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Field Report

Evaluation of ergonomic physical risk factors in a truck manufacturing plant: case study in SCANIA Production Angers

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Abstract: The aims of this study were 1) to assess the ergonomic physical risk factors from practitioner's viewpoint in a truck assembly plant with an in-house observational method and the NIOSH lifting equation, and 2) to compare the results of both methods and their differences. The in-house ergonomic observational method for truck assembly i.e. the SCANIA Ergonomics Standard (SES) and the NIOSH lifting equation were applied to evaluate physical risk factors and lifting of loads by operators. Both risk assessment approaches revealed various levels of risk, ranging from low to high. Two workstations were identified by the SES method as high risk. The NIOSH lifting index (LI) was greater than two for four lifting tasks. The results of the SES method disagreed with the NIOSH lifting equation for lifting tasks. Moreover, meaningful variations in ergonomic risk patterns were found for various truck models at each workstation. These results provide a better understanding of the physical ergonomic exposure from practitioner's point of view in the automotive assembly plant.

Key words: Ergonomics, Workload, Variability, Assembly manufacturing plant

Introduction

The prevalence of work related musculoskeletal disorders (WR-MSDs) is high in the automotive industry[1, 2]. Many tasks have to be performed in an automotive assembly line including tightening, picking up, lifting and material handling. These operations involve physical ergonomic risk factors such as repetition, forceful exertion, awkward postures, vibration etc. Furthermore, short cycle time and insufficient recovery time related to assembly line have often accumulative effects on the risk exposure[3, 4]. A dose-response relationship between physical ergonomic risk exposure and the prevalence of WR-MSDs has been reported in the automotive assembly operations[5, 6].

Measurement of physical risk factors in different occupations has been a challenge for ergonomists/practitioners and managers. They need to assess physical risk factors accurately to establish priorities for ergonomic interventions[7]. Many scientific methods are available for assessing physical risk factors, including observational

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methods, subjective or self-reported assessment and direct measurement techniques[6, 8]. Due to constraints of time and resources in most industries, practitioners prefer observational methods. A number of observational methods (such as RULA[9], REBA[10], OCRA[11], QEC[12], the NIOSH equation[13] etc.) have been developed in the ergonomic literature[6, 14, 15]. Kee and Karwowski applied REBA, RULA, and OWAS in various industrial sectors and compared their results[15]. Chiasson *et al.* compared eight methods including QEC, FIOH, RULA, REBA, HAL, JSI, OCRA and EN 1005-3 standards over four years at 224 workstations[16]. However, automotive companies have created in-house observational method which is customized to their own risk factors[17]. Few literatures involved have addressed applied researches that assess ergonomic workloads with the in-house ergonomic method[16, 17]. Törnström *et al.* reported factors supporting and hindering the implementation and application of an in-house ergonomic method[18]. Berlin *et al.* compared Swedish national legislation with an in-house ergonomic method in an automotive corporation to determine whether they are equivalent[17]. To our knowledge, few research studies have reported ergonomic risk factors with an in-house method from a practitioner's perspective and most of existing studies are research-oriented on the base of expert's perspective[17]. Furthermore, no research has compared an in-house ergonomic method with commonly used methods such as the NIOSH equation. The aim of this study was therefore to assess WR-MSDs risk factors in a truck assembly plant from practitioner's viewpoint by use of an in-house ergonomic method. A further objective was to compare the results of its lifting component with the NIOSH lifting equation.

Methods

Workplace descriptions

Eleven workstations (known as work position in the factory) were selected from one sector (known as cluster) of a truck assembly plant for data collection. The workstations studied involved various assembly tasks. Seventeen operators worked in these workstations, and the mean age and the length of work experience in the current job were 42.0 (±7.6) yr and 15.2 (±7.2) yr, respectively. The factory created smaller groups of operators (Improvement Groups (IGs)) in the sector under investigation to achieve continuous improvement. The operators rotated between the workstations of each group every two hours. Table 1 presents three IGs and the number of workstations and tasks.

Given the variations in truck models for each workstation, there are extra or different tasks which cause variations in physical risk factors. We therefore considered significant variations in truck models as well as standard trucks, and finally 28 assessments were performed. The cycle time (known as takt time in the factory) for each workstation was 11 min, which included the time for performing the assigned tasks plus recovery time.

The production volume of the factory was based on the cycle time and 35 trucks were daily produced. The reasons for studying these workstations were either operators' complaints or the amount of absenteeism. Ergonomic assessments were performed with both the SCANIA Ergonomic Standard method (SES) and the NIOSH lifting equation. Assessment was undertaken for one operator for each workstation. Where a workstation needed more than one operator, e.g. middle mudguard assembly, two operators were assessed.

Data collection

A checklist was filled out to collect descriptions of workstations (tools, constraints etc.) before the ergonomic assessment. Weights of objects (dynamometer), magnitude of forces (dynamometer), and handle diameters (calliper) were measured and recorded. Video recording was performed for all workstations assessed, and the ergonomist attempted to position a mobile camera in order to record the whole body throughout video recording. The recordings allowed the researcher to perform a more precise evaluation of the workstations. The study was performed from September 2012 to March 2013 as the majority of workstations were observed and assessed several times. Changes in the workstations were therefore taken into account over this period. An ergonomist analysed workstations using the SES method and recorded movies, and in some cases two ergonomists discussed and decided the assessment scores. If workstations evaluated with the SES method involved high risk lifting tasks, they were analysed more precisely by the NIOSH revised equation method and the results of the NIOSH equation were taken into account to determine the final evaluation of each workstation.

Concept and background of the SES method

The SES is an in-house observational method which was implemented by SCANIA group to identify the potential of physical ergonomic risk factors in the truck manufacturing plant. This screening tool was developed by Saab Automobile and adapted to Scania conditions according to the ergonomic requirements of Swedish

Table 1. Workstations, truck types, approximate number of tasks performed, task description and predominant risk factors for each workstation

Workstations	Truck types	Number of tasks	Task description	Principle risk factors
Improvement Group 1 (IG_1)				
Preparation of air filter and cab tilt cylinder	Standard Other model (High air intake)	60	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	Standard Other model (Air pipe) Other model (High air intake)	28	Air filter, air pipe, heat cover and cab tilt cylinder assembly	Heavy material handling, repetitions, space restriction
Boarding steps and mudguards; left and right	Standard	40	Assembly of left and right boarding steps + Assembly of left and right rear mudguards with side lamps	Heavy material handling, repetitions, vibration
Variant Workstation	Hydraulic kit	9	Hydraulic kit assembly	Heavy material handling
	Middle mudguards Y mudguards	22	Assembly of middle mudguards Assembly of Y mudguards	Heavy material handling, repetitions
	Additional boarding steps	7	Assembly of boarding steps	Repetition
Improvement Group 2 (IG_2)				
Picking Area	Picking up bumper Picking up equipment Sun visor Rear bar	29	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	Standard Other model (Heavy duty front) Other model (Protruded)	33	Bumper pre-assembly and washer container assembly	Force exertion, awkward posture
Preparation Bumper 2	Standard Other model (Heavy duty front)	17	Bumper pre-assembly near the line	Force exertion, awkward posture
Bumper Assembly on Truck	Standard Other model (Heavy duty front) Other model (Protruding)	27	Finishing bumper pre-assembly, filling washer liquid, placing bumper on the chassis	Force exertion, awkward posture, bending, twisting, vibration
Improvement Group 3 (IG_3)				
Mounting Selective Catalytic Reduction (SCR) Tank	Standard Other model (Euro 6 SCR)	38	SCR Tank assembly preparation of lighting box	Force exertion, heavy material handling, repetitions
Preparation SCR Tank	Standard Other model (Euro 6 SCR)	23	SCR Pre-assembly and sequencing	Awkward posture, forceful exertion, movement
Variant Workstation	Hydraulic kit	9	Hydraulic kit assembly	Heavy material handling
	Lighting box	13	Preparation front lighting box	Awkward posture

legislation and Scania's health and work environment policy. By assessing multi-tasks workstations on the line, it evaluates the postures of the whole body or body region, manual force exerted, and manual handling. The SES method includes 20 criteria which are classified in four categories; including repetition, work posture, lifting and energy consumption (Table 2). The evaluation index of this method is not only based on subjective assessment, but also on measurable factors such as weight, mechanical forces (measured by dynamometer), object diameter and distance. The results are sorted into zones for prioritization of each assessment. Green or normal zones have minimal risk of musculoskeletal disorders, and these are acceptable. Yellow zones have moderate risk of musculoskeletal disorders, and workstation assigned yellow might need some improvement in the future. Red indicates an action zone with considerable risks of musculoskeletal disorders, and changes are required as soon as possible. Finally, double red zones have potentially excessive ergonomic risks. Tasks assessed as double red should be stopped immediately and a solution found to eliminate or reduce the risk. While the operator was working, each criterion (in

Table 2. Risk factors taken into account by both the SES and NIOSH equation methods

Risk factors	SES component (prioritization: Green, Yellow, Red, Double red)	NIOSH equation
Repetition	Repetition per hour - <150 rep/h **Green** - 150–300 rep/h **Yellow** - >300 rep/h **Red** - >600 rep/h **Double red**	Frequency Duration of lifting period (time/min)
Occurrence of work posture	Work postures during the operation - Standing/walking/sitting **Green** - Uncomfortable/twisted position while standing/sitting **Yellow** - Lying, kneeling, squatting, reclining on one side or back, standing on one leg **Red**	Horizontal lifting distance (H) Vertical lifting height (V) Asymmetry (A) Vertical travel distance (D)
Access, hidden assembly	Access hidden by obstructions in the workspace - Top or front Free access, no obstruction **Green** - Side Workplace **Yellow** - Under or behind **Red**	NA†
Clearance for hand and finger	Clearance for manual fitting of parts Hand distance: ≥2.5 cm **Green**; <2.5 cm **Red** Finger distance: ≥1.0 cm **Green**; <1.0 cm **Red**	NA
Hand workspace	The workspace (box) in which the hands must be held during the operation - In box **Green** - Outside box **Red**	NA
Hand grip	Quality of handgrip, diameter/thickness of the tool - Ø >2–4 cm. Even and not slippery **Green** - Ø 0.6–2 cm or >4–7 cm **Yellow** - Ø <0.6 or >7 cm Sharp edges, slippery or hot surfaces **Red**	Gripping (C)
Surface area for pressure	Accessible surface of a part which fingers has contact during activity (>1 kg) Finger / Palm - Ø ≥1.5 cm Ø ≥3.0 cm or A ≥1.7 cm^2 or A ≥7 cm^2 **Green** - Ø <1.5 cm Ø <3.0 cm or A <1.7 cm^2 or A <7 cm^2 **Red**	NA
Component size	Component size when handling: (Size (mm) = Length + Height + Width) - <1,000 mm **Green** - 1,000–2,000 mm **Yellow** - >2,000 mm **Red** - >4,000 mm **Double red**	NA
Back posture	Static work posture ≥5 s–Back - 0–20° bending forward **Green** - 20–45° bending forward/ 20–45° sideways/rotation **Yellow** - >45° bending forward or >45° sideways/rotation or bending backward **Red**	NA
Neck posture	Static work posture ≥5 s–Neck - 0–20° bending forward **Green** - 20–45° bending forward or 20–30° sideways/rotation **Yellow** - >45° bending forward or >30° sideways/rotation or bending backwards **Red**	NA
Shoulder posture	Static work posture ≥5 s: Shoulder/Arm bending movement forward/outward movement - <45° upper arm lifting **Green** - 45–90° upper arm lifting **Yellow** - >90° upper arm lifting **Red**	NA
Wrist posture	Work posture–Wrist - Neutral wrist **Green** - Non-neutral wrist **Red** ● >30° bending upward ● >45° bending downward ● >10° bending sideways	NA

Table 2. Continued

Risk factors	SES component (prioritization: Green, Yellow, Red, Double red)	NIOSH equation
Lifting torque–Two-handed lifts	The torque for a two handed lift: Weight (kg) × Horizontal distance (m) × 10 N=Lifting torque (Nm) - <10 Nm **Green** - 10–35 Nm **Yellow** - >35 Nm **Red** - >70 Nm **Double red**	Lifting Index High risk >1.6
One-handed lifts	The weight of the object being lifted or held in one hand - <2 kg **Green** - 2–5 kg **Yellow** - >5 kg **Red** - >10 kg **Double red**	NA
Whole Body Push /Pull Force	Force required for pushing/pulling Initial force (starting) Continuous - <100 N <50 N **Green** - 100–150 N 50–110 N **Yellow** - >150 N >110 N **Red** - >300 N >220 N **Double red**	NA
Hand pushing and pulling	Force required to insert/remove an object, fastener, tighten with a torque wrench, etc., using the palm or the whole of one hand/arm. Neutral wrist Non-neutral wrist - <45 N <10 N **Green** - 45–90 N 10–45 N **Yellow** - > 90 N >45 N **Red** - >180 N >90 N **Double red**	NA
Pushing, pulling with fingers	The force required to squeeze/insert/remove an object, fastener, electrical connector, seal, hose, etc., using a finger/fingertip, or holding an object using fingertips and thumb in a pinch grasp. Neutral wrist Non-neutral wrist - <10 N <5 N **Green** - 10–45 N 5–25 N **Yellow** - >45 N >25 N **Red** - >90 N >50 N **Double red**	NA
Movement	Number of continuous steps taken within the workspace - 1–10 cont. steps **Green** - 11–30 cont. steps **Yellow** - >30 cont. steps **Red**	NA
Climbing/stepping over	Total distance of steps up and down over one minute: stepping / climbing up or down from raised floors, ramps, trucks - <0.6 m/min **Green** - 0.6–1.5 m/min **Yellow** - >1.5 m/min **Red** - >3 m/min **Double red**	NA
Tightening torque, hand and power tools	Rotational force needed to achieve a specified tightening torque Two hand grip One hand grip Angle machine Pistol machine El Pneumatic El Pneumatic - <20 Nm <10 Nm <4 Nm <2 Nm **Green** - 20–50 Nm 10–40 Nm 4–8 Nm 2–6 Nm **Yellow** - >50 Nm >40 Nm >8 Nm >6 Nm **Red** Straight machine <3 Nm without reaction bar **Green** >3 Nm without reaction bar **DRV**	NA

†NA: Not applicable

Table 3. Prioritization of risk factors by both methods

Methods	Evaluation Criteria	Green	Yellow	Red
Ergonomic Standard method (SES)	Number of Yellows[†]	0–8	9–16	≥17
	Number of Reds	0–6	7–9	≥10
	Number of Yellows + Reds	0–16	-	≥17
	Number of Double Reds	0	-	1–32
NIOSH Lifting Equation	Lifting Index	<1	1–1.6	>1.6

[†]The worst color dictates the final evaluation of the workstation

reality and again on video) was evaluated in the SES template, either as Green, Yellow, Red or DR (Double Red) depending on risk factor arising (Table 2).

When the evaluation was performed and the template was completed, a risk colour is calculated for each workstation according to the number of yellows, reds and double reds identified (Table 3). The worst colour being considered the final evaluation of the workstation. These color coding was extracted from the Toyota method of visualization and the Swedish legislation for Ergonomics[17].

NIOSH lifting equation

This method assesses the risk of musculoskeletal disorders in repeated lifting tasks. Seven factors including load (L), horizontal lifting distance (H), vertical lifting height (V), vertical travel distance (D), asymmetry (A), duration of lifting period (F) and gripping (C) are entered into the equation and multiplying them provides a recommended weight limit (RWL) for the task (Table 2). The ratio of the actual weight lifted to the RWL yields the lifting index (LI). The NIOSH lifting equation assumes that non-lifting manual activities are minimal, but assembly jobs include many non-lifting tasks such as pushing, pulling, carrying and walking during one cycle time. To customize the NIOSH equation results to the assembly process, it was decided to consider an action zone for a lifting index >1.6, the reason being that there were other tasks such as pushing, pulling, climbing and carrying in the assembly process besides lifting tasks[13, 19]. Thus, when the lifting index value was less than one, the task was considered to be a green or safe zone, when it was between 1–1.6 the task was regarded as a yellow or risk zone and the task was considered to be a red or action zone for a lifting index of more than 1.6 (Table 3). The NIOSH equation was calculated both at the origin and destination of the material handling tasks and the worst lifting index was recorded.

Comparison between methods

Table 2 shows the risk factors assessed by both methods used in this study. The SES method assessed lifting tasks by taking into account the weight and the distance from the body. The torque for two handed lifting was calculated and then evaluated according to a four-point colour scale (Table 2). Lifting torque >35 Nm was considered to be red and lifting torque >70 Nm was double red. These components of the SES method were compared to the results of the NIOSH equation.

Results

Out of 580 components of the SES method evaluated, 2.9% were assessed as having excessive ergonomic risk (double red), 25.1% as high risk (red) and 34% as moderate (yellow). Most of the excessive risks were related to two-handed lifting tasks. The results of the SES method showed that 41.4% of lifting tasks were double red (torque for two-handed lifting tasks >70 Nm), 20.7% red (torque for two-handed lifting tasks >35 Nm) and 24.1% yellow (torque for two-handed lifting tasks >10 Nm). The NIOSH equation method was therefore used to reassess these lifting tasks and the results of the NIOSH equation were taken into consideration to calculate the final colour of the workstations. Table 4 provides a summary of the NIOSH equation results for 20 lifting tasks. The lifting index varied between 0.2 for the additional boarding step lifting task to 2.8 for the hydraulic kit lifting task. The mean lifting indices for these tasks at origin and destination were 1.14 (±0.6) and 1.12 (±0.66), respectively. Out of the tasks evaluated, 35% had a lifting index higher than 1.6 (red), 20% had a lifting index between 1–1.6 and 45% had a lifting index of less than 1. Four lifting tasks in which the objects lifted weighed more than 14 kg were assigned LI >2. Manipulation of the hydraulic kit was identified as the highest risk task, the lifting index of which was 2.6 at origin and 2.8 at destination. The results showed that assessment of the SES component for lifting loads disagreed with the NIOSH equation and the lifting tasks were assessed as higher risks by the SES method compared to the

Table 4. Evaluation of lifting tasks by NIOSH equation and SES method

Lifting tasks	NIOSH equation					SES method	
	Weight (kg)	Horizontal distance (cm)	Vertical distance (cm)	Lifting index	Color	Lifting torque (Nm)	Color
Lifting completed air filter (end of pallet)	12	80	108	1.9	Red	96	Double red
Lifting completed air filter	13	40	122	1.1	Yellow	52	Red
Lifting cab tilt cylinder	10	50	140	1.2	Yellow	50	Red
Lifting air intake	5.9	85	140	1.1	Yellow	50.1	Red
Lifting and carrying right mudguards	15.2	40	104	1.2	Yellow	62.4	Red
Lifting and carrying left mudguards	15.2	58	105	1.7	Red	87.9	Double red
Lifting 3rd boarding steps	2	68	70	0.2	Green	13.6	Yellow
Lifting SCR tank	12	90	70	2.1	Red	108	Double red
Lifting beam cable	5	50	40	0.5	Green	25	Yellow
Lifting light box	5.3	60	160	0.8	Green	31.8	Yellow
Lifting socket screwdriver 1	7.4	50	80	0.7	Green	36.8	Red
Lifting socket screwdriver 2	6.4	53	80	0.6	Green	31.8	Yellow
Lifting pallet lid	6	58	147	0.8	Green	36	Red
Lifting pallet lid of sun visor	15	60	120	2.3	Red	90	Double red
Lifting plastic box	9.5	44	128	0.9	Green	41.8	Red
Lifting plastic box	8.4	40	105	0.6	Green	33.6	Yellow
Lifting assembled SCR tank	14.5	57	100	1.7	Red	82.6	Double red
Lifting heat shield	4.6	65	104	0.6	Green	52.2	Red
Lifting assembled SCR tank (small)	13.7	40	80	1	Yellow	90.2	Double red
Lifting hydraulic kit	14.5	90	110	2.8	Red	129	Double red
Lifting middle mudguard	14	70	1.2	2.6	Red	98	Double red

NIOSH equation method (Table 4).

More red assessments were identified at two workstations (*'Preparation of Air Filter and Cab Tilt Cylinder'* and *'Boarding Steps & Mudguards'*, 40% and 38% of SES components, respectively) than at the other workstations (Table 5). The principle high risk tasks (40% of red assessments) at the *'Preparation of Air Filter and Cab Tilt Cylinder'* workstation were manual lifting and carrying the Selective Catalytic Reduction (SCR) tank, cab tilt cylinder and air filter. The other tasks, including tightening and carrying small parts, were assessed as yellow (25%) and green (35%).

The main tasks which were evaluated as high risk in the *'Boarding Steps & Mudguards'* workstation consisted of connecting the electrical cables, picking up and placing boarding steps, handling and positioning mudguards. The main risk factors at this workstation were manual lifting of two mudguards (15.2 kg) which was evaluated as red for the left side and yellow for the right side by the NIOSH equation. The operators were also exposed to repeated actions for more than 30% of the takt time (Table 6). The duration of exposure to awkward back, shoulder, and wrist postures for this workstation was 18.8 min per two hours. The same pattern of risk exposure was observed for left and right workstations (Table 7).

At the *'Air Filter & Cab tilt Cylinder Mounting'* workstation, 33.3% of the SES components were red, 38% of the components were yellow and 28.7% were green. The lifting the air filter (LI=1.9) and the cab tilt cylinder (LI=1.2) from trolley, carrying and mounting, and connecting the cables and hoses were identified as high risk tasks at this workstation. At this workstation, the pattern of risks for variations in truck models was substantially different from that for standard trucks, while the number of red and yellow assessments was approximately the same (Fig. 1). Awkward back and shoulder postures were reported for other truck models while these risk factors were minor for standard truck model (Table 7).

The *'Bumper Assembly on Truck'* and *'Mounting SCR Tank'* workstations were found to be the highest ergonomic physical workload workstations. At the *'Bumper Assembly on Truck'* workstation, the unlocking lifting tool task was assessed as double red, the positioning and tightening of bumper tasks were red (30% of SES component), the bumper movement and preparation tasks were yellow (40%) and the other tasks were green (25%). The

Table 5. Ergonomic evaluation for different workstations evaluated by SES methods and NIOSH equation

Workstation	Truck type	Occurrence Rate of truck in the line (%)	Double red evaluations† n (%)	Red evaluations† n (%)	Yellow evaluations† n (%)	Final colour of workstation†
Working Group 1						
Preparation of air filter and cab tilt cylinder	Standard	35	0	8 (40)	5 (25)	Yellow
	Other (Higher Air Intake)	19	0	8 (40)	4 (20)	Yellow
Air filter and cab tilt cylinder mounting	Standard	35	0	7 (33.3)	8 (38)	Yellow
	Other (Air Pipe)	5	0	7 (35)	7 (35)	Yellow
	Other (Higher Air Intake)	20	0	7 (33.3)	8 (38)	Yellow
Boarding steps and mudguards; left and right	Right	100	0	8 (38)	8 (38)	Yellow
	Left	100	0	7 (33.3)	9 (42.8)	Yellow
Variant Workstation	Middle Mudguards	10	0	5 (25)	6 (30)	Green
	Y Mudguards	4	0	3 (15)	4 (20)	Green
	Additional Boarding Steps	4	0	5 (23.8)	5 (23.8)	Green
Working Group 2						
Picking area	Picking up Bumper	100	0	2 (10)	6 (30)	Green
	Picking up Equipment	100	0	4 (20)	6 (30)	Green
	Sun Visor	100	0	6 (28.5)	5 (23.8)	Green
	Rear Bar	7	0	2 (10)	6 (35)	Green
Preparation Bumper 1	Standard	80	0	3 (14.3)	12 (57.1)	Yellow
	Other (Heavy Duty Front)	6	0	6 (30)	6 (30)	Green
	Other (Protruded)	12	0	4 (20)	8 (40)	Green
Preparation Bumper 2	Standard	80	0	4 (20)	7 (35)	Green
	Other (Heavy Duty Front)	6	0	4 (20)	8 (40)	Green
Bumper Assembly on Truck	Standard	80	1 (4.8)	5 (23.8)	8 (38)	Red
	Other (Heavy Duty Front)	6	0	4 (20)	6 (30)	Green
	Other (Protruded)	12	1 (5)	7 (35)	5 (25)	Red
Working Group 3						
Mounting Selective Catalytic Reduction (SCR) Tank	Standard	65	1 (5)	6 (30)	8 (40)	Red
	Other (SCR Euro 6)	4	1 (5)	7 (35)	7 (35)	Red
	Other (SCR 50 Lit)	3	1 (5)	6 (30)	6 (30)	Red
Preparation of SCR Tank	Standard	65	0	3 (15)	8 (40)	Green
	Other (SCR Euro 6)	4	0	5 (25)	6 (30)	Green
Variant Workstations	Hydraulic Kit	4	0	4 (20)	9 (45)	Yellow
	Lighting Box	100	0	1 (5)	6 (30)	Green

†The results of the SES method and the NIOSH equation

Table 6. Number of tasks requiring repeated action in workstations evaluated

Repeated tasks	Number of articles per takt time	Repetition per takt time for each article	Repetition per hour	Total colour of repetition
Inserting mudguard screws	9	4	180	Yellow (>30% of takt time)
Inserting cab tilt nuts and screws	13	2	130	Green
Tightening nuts of cab tilt on the chassis	16	2	160	Yellow (>30% of takt time)
Inserting bolts for bumper	10	4	200	Yellow (>30% of takt time)
Fitting cable tie with a stripe pistol	12	-	60	Green
Pushing and inserting clips	17	2	170	Yellow (>30% of takt time)
Tightening screws with screw drivers	30	-	150	Yellow (>30% of takt time)

Table 7. Duration of exposure for trunk, back, neck, shoulders and wrists in each takt time (11 min) for different workstation assessed by SES method

Workstation	Truck Types	Occurrence Rate %	Work posture [a] (S)	Static back posture [b] (S)	Static neck posture [c] (S)	Shoulder and Arm posture [d] (S)	Wrist posture [e] (S)	Duration of exposure for awkward postures per 2 h (min)
Preparation of air filter and cab tilt cylinder	Standard	66	NA[†]	NA	15	NA	24	4
	Higher Air Intake	22	NA	NA	45	NA	45	3
Air filter and cab tilt cylinder mounting	Standard	66	51	NA	NA	NA	57	12
	Air Pipe	5	21	10	NA	59	41	1
	Higher Air Intake	22	51	10	NA	20	55	5
Boarding steps and mudguards; left and right	Right	100	NA	10	6	29	68	18.8
	Left	100	6	29	NA	27	51	18.8
Variant Workstation	Middle Mudguards	10	NA	30	NA	NA	82	0.19
	Y Mudguards	4	NA	NA	NA	NA	54	0.04
	Additional Boarding Steps	4	41	23	13	NA	28	0.07
Picking Area	Picking Equipment	100	NA	NA	NA	42	5	8
Preparation Bumper 1	Standard	80	NA	NA	NA	NA	79	11
	Heavy Duty Front	6	101	41	17	36	92	3
	Protruded	12	NA	56	10	NA	62	1
Preparation Bumper 2	Standard	80	NA	NA	NA	57	28	12
	Heavy Duty Front	6	9	NA	NA	22	20	1
Bumper Assembly on Truck	Standard	87	51	10	NA	NA	15	11
	Heavy Duty Front	6	11	NA	NA	45	8	1
	Protruded	12	35	NA	NA	18	5	1
Mounting SCR Tank	Standard	65	13	NA	NA	NA	51	6
	Euro 6SCR	4	110	NA	43	NA	101	3
	50 Lit SCR	3	25	NA	22	NA	67	0.19
Preparation SCR Tank	Euro 6 SCR	4	0	14	49	56	34	2
Variant Workstation	Hydraulic Kit	4	0	0	25	0	18	0.29

[a] Lying, kneeling, squatting
[b] >45° bending forward or sideways/rotation
[c] >45° bending forward or >30° sideways/rotation or bending backwards
[d] >90° forward bending movement (flexion) or outward movement (abduction)
[e] >30° bending upward, >45° bending downward, >10° bending sideways
[†] Not applicable, this workstation had no awkward postures

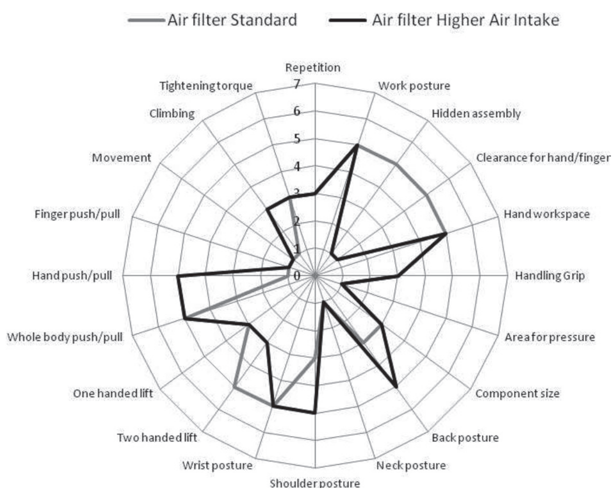

Fig. 1. Pattern of risk factors at '*Mounting Air filter and cab tilt cylinder on chassis*' workstation for standard and variant (higher air intake) trucks.

overall colour evaluation of this workstation was red. The total number of repeated actions for this workstation was 200 similar actions per hour that were related to inserting screws for mounting the bumper on the chassis (Table 6). The ergonomic risk factors for other truck models were different at this workstation as 20% of the SES component was red for the Heavy Duty Front truck model, and the double red task did not exist.

The hose connecting task was assessed as double red at the *'Mounting SCR Tank'* workstation because it required excessive whole body and arm force. Furthermore, lifting (LI=1.7) and mounting the SCR tank, tightening and cabling were the high risk tasks (30% red points of SES component) at this workstation. Squatting and awkward wrist postures were found at this workstation for standard trucks though the duration of exposure every two hours was six minutes. The overall ergonomic evaluation score for the *'Mounting SCR Tank'* station was red.

At the *'Sun Visor Preparation'* workstation, manipulation of the box lid, as shown in Table 4, was evaluated by the NIOSH equation as a red lifting task (LI=2.3). A significant number of red (28.5%) and yellow (23.8%) tasks were identified at this workstation by the SES method (Table 5). Red evaluations were related to picking up and handling tasks as well as positioning the sun visor. The inserting clips task was repeated 170 times per hour and was assessed as a moderate risk factor. Moreover, the force that was required to squeeze and insert clips by fingers and thumbs was 70N (red).

The results of the SES evaluation for each component (criterion) are presented in Table 8. Exposure to high risk factors for wrist postures was observed at 86% of the workstations. High risk shoulder postures and awkward work postures (lying, kneeling and squatting) were found at approximately 45% of the workstations. Moderate exposure (yellow) to different risk factors (SES components) was observed more frequently than excessive exposure (red and double red). Eighty percent of the workstations were exposed to moderate risk of hand grip and using screwdrivers (excessive torque) (Table 8).

The levels of risk for standard vehicles and other models at an overall glance showed that the majority of workstations (53.6%) were evaluated as moderate (yellow), 17.8% (5 stations) were classified as high risk (red) and 28.6% as moderate risk (yellow).

Discussion

This study was designed to identify exposure to risk factors that might contribute to WR-MSDs in a truck assembly plant. An in-house ergonomic method and the NIOSH equation were applied as screening tools to evaluate workstations from practitioner's viewpoint and the results were compared. Most of the workstations (for standard trucks and other models) in the study were evaluated as having moderate exposure to risk factors.

The disagreement was observed between the results of the SES method and the NIOSH equation. The main reason is that the variables of exposure assessment were considered differently in each method. SES evaluates lifting torque using weight of objects lifted and the horizontal distance from the body (based on Swedish legislation), while the NIOSH equation considers not only horizontal distance but also other lifting variables such as vertical distance, coupling, asymmetry and frequency. According to the standard NIOSH equation method, a lifting index >3 would be a significant risk for low back pain[13], whereas we modified the prioritization scale and a lifting index >1.6 was considered high risk in this survey. The reason for this modification was the combination of other tasks such as pushing, pulling, climbing and carrying in the assembly process besides the lifting tasks. Despite this modification and the increased sensitivity of the NIOSH method, the NIOSH approach ranked most lifting tasks as moderate or low risk compared to the SES method. The results of the NIOSH equation seem to be closer to reality because the SES component overestimated the risk exposure, and even loads weighing <5 kg were assessed as moderate risk (Yellow). Horizontal distance had a significant effect on the results of both methods, and precise

Table 8. Distribution of different ergonomic risk factors at workstations

Risk factors	High risk (red and double red)		Moderate risk (yellow)	
	N	%	N	%
Repetition	0	0	7	24.1
Work posture	13	**44.8**	7	24.1
Access, hidden assembly	11	37.9	7	24.1
Clearance for hand, finger or tool	9	31	0	0
Workspace for hands	11	37.9	0	0
Hand grip	4	13.8	24	**82.7**
Surface area for pressure	3	10.3	0	0
Component size	6	20.7	13	44.8
Static back posture	10	34.5	17	**58.6**
Static neck posture	11	37.9	15	48.3
Static shoulder posture	13	**44.8**	13	44.8
Wrist posture	25	**86.2**	0	0
Lifting with two hands (NIOSH method equation)	9	31	4	13.8
One-handed lifts	3	10.3	19	**65.5**
Pushing/Pulling Force-Whole Body	9	31	16	55.2
Pushing/pulling with the hand, arm	6	20.7	6	20.7
Pushing, squeezing, and pulling with fingers	6	20.7	11	37.9
Movement (continuous steps)	1	3.4	7	24.1
Climbing/stepping over	0	0	1	3.4
Tightening torque, hand and power tools	5	17.2	20	**87**

Considerable exposure in bold

measurement of horizontal distance is difficult in the real situation when operators have to perform their tasks over a determined cycle time. A laboratory assessment showed that frequency and horizontal distance had the greatest effect on the NIOSH results, although these parameters were subject to high measurement errors[20]. Using the NIOSH approach as a routine method would be somewhat difficult for practitioners because it requires measurement of several variables and interferes with the normal pace of the assembly process.

Awkward posture was a frequent risk factor at various workstations. The durations of exposure to awkward work postures for operators at the '*Boarding step and Mudguard*' workstation (left & right) were longest compared to other workstations, the possible reason being the quantity of tasks (assembly of two main parts of a truck i.e. mudguards (front and rear) and boarding steps) that had to be performed at this workstation. Hidden access and obstructions in the workspace were the reasons for many awkward postures which forced the operator to bend over the side of a truck or required turning to gain visual or manual access. At the air filter workstation, tightening the air intake pipe in an obstructed workspace required awkward postures of the neck, wrists and hands for which replacing current screwdrivers with new long nose ones was suggested. Unloading parts from a pallet forced operators to work out of the hand workspace which caused awkward postures. Changing the packaging of the pallet was recommended to reduce this risk factor. Tightening the screws below the bumper (hidden access) required kneeling with awkward neck and back postures at the '*Bumper Assembly on Truck*' workstation (Fig. 2). It is therefore suggested that another tightening tool should be developed to avoid hidden access and facilitate tightening the screws below the truck chassis.

Hand/wrist risk factors such as wrist bending, hand/finger clearance, hand grip and excessive hand/finger force were observed to be high or moderate in approximately for most of workstations. Furthermore, exposure to moderate hand/wrist risk factors related to use of screwdrivers was relatively high for the workstations analysed. The main reasons for finding high risk exposure for the hand/wrist were the characteristics of truck assembly jobs which required intensive hand activities. Activities and tasks in many workstations involved short clearance between hand and parts/tools for manually assembled elements (small space). More force was therefore required or there was a risk of catching/knocking the hand/finger in such tasks[21].

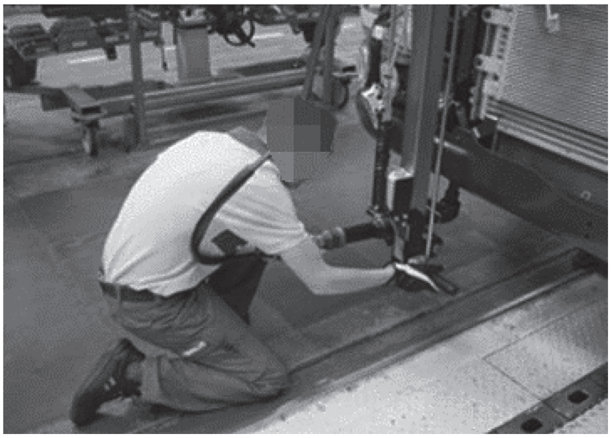

Fig. 2. Tightening screws at '*Mounting bumper on chassis*' workstation caused awkward trunk and neck postures.

Operations for connecting or removing hoses, small parts, fasteners, and electrical connectors involved forceful hand movements and wrist bending. Unlocking the bumper lifting tool operation required such excessive force for fingers that these tasks were evaluated as double red. Immediate improvement was therefore needed and changes were recommended in the anti-lock system of the lifting tool in our further research. Furthermore, the majority of tasks at different workstations required using screwdrivers (weighing between 2–4 kg) which were vibrating tools with sometimes a forceful reaction at the end of tightening. All these operations increased the risk of musculoskeletal disorders for the hand/wrist. The same risk exposure pattern has been reported in other studies in the automotive industry[22)]. Recent studies showed an association between high levels of hand force, wrist bending and vibration with the incidence of carpal tunnel syndrome (CTS). In a cross sectional study a significant relationship was observed between hand force and CTS[23)].

Shoulder elevation (>90°) or abduction to the side were observed in most workstation and they are clearly risk factors for shoulder disorders. The main reasons for awkward shoulder postures were picking up the parts from the racks, assembling and mounting the parts high on the trucks and using screwdrivers suspended at height. Furthermore, the gestures of some operators when tightening with screwdrivers necessitated excessive arm elevation, whereas this was not the case for all operators for the same task. However, mild abduction was observed for most tightening tasks with screwdrivers. In another study in an automobile assembly plant, shoulder flexion was often recorded for the operation of hand-held tools[24)]. Organizational changes are recommended to distribute high risk tasks for shoulders (red) to other workstations. This allows avoiding several high risk tasks in sequence at one workstation. It is of note that, although the nature of truck assembly requires excessive arm elevation due to the size of vehicles, a small number of single tasks required excessive arm elevation for prolonged durations. The SES method did not have the criteria to measure left and right shoulder risk factors separately and the static shoulder postures reported in this study were an accumulation of assessments for both sides.

Approximately 35% of workstations were evaluated as high risk for back posture (bending back forward >45° or rotation). This percentage was less than those for neck, shoulders and wrists. Nevertheless, back disorders are common, particularly among truck assemblers. Other reasons such as lifting heavy objects and material handling might be the main cause of the high prevalence of back disorders in truck assembly plants. Lifting heavy objects was a routine task at most workstations due to the size of objects and parts related to truck assembly. Strong evidence found in recent studies showed that manual lifting and handling of heavy objects are the main risk factors for low back pain[25)].

Highly repetitive tasks (>150 times/h[26)]) were mostly observed for the inserting and tightening screws/bolts, tightening with a torque wrench and turning the handle of an assembly wagon. Most workstations involved inserting and turning screws, which was a repetitive action for wrists and fingers. Such repeated rotation in the wrist might result in symptoms of CTS in workers[27)]. Studies have demonstrated increased incidence of CTS in workers exposed to repeated wrist flexion, extension and rotation[28)]. It is proposed in further research to modify the design of the assembly wagon to reduce the amount of repetition.

The SES results assessing ergonomic risk factors for other truck models generally indicated greater risk than for standard trucks. Our findings prove that we have to take into account variations in truck models in workstations on the assembly line and evaluate/analyse their ergonomic risk factors. Most assembly manufacturers currently believe that assessing the potential of ergonomic risk factors for more frequent types of products is sufficient. However, we observed that risk factors changed during eight working hours at one workstation or the pattern of risks was very dissimilar for different products.

The final colour of each workstation was the indicator of ergonomic risk factors for interventions and improvements in this factory. However, the results of this study showed that two workstations with the same final colour (for example yellow) did not always have the similar number of red or yellow risk factors (different ergonomic workloads). It was a limitation of the SES method which considered a range of yellow or red evaluations as the same final colour. It was therefore decided in the factory that ergonomists and engineers should take into account not only the final colour of each workstation but also the numbers of double red, red and even yellow evaluations. Another limitation of the SES method, and perhaps of many observational methods, was that the duration of exposure and frequency of risk factors could not be measured. When using the SES method, observers should estimate the angles of a posture and classify it in the three-color ranking scale. The ability to identify neutral or non-neutral postures is sometimes a problem, particularly for micro-postures such as the wrist and neck[14]. This might be the source of variability and disagreement between the results of different users of the SES. Moreover, postures such as twisting, extension, flexion and lateral bending were not evaluated separately and a single item assessed all these risk factors for each body part. A red evaluation for back, neck or shoulders might thus relate to flexion, extension, twisting or using two bad postures simultaneously (flexion and twisting) except when the observer provided supplementary explanation in a note (the SES method allows observers to provide supplementary notes). Awkward postures might therefore be underestimated by combining several risk factors in one item.

In conclusion, the evaluation of the ergonomic physical exposure by an in-house ergonomic method (SES) showed that awkward trunk postures, hand/wrist risk factors and awkward shoulder postures were the common ergonomic workload in the truck assembly plant. Furthermore, comparing the results of the SES method with the NIOSH lifting equation for lifting heavy objects (frequent tasks at most workstations) showed that the SES method was biased towards sensitivity and over-estimation of material handling risks. However, application of the NIOSH equation interfered with the normal pace of work process in the assembly plant.

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