following a combination of ergonomics interventions (Arezes and Serranheira, 2017; Daniels et al. 2017; Driessen et al. 2010; Neumann et al. 2010; van Eerd et al. 2010). However, some studies showed an increase in physical work demands after interventions (Driessen et al. 2011). Van der Molen et al. (2005) reported that most of the studies with the combined technical and organizational interventions showed a reduction in physical work demands (van der Molen et al. 2005).

MSDs symptoms did not significantly reduce after the interventions in our study. These symptoms might be due to various determinants (individual characteristics, leisure time, and psychosocial factors) that our research could not consider all of them. A few studies reported a significant decrease in MSDs symptoms after the interventions. Van de Molen et al. and Rivilis et al. reported moderate evidence of the effectiveness of interventions on musculoskeletal symptoms (van der Molen et al. 2005; Rivilis et al. 2008). Haslam et al. (2018) reported a significant reduction in physiological factors after a tailored intervention, but they did not report MSDs symptoms (Haslam et al. 2018). Faisting & Sato (2019), Yu et al. (2013), Driessen et al. (2011), Hogan et al. (2014), Stacy et al. (2010), Gupta et al. (2018), and Verbeek et al. (2011) reported that the interventions such as manual material handling devices, participatory ergonomics, and training were ineffective in decreasing MSDs symptoms and pain. It is difficult to conclude the immediate effects of interventions on MSDs symptoms because of the complex nature of musculoskeletal disorders. Therefore, an intervention study focused only on the physical aspects might not necessarily reduce MSDs symptoms.

In this study, engineering solutions often had a single-factor impact, and they reduced one or two dimensions of physical risk factors in the workstations. Designing a new unlocking system reduced fingertip and thumb force, but a small contact surface risk factor with relatively high force (>1kg) arose for the palm. Another limitation of this ergonomic measure was that some operators still preferred the old unlocking system, and it was difficult to change their habits. The same problem arose with the new lifting tool for lifting and carrying the rear and front mudguards. Some operators insisted on handling the mudguard, manually, although it weighed more than 12kg. They believed that lifting and carrying with the lifting device would be time-consuming. It seems that if end-users' preferences are considered over designing and implementing ergonomic measures, interventions might be more successful. New technical solutions must eliminate any possibility of using the previous way of performing the task, as the operators' habits often prevent the success of technical measures. Changing people's behavior is necessary for the success of interventions, which require training, the participation of stakeholders, and sometimes the mandatory rules (van der Molen et al. 2005). Previous studies have demonstrated that behavior's changes might achieve by a combination of sound implementation strategies such as considering sense-making, decision-making, and learning processes, exercise training, and tailored interventions to individual job demands (Barrett et al. 2005; Clemes et al. 2010; Knibbe & Friele 1999; Umar et al. 2018). Hogan et al. reported very little success in behavior changes in previous intervention studies (Hogan et al. 2014). Haslam et al. proposed tailored interventions to achieve more success in behavior changes (Haslam et al. 2018; Barrett et al. 2005; McDermott et al. 2012).

Three other engineering solutions successfully achieved the desired objectives. An embedded camera in the hand-held screwdriver machine reduced the duration of exposure to awkward postures (length of kneeling, squatting, and awkward neck postures). Nevertheless, some awkward postures remained because of other tasks, such as putting the bumper on the chassis. A gripping tool for handling the air filter succeeded in reducing the duration of exposure to air filter handling. We combined two interventions in this case, i.e., new lifting device and reorganization/redesign of the workplace and tasks, which successfully decreased physical work demands at this workstation.

The inclusion of the new product assembly (Euro 6 SCR tank) was not initially planned in the context of this research, but it occurred due to the ever-changing context of automotive industries. The design of the new generation of the SCR tank required lifting and carrying with lifting devices that reduced physical risk factors. The operators had to use the new safer system, whereas they handled manually loads of more than 13 kg in the first assessment time. Proactive ergonomics such as well-designed products and tasks might be much more useful than reaction interventions. Design engineers usually overlook the value of ergonomically designed products and proactive ergonomics (Falck et al., 2010). This study showed that considering ergonomic devices such as lifting tools very early in the design might easily convince the operators to use them satisfactorily.

The engineers reorganized and redesigned the tasks of workstations based on the ergonomic evaluation over changing the cycle time. They distributed high-risk tasks between different workstations, particularly within newly created workstations. The second assessment time reduced the content of each workstation. The new concept was not entirely different, but the high-risk tasks were better distributed. The number of high and moderate risk factors reduced in the second assessment time. Otto & Scholl (2011) showed that rebalancing at an automobile assembly workstation could significantly reduce ergonomic risk factors, in many cases, without creating new workstations (Otto & Scholl 2011). In our study, the sector's manager and engineers—based on research team advice—balanced the workstations or the IG by transferring the tasks between work positions/IG—not by computational experiments on the data set such in Otto & Scholl's study. The effectiveness of reorganization and redesign of the workstation on reducing risk factors and MSDs symptoms are not evident in the literature. Daniels et al. (2017) reported that job redesign interventions might be successful if they combine with training and other employment practices (Daniels et al. 2017). Stock et al. (2018) and Westgaard & Winkel (1997) reported little evidence to confirm a significant effect of organizational factors on reducing MSDs symptoms (Westgaard & Winkel 1997; Stock et al. 2018). Balanced workstations reduced physical workload; however, we could not distinguish which interventions (engineering or organizational solutions) were most effective.

Developing dialogue processes with the managers, engineers, and operators was a crucial factor in implementing the interventions. The research team provided several opportunities for dialoguing and giving feedback about risk factors, MSDs symptoms, and the proposed solutions to the top and middle managers, engineers, technicians, and operators. The engineers and operators actively engaged in developing solutions. This strategy increased the involvement of decision-makers and stakeholders in the interventions. Neumann et al. (2012) proposed the involvement of stakeholders from different system levels in the interventions by providing feedback relating to risk factors, disorders, quality defects, and productivity. This approach helps the stakeholders to find the solutions themselves and aims to reach 20% improvement in both human well-being and system performance (Neumann & Village 2012). Organizational interventions—contrary to single technical interventions that are often implemented at a specific level—require the involvement of all levels of the organization (Dasgupta et al. 2017). Previous studies consensually reported that a successful intervention needs commitment, and participation of managers, engineers, and workers (Burgess-Limerick 2018; Winkel et al. 2017; Daniels et al. 2017; van Eerd et al. 2010; McDermott et al. 2012; Haslam et al. 2018; Clemes et al. 2010; Yassierli, 2017).

This study might suffer from some limitations. We could not control the daily changes in the real setting, such as production changes and the usual modifications in the process due to continuous improvement policy. Furthermore, this study could not claim the effectiveness of the interventions on changing operators' behaviors. To achieve effective behavioral changes in operator performance, we propose an implementation strategy that influences the awareness, attitudes, and performance of people. Another limitation of this study is the evaluation bias related to self-reported information (MSDs symptoms) and the in-house observation method. The small sample size answered MSDs symptoms questionnaire limited to conclude the positive influence of the interventions on MSDs symptoms. However, we considered the similar parameters before and after interventions—the assessor, the evaluation tools, and the methodology for approaching the operators were identical in both parts of the study. It was challenging to engage another sector as a control group in the study. We only used the data gathered by the factory's ergonomists with the same methodology to compare with our results. Furthermore, we could not obtain MSDs symptoms from the control group because of the unavailability of the operators.

Conclusion

The findings of this study showed that a combination of ergonomic interventions, including engineering and organizational interventions along with stakeholder's involvement, reduce physical risk factors. The effects of interventions on ultimate MSDs were ambiguous, but the participants reported fewer MSDs symptoms after interventions. Developing dialogue processes and involving different stakeholders substantially supported the implementation of interventions.

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Table 1: Description of the Improvement Groups (IG) and various workstations of the sector assessed before the intervention

Improvement Group	Workstations	Number of tasks	Lifting tasks needed the NIOSH lifting equation	Task description	Principle risk factors
IG_1	Preparation of air filter and cab tilt cylinder	60	Lifting completed air filter Lifting cab tilt cylinder Lifting heat cover	Air filter, air pipe, heat cover and cab tilt cylinder pre-assembly	Awkward posture, forceful exertion, material handlings
	Air filter and cab tilt cylinder mounting	28	Lifting completed air filter Lifting cab tilt cylinder Lifting Air intake	Air filter, air pipe, heat cover and cab tilt cylinder assembly	Heavy material handling, repetitions, space restriction
	Boarding steps and mudguards; left and right	40	Lifting 3rd boarding steps Lifting left/right mudguards Lifting middle mudguard	Assembly of left and right boarding steps + Assembly of left and right rear mudguards with side lamps	Heavy material handling, repetitions, vibration
IG_2	Picking Area	29	Lifting beam cable Lifting socket screwdriver 1 Lifting pallet lid Lifting plastic box	Preparing kit for bumper; Placing bumper beam in sequence; Preparing sun visor; Picking up rear beam	Heavy and light material handling, bending and twisting
	Preparation Bumper 1	33	-	Bumper pre-assembly and washer container assembly	Force exertion, awkward posture
	Preparation Bumper 2	17	-	Bumper pre-assembly near the line	Force exertion, awkward posture
	Bumper Assembly on Truck	27	-	Finishing bumper pre-assembly, filling washer liquid, placing bumper on the chassis	Force exertion, awkward posture, bending, twisting, vibration
IG_3	Mounting Selective Catalytic Reduction (SCR) Tank	38	Lifting assembled SCR tank Lifting light box	SCR Tank assembly, hose connection, preparation of lighting box	Force exertion, heavy material handling, repetitions
	Preparation of SCR Tank	23	-	SCR Pre-assembly and sequencing	Awkward posture, forceful exertion, movement

Table 2: Risk factors evaluated by the in-house ergonomics method

Risk categories	Details of evaluation						Risk prioritization
Repetition	The number of same actions per hour						Green Yellow Red
Posture	Work postures	Access Hidden assembly	Clearance for hand/ finger	Surface area for pressure	Component size	Neck, Back, shoulder, and wrist posture	
Force	One handed Lifting		Whole Body Push /Pull		Hand push/ pull	fingers Push/ pull	
Energy consumption	Movement		Climbing/stepping over		Tightening with power tools		

Table 3: Risk evaluations with the observational method in the initial and second assessment time.

Workstation in the initial assessment time		Workstation in the second assessment time	Ergonomic evaluation changes in workstation					
			Initial overall color	New overall color	Number of yellow criteria		Number of red criteria	
					Initial	New	Initial	New
Preparation and assembly of SCR[†] tank								
Preparation of SCR Tank	Euro 5 SCR tank	Layout changes, without changes in tasks, another operator was added	Yellow	Yellow	7	9	3	1
	Euro 6 SCR tank	New SCR tank generation, the similar tasks as the initial generation but hose connection performed in this position	-	Red	-	7	-	4
Mounting SCR Tank on chassis	Euro 5 SCR tank	Lifting of the reservoir tank, connecting two hoses, tightening hose clamp, and finishing SCR cable tasks performed in another position	Red	Green	8	7	6	3
	Euro 6 SCR tank	New SCR tank generation: similar tasks as Euro 5 SCR tank but the reservoir lifted by the lifting tool, and the hose connecting task transferred to Preparation SCR position	-	Green	-	7	-	4
Air filter Preparation and Assembly								
Air filter preparation		Air filter, air pipe, heat cover preparation	Yellow	Green	5	7	8	2
		Picking up and preparation of SCR, cab tilt cylinder	-	Green	-	5	-	7
Air filter assembly on chassis		Assembly of Air filter, air pipe, cab tilt cylinder, pump and hoses (heat cover assembly task transferred to another position)	Yellow	Yellow	7	5	7	8
Bumper Zone								
Picking up bumper, sun visor, pump, washer tank, and fog lamp preparation		Picking up bumper and sun visor tasks transferred to another section, but the pump, washer tank, and fog lamp preparation tasks merged in the following workstations			-			
Bumper Preparation position 1		Bumper preparation position 1 (pump preparation added, bumper cable rooting transferred to position 2, putting the bumper on the wagon was eliminated)	Yellow	Green	12	6	3	2
		Bumper preparation position 2 (bumper cable rooting and washer tank preparation tasks)	-	Green	-	4	-	1
		Bumper preparation position 3 (Fog lamp assembly and front right assembly tasks)	Green	Green	7	4	4	4
Bumper Preparation position 2		Bumper preparation position 4 (filling washer tank, light cable routing, tightening lightbox, fog lamp cable routing)	-	Yellow	-	9	-	4

Assembly of Bumper on chassis	Bumper assembly and tightening position 5 (filling washer tank, tightening lightbox, and front light cable rooting transferred to the previous positions)	Red	Yellow	8	6	5	8
Boarding Step and Mudguard Assembly Zone							
Right Boarding steps and Mudguards	Right boarding step assembly and right rear mudguard bracket	Yellow	Yellow	8	5	8	7
	Right mudguard assembly (heat cover assembly task transferred)	-	Green	-	6	-	5
Left boarding steps and Mudguards	Left boarding steps assembly and rear mudguard bracket left	Yellow	Green	9	8	7	5
	Left mudguard assembly (fit air pipe to air inlet pipe)	-	Green	-	4	-	5

† Selective Catalyst Reduction

Table 4. Results of non-parametric Kruskal-Wallis by workstation and Improvement Group (IG) for the lifting index, yellow, and red evaluations before and after the intervention. Significant P-values (<0.05) are in bold.

Ergonomic workload	By workstation			By IG		
	Initial assessment time (11 min)	Second assessment time (8 min)	Both assessment time	Initial assessment time (11 min)	Second assessment time (8 min)	Both assessment time
NIOSH Equation Lifting Index (LI)	0.16	0.75	0.89	**0.006****	0.26	0.11
Yellow ergonomic workload	0.19	0.09	0.26	0.93	0.42	0.75
Red ergonomic workload	**0.04***	**0.03***	**0.002****	**0.001****	0.38	**0.006****

Table 5: Musculoskeletal symptoms using a Nordic questionnaire in a Visual Analog Scale (VAS) at the time of filling out the survey before and after interventions only for the intervention group.

	All respondents				Same respondents				
	Initial assessment time (n=15)		Second assessment time (n=21)		Initial assessment time (n=11)		Second assessment time (n=11)		P-value † for same respondents
	n	%	n	%	n	%	n	%	
Neck, VAS ‡ ≥ 5	5	33	2	10	3	27	1	9	0.63
Shoulders and arm, VAS ≥ 5	10	67	7	35	6	55	4	36	0.63
Elbows and forearms, VAS ≥ 5	8	53	8	40	5	45	4	36	1.00
Wrist and hands, VAS ≥ 5	7	47	8	40	4	36	3	27	1.00
Fingers, VAS ≥ 5	5	33	4	20	2	18	2	18	1.00
Upper back, VAS ≥ 5	5	33	5	25	5	45	2	18	0.25
Lower back, VAS ≥ 5	7	47	7	35	5	45	3	27	0.50
Hip and thigh, VAS ≥ 5	4	27	2	10	3	27	1	9	0.63
Knee and leg, VAS ≥ 5	3	20	6	30	3	27	3	27	1.00
Ankle / Foot, VAS ≥ 5	4	27	4	20	3	27	2	18	1.00

†Mac Nemar exact test for 11 operators who responded for both assessment times
‡VAS, Visual analog scale for pain

Figure 1. Conceptual framework used in this intervention research

Figure 2. a) Initial unlocking system for bumper lifting tool required an excessive force (200 N) from the thumb and index finger, b) new unlocking system for bumper lifting tool eliminated thumb and index finger involvement by using the palm/several fingers.

Figure 3. a) Old tightening tool for bumper screw required kneeling and awkward neck and back postures; b) new system designed with camera near the jib (the flash in the above picture shows the location of camera) of the lifting tool and monitor at the eyes level of the operator; c) modified tightening device eliminated kneeling and awkward postures.

Figure 4. Lifting and carrying air filter (12-16 kg) caused low back pain and awkward posture.

Figure 5. A new gripping tool for lifting air filter eliminated the risk of low back pain due to lifting a heavy object.

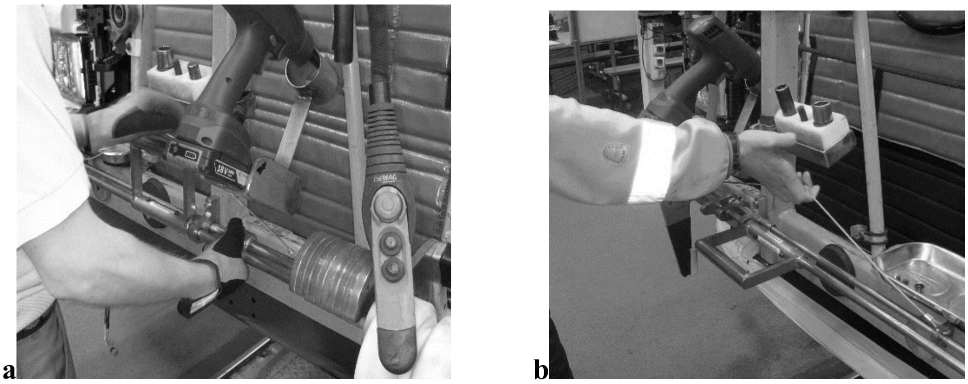
Figure 6a. Lifting and carrying of rear mudguards (15kg) manually, a risk factor for low back pain; b) new lifting tool used for lifting and carrying mudguards

Figure 7. a) Manually turning the Selective Catalyst Reduction (SCR) wagon handle (repeated action). b) A screwdriver replaced the manual turning handle, which eliminated repeated actions.

Figure 8. Distribution of a) green ergonomic evaluations b) yellow ergonomic evaluations and c) red ergonomic evaluations for both assessment times.

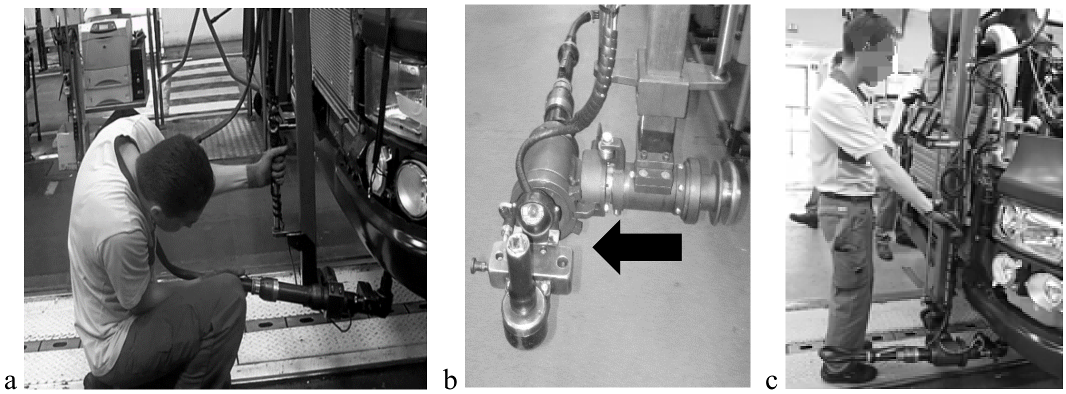
Figure 9. a) The distribution of red ergonomic evaluations for the initial assessment time over three Improvement Groups (IGs) b) the distribution of red ergonomic assessment for the second assessment time.

Figure 1. Conceptual framework used in this intervention research



a b

Figure 2 a) Initial unlocking system for bumper lifting tool required an extra force (200 N) from thumb and index finger, b) new unlocking system for bumper lifting tool eliminated thumb and index finger involvement by using the palm/several fingers



a b c

Figure 3. a) Old tightening tool for bumper screw required kneeling and awkward neck and back postures; b) new system designed with camera near the jib (the flash in the above picture shows the location of camera) of the lifting tool and monitor at the eyes level of the operator; c) modified tightening tool eliminated kneeling and awkward postures

Figure 4. Lifting and carrying air filter (12-16 kg based on truck variants) caused low back pain and awkward posture

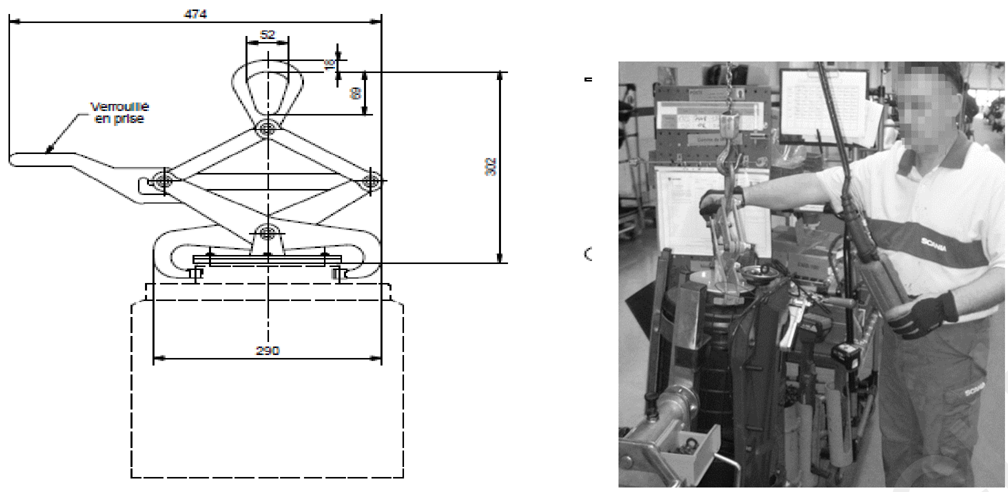
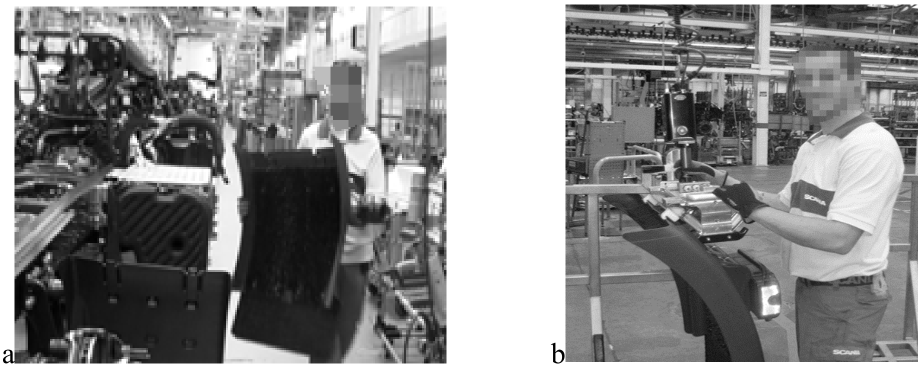


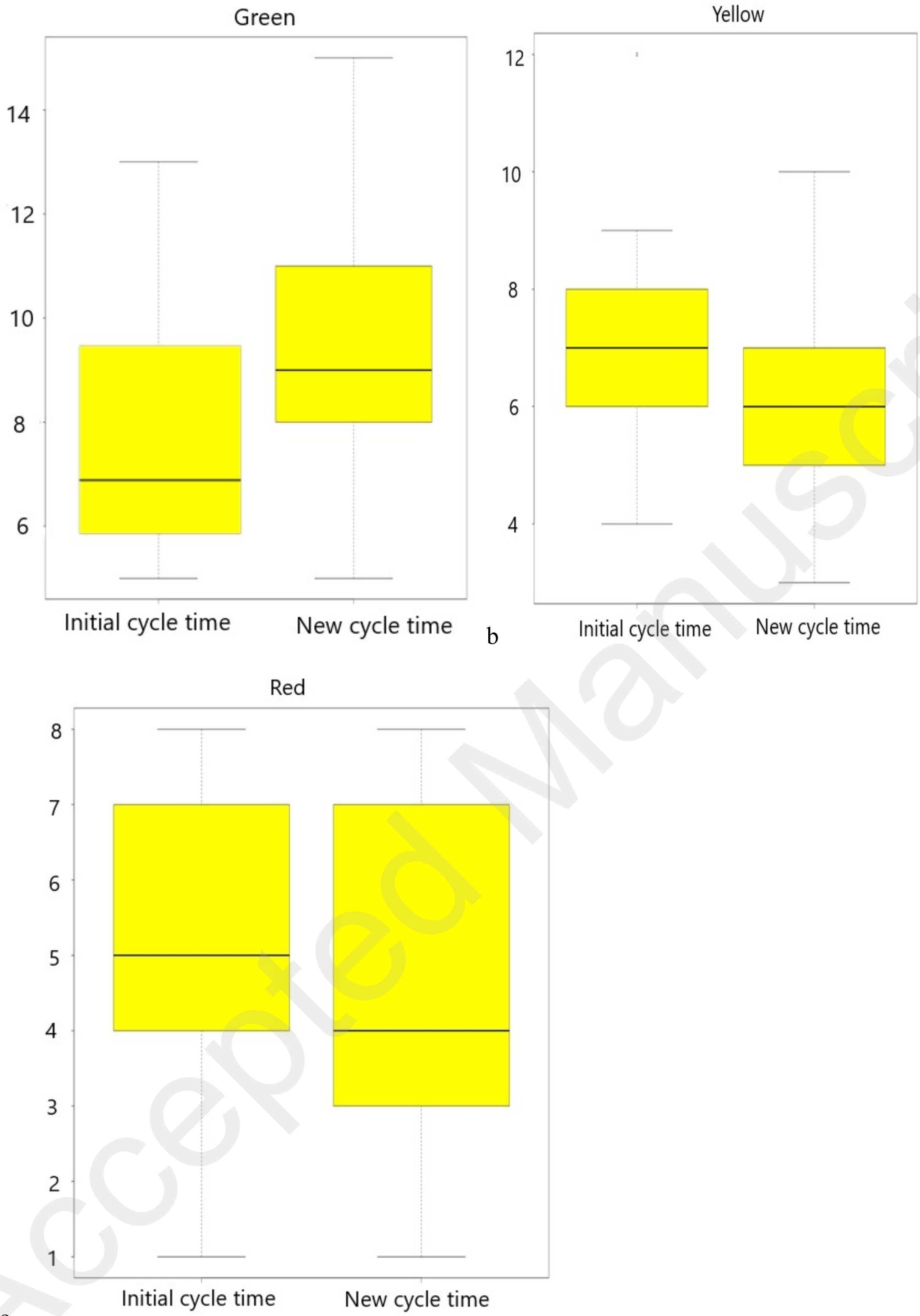
Figure 5. A new gripping tool for lifting air filter eliminated the risk of low back pain due to lifting a heavy object



a b

Figure 6. a. Lifting and carrying of rear mudguards (15kg) manually, major risk factor for low back pain; b) new lifting tool used for lifting and carrying mudguards

Figure 7. a) Manually turning the Selective Catalyst Reduction (SCR) wagon handle (repeated action). b) A screwdriver replaced the manual turning handle, which eliminated repeated actions.



c

Figure 8. Distribution of a) green ergonomic evaluations b) yellow ergonomic evaluations and c) red ergonomic evaluations for both cycle times

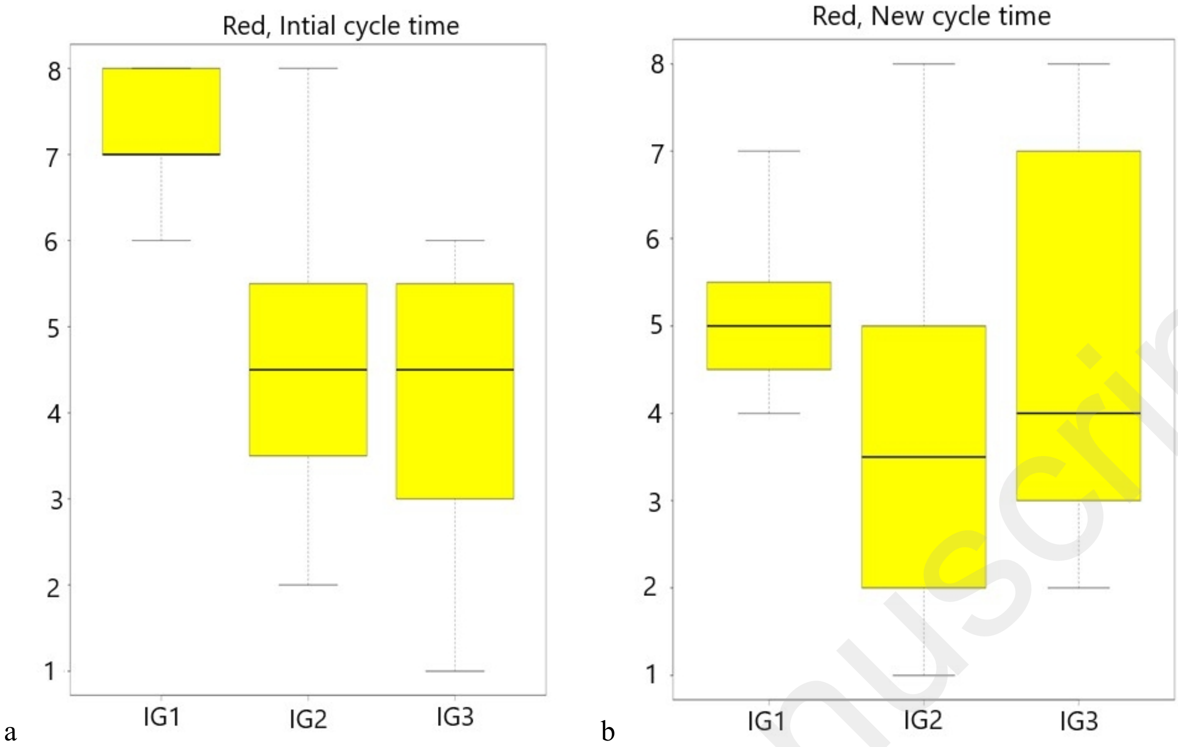


Figure 9. a) The distribution of red ergonomic evaluation for the initial cycle time over three Improvement Groups (IGs) b) the distribution of red ergonomic evaluations for the new cycle time

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