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Evaluation of ergonomic approach and musculoskeletal disorders in two different organizations in a truck assembly plant

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A B S T R A C T

The aim of this study was to assess the ergonomic physical exposure, organizational and psychosocial factors in a truck assembly plant for two different cycle times (11 min and 8 min). A self-reported questionnaire was applied to evaluate subjective physical exposure, organizational and psychosocial factors by operators in two organization of an assembly process. The initial cycle time was 11 min (system A) and the new was 8 min (system B). The same work and assembly tasks had to be completed in both systems. However, the organization and distribution of the tasks and workstations were reorganized. The results of the questionnaire showed that subjective estimation by the operators regarding ergonomic risk factors was better in the new organization and self-reported WR-MSDs symptoms were fewer. However, exposure to risk factors and WR-MSDs symptoms was not statistically different between two cycle times. The findings provide better understanding of how organizational changes can modify ergonomic exposure in manufacturing assembly industries. Effective interventions are thus not only engineering solutions but also organizational and administrative adaptations.

1. Introduction

Manufacturing success in the competitive industrial world depends on employees' wellness and reducing costs (Falck and Rosenqvist, 2012; Törnström et al., 2008). Although ergonomics is integrated in the production system of many industries to improve human wellbeing and to prevent work related-musculoskeletal disorders (WR-MSDs), these disorders are still the main cause of occupational disease in many countries (Putz-Anderson et al., 1997; Roquelaure et al., 2002a). Claims for WR-MSDs have increased and it is estimated that 40% of occupational costs are related to WR-MSDs (Speklé et al., 2010). Forty-five million employees are affected by WR-MSDs in Europe, and in France 46,537 of all occupational claims in 2012 (86%) were for WR-MSDs (Roquelaure et al., 2002b; Caisse nationale…, 2012). In addition to the effects of WR-MSDs on business performance, they have considerable impact on human quality of life as they are the main causes of discomfort and pain in the workplace. WR-MSDs present serious ergonomic problems, particularly in the automobile industry due to the wide variety of ergonomic high risk tasks including tightening, picking up, lifting, material handling, as well as the characteristics of assembly line work (Wang et al., 2011). Several dimensions of ergonomics such as physical, organizational and psychosocial risk factors may be reasons for disorders among assembly operators. Physical risk factors, including repetition, awkward postures, forceful movements and heavy lifting can increase the risk of WR-MSDs (Fredriksson et al., 2001; Widanarko et al., 2014, 2015). Organizational risk factors such as time constraints, work rate and workload also have a role in the prevalence of WR-MSDs. Furthermore, psychosocial risk factors such as low decision latitude, high psychological demands, and low social support may influence these disorders. Recent studies have shown that these factors may independently increase the risk of musculoskeletal disorders or the interactive effect between them may cause WR-MSDs (Widanarko et al., 2014; Widanarko, 2013). Inman et al. (2003) showed that the odds of WR-MSDs for physical risk factors and time constraints (organizational risk factors) was 2.61, while the independent effects of these risk factors was less than one (Inman et al., 2003). In a study in a large population, Widanarko et al. (2014) showed that physical, organizational and psychosocial risk factors were independently associated with WR-MSDs. Moreover, the combined effects of these risk factors significantly

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increased the risk of WR-MSDs. However, good conditions of organizational and psychosocial factors can reduce the adverse effects of high physical workloads (Widanarko et al., 2014, 2015; Widanarko, 2013).

In order to adjust work situations and reduce WR-MSDs, there are many physically oriented intervention studies in manufacturing assembly industries. However, few studies have investigated organizational changes and their consequence for WR-MSDs. The effects of long and short cycle times were investigated by Johansson et al. in a truck manufacturing company, and musculoskeletal symptoms were similar in both systems. However, fewer physical risk factors were reported for the long cycle time (Johansson et al., 1993). Fredriksson et al. (2001) reported that changing from a line out system with a long cycle time (20 min) to a line system with a short cycle time (90 s) decreased physical risk factors significantly (Fredriksson et al., 2001). However, musculoskeletal symptoms and perceived physical exertion increased. It was concluded that psychosocial factors and poor organization design could increase musculoskeletal disorders although the new organization had improved physical working conditions. A new designed flow-line process increased the prevalence of musculoskeletal symptoms for fish-filleting plant operators. The authors concluded that all dimensions of work characteristics should be taken into account to reduce musculoskeletal symptoms (Ólafsdóttir and Rafnsson, 1998). Some advantages of a long cycle time were reported if physical and psychosocial aspects were considered in the design of the production line. The complex nature of musculoskeletal disorders means there is a need to evaluate the various elements of the ergonomic approach and consider them as a principle for designing new organization (Johansson et al., 1993; Kadefors et al., 1996; Engström et al., 1999).

Reorganization of workstations for the reason of increase of production volumes were undertaken in a truck assembly plant in France. The cycle time was decreased from 11 min to 8 min and over this reorganization ergonomic approach was considered. Furthermore, technical improvements were implemented in the reorganized production line in order to reduce the physical ergonomic workload. The purpose of this study was both to investigate ergonomic approach elements in truck assemblers including physical, organizational and psychosocial factors from operator's viewpoint and to evaluate the likely changes in the ergonomic factors after reorganization in the new cycle time. Our hypothesis was that fewer physical risk factors and musculoskeletal symptoms should occur in the new system because of reorganization of the high workload tasks between different workstation, technical ergonomic changes and reduced working at the hard workstations.

2. Materials & methods

2.1. Workplace description

This study was carried out as a follow up investigation into two production cycle times of a truck assembly plant in France. The cycle time (known as takt time in the factory) is defined as time for performing the assigned tasks in addition to recovery time. The initial cycle time was 11 min (system A) and the second cycle time was 8 min (system B). Eleven workstations (known as work position in the factory) from one sector of the truck production plant were selected for data collection and each workstation included a number of sequential assembly tasks. For production reasons the factory decided to change the cycle time from 11 min to 8 min. The organization of the workstations was therefore changed and some tasks were transferred between workstations and certain new posts were created. Furthermore, extra operators joined a variety of workstations. However, the main tasks of most workstations remained unchanged. In system A, the “Selective Catalyst Reduction (SCR) tank” workstation included unloading and transferring the support by means of a lifting tool. The principle components of the SCR support tank were then assembled in sequence and finally the completed assembly was fed up the line by wagon. The changes regarding system B at this workstation were almost entirely organizational. As the layout and the zone of SCR support assembly was changed, many non-necessary movements which related to picking up components were eliminated. Furthermore, another operator was added to this area to perform the extra tasks so that the tasks at this workstation in the new cycle time were the same as the former system. Completed SCR support tanks were assembled in the truck chassis at another workstation on the line. In system A, this post included tasks such as assembling and tightening the reservoir, and connecting hoses and cables. In the new system connecting two hoses, tightening hose clamps and finishing cable rooting on the top of the SCR tank were performed by another operator. The third workstation in system A was preparation and picking up the air filter, air pipe, heat cover, SCR tank, cab tilt cylinder and straining cylinder. One operator performed these tasks in three cycle times. In system B, this post was broken down into two posts i.e. “picking up the SCR tank and cab tilt cylinder” as well as “preparation and picking up air filter, air pipe, and heat cover”. Furthermore, the straining cylinder task was transferred to another post (assembling air filters in the line) but some extra tasks were added into “picking up the SCR tank and cab tilt cylinder” workstation because of changes in the production. Some modifications were also performed in the layout and organization of this zone.

Preparation and integration of the bumper on the chassis was performed in the zone near the assembly line in system A and it included four workstations in which one operator worked (11 min for each post). The main tasks of these series of workstations were preparation of the washer tank, fog lamp, cab tilt pump, picking up bumper and sun visor, preparation of the bumper, assembly of light box, and bumper assembly on the chassis and tightening. In system B, this workstation was divided into five workstations (8 min for each post). The tasks in this zone were almost the same as the initial system but two tasks including picking up the bumper and sun visor were transferred to other sectors of the factory. The “air filter assembly on the chassis” workstation included assembling the air filter, air pipe, cab tilt cylinder, heat cover and connecting hoses on the chassis in the initial system. In system B, the heat cover assembling task was transferred to the right mudguard workstation and the cylinder straining task was added to this post. Two workstations, i.e. boarding steps and mudguards left and right on the initial system, were distributed to four workstations (i.e. boarding steps left and right and mudguards left and right). Fitting together the air pipe and the inlet pipe task and heat cover assembly task were added to these workstations. Overall in system B, two tasks (picking up the bumper and sun visor) were eliminated (transferred to other parts of the factory) and one task (Fitting together air pipe and inlet pipe) were transferred to this zone. System A comprised eleven workstations and system B fourteen workstations (Table 1).

2.2. Procedures and subjects

The first part of the study for initial cycle time was performed before the summer vacation in July 2013. The new system and organization were then established during the holiday. The second part of study was carried out in March 2014 seven month after changing the cycle time, when the operators had adapted to the new conditions. The operators in the initial and second phase were the same but extra people were employed at the new workstations. System A, therefore, comprised 17 workers and system B included

Table 1
Changes in the workstations and task distributions in the new organization (system B).

Workstations (system A)	Changes in system B
Preparation and assembly of SCR tank	
Preparation of Selective Catalyst Reduction (SCR) Tank	Without changes in tasks, another operator was added
Mounting SCR Tank	Connection of two hoses, tightening hose clamp, and finishing SCR cable performing in another position
Bumper Zone	
Picking up bumper, sun visor, rear bar, pump, washer tank and fog lamp preparation	Picking up bumper and sun visor tasks were transferred to another section, pump, washer tank and fog lamp preparation merged in the following work station
Preparation Bumper 1	Bumper preparation station 1 (pump preparation was added, bumper cable rooting was transferred to station 2, putting bumper on the beam was eliminated) Bumper preparation station 2 (bumper cable rooting, washer tank preparation)
Preparation Bumper 2	Bumper preparation station 3 (Fog lamp assembly, front right assembly) Bumper preparation station 4 (washer tank filling, light cable rooting, tightening light box, fog lamp cable rooting)
Bumper Assembly on Truck	Bumper assembly and tightening Station 5 (washer tank filling, tightening light box, front light cable rooting transferred)
Filter Preparation and Assembly	
Preparation of air filter and cab tilt cylinder	Air filter, air pipe, heat cover preparation Picking and preparation SCR, cab tilt cylinder
Air filter and cab tilt cylinder mounting	Assembly of Air filter, air pipe, cab tilt cylinder, pump and hoses (heat cover assembly task was transferred)
Boarding Step and Mudguard Assembly zone	
Right Boarding steps and Mudguards	Boarding step assembly and right rear mudguard bracket Right Mudguard assembly (fit air pipe to air inlet pipe)
Left Boarding steps and Mudguards	Boarding steps assembly and rear mudguard bracket left Right Mudguard assembly (heat cover assembly task transferred)

24. Fifteen and 21 operators from systems A and B participated in this study, respectively, and twelve were in both cycle times. The reasons that two people from system A and three people from system B did not participate in the study were either unwillingness or absence. Data collection was performed by the ergonomist with the help of industrial engineers and technicians. Each subject in the two cycle times answered the self-reported questionnaires about physical ergonomic exposure, organizational/psychosocial factors, and musculoskeletal symptoms. Furthermore, interviews using the Borg scale were performed to measure perceived physical exertion in both cycle times.

2.3. Reference group

French surveillance data were used as reference group. We selected the subjects from a cohort study named COSALI (Roquelaure et al., 2006a, 2006b). The aim for this cohort was to assess the prevalence of WR-MSDs and their risk factors in the working population in France's Pays de la Loire region. This cohort included 3710 workers, among them 362 were blue-collar operators in the manufacturing and assembly industries, and these were chosen as reference group. The results of self-reported questionnaires for the variables used in our study were compared. The mean age of the reference group was 39.6 (±10.1) and the length of work experience for 43% of them was more than 10 years.

2.4. Self-reported musculoskeletal symptoms

Musculoskeletal symptoms in the neck, shoulders, elbows/forearms, hands/wrists, back and lower limbs were evaluated by a modified version of the Nordic Musculoskeletal Questionnaire (Kuorinka et al., 1987). The prevalence of musculoskeletal symptoms was defined as pain, numbness or stiffness for different parts of the musculoskeletal system. We asked the operators to determine their pain or discomfort in each region of the body at the moment of filling out the questionnaire on a 0–10 scale. Pain intensity ≥5 at the time of filling out the questionnaire was considered as a musculoskeletal symptom. We did not compare the results with reference data because the reference group reported symptoms experienced during the preceding 12 months.

2.5. Self-reported physical and organizational risk factors

The second part of the questionnaire evaluated subjective estimation of physical ergonomic exposure. This section was developed according to the European consensus criteria on WMSD risk factors in the upper limbs (Sluiter et al., 2001). One question including repeated actions/gestures asked about repetition. Two illustrated questions evaluated the duration of neck flexion/extension. Work with the arms >90° and between 45° and 90° as well as rotation of the arms were illustrated to assess shoulder postures. Seven illustrated questions assessed wrist and forearm risk factors. Finally, to evaluate material handling and push/pull activity, five questions asked about the weight of loads to be lifted or carried during the working day. Physical exposure was assessed by a four-point scale, i.e. "never", "sometimes", "often" and "always". If the operators answered "often" or "always", it was defined as 2 h/day and 4 h/day exposure to risk, respectively. We also interviewed operators to evaluate perceived physical exertion on the RPE Borg scale (Borg, 1990). The interview was performed by an ergonomist using the Borg scale in two periods of time, the Friday afternoon and Monday morning. The aim was to evaluate the difference between perceived physical exertion at the end of the week and after resting over the weekend. The original Borg method with the scale ranging from 6 "very very light" to 20 (very very hard) was used in this study. We considered the third quartile (score ≥15) as high perceived physical exertion for both cycle times.

We asked employees to report organizational constraints in the workplace. Two categories of questions were defined including workload (working hours, attention and high load activities and etc.) and work rate which are related to organizational factors (technical constraints, dependence to the others, mandatory procedures, monitoring and etc.). As for self-reported physical risk factors, the four-point scale was used to rate organizational risk factors.

2.6. Psychosocial factors

Work psychosocial factors were evaluated by the French version of Karasek Job Content Questionnaire (Karasek et al., 1998; Niedhammer et al., 2006). This questionnaire includes 26 questions categorized into three dimensions. The first dimension involves decision latitude which includes questions such as control over work, and work stimulus. The second dimension involves psychological workload and the third dimension social support at work, defined as supervisor climate and relationships with colleagues. To determine the prevalence of job strain and iso-strain in the study population, the scores for low decision latitude, high psychological demand and low social support were dichotomized according to the median of the French Medical Surveillance of Occupational Risk Exposure (SUMER) study. High psychological demands and low decision latitude were thus two dimensions which determined job strain and high psychological demand and low decision latitude and low social support together provided iso-strain.

3. Results

3.1. Self-reported musculoskeletal symptoms

All the subjects in this study were men, with a mean age of 42.0 (±7.6) years for cycle time A and 38.1 (±8.7) years for cycle time B. The mean length of work experience in the current job was 16.0 (±6.6) years for cycle time A and 13.0 (±8.1) years for B.

Table 2 shows the prevalence of musculoskeletal symptoms among the study population in both cycle times. The prevalence of symptoms for the shoulders, elbows and wrists was 67%, 53% and 47%, respectively, for cycle time A. In cycle time B, the prevalence of shoulder, elbow and wrist symptoms was reported as 35%, 40% and 40% respectively. The prevalence of symptoms in the lower back was also reported to be as high as 47% for subjects in cycle time A and 35% for subjects in cycle time B. The study population in cycle time A had higher prevalence of symptoms in the upper limbs, back and lower limbs compared to cycle time B (except for knee symptoms). Analysis of differences regarding prevalence of musculoskeletal symptoms showed no significant difference between cycle times A and B.

3.2. Subjective assessment of physical and organizational ergonomics workload

Table 3 shows organizational ergonomic characteristics related to work rate and workload for both cycle times. More than 70% of the operators reported technical constraints (mandatory use of tools and devices) imposed by work rate in both cycle times. Dependence on other operators' activities increased in cycle time B by 67%, compared to 47% in cycle time A. However, Mac Nemar exact test between the same respondents for this factor showed non-significant differences in both cycle times (P-value = 0.38). Other organizational characteristics imposed by work rate were reported to be high in both cycle times (Table 3). Organizational characteristics due to the workload were less often reported by operators. Fifty-two percent of operators reported "working outside normal hours" in cycle time B more than the percentage reported in cycle time A (33%). Working too fast for precise operation was reported to be 47% in cycle time A versus 25% in cycle time B. The difference between organizational risk factors was measured with Mac Nemar exact test for the same respondents in both cycle times. None of the organizational characteristics were significantly different between the two cycle times.

Table 4 shows biomechanical risk factors reported by assemblers. Back risk factors (back flexion >2 h) were reported by 100% of operators in cycle time A and 75% in cycle time B. In the reference data from other industries in France, 55% of the operators reported back flexion. However, truck assembly operators reported a low percentage of back flexion >4 h, that was similar to reference data. Shoulder risk factors including abducted arms and arms working above shoulder level were reported by 53% and 33% in cycle time A, while for cycle time B they were 52% and 24%, respectively. Elbow and wrist risk factors were also reported to be high for both cycle times. The subjects reported higher exposure to elbow flexion (cycle time A = 80% and B = 62%), pronation/supination movements (cycle time A = 64% and B = 38%), pinch grip (cycle time A = 73% and B = 43%), and hand-arm vibration (cycle time A = 40% and B = 38%) compared to reference data on French blue-collar operators in the manufacturing and assembly industries. However, blue-collar operators in the French reference data had higher percentages of repeated actions than in our study (Table 4). Component handling was mainly related to weights below 4 kg, and 47% of the subjects in system A and 29% in system B reported exposure to material handling below 4 kg. Exposure to material handling was reduced in cycle time B, although the difference between the two cycle times was not significant. Relationships were studied between physical ergonomic risk factors and musculoskeletal symptoms in operators in truck manufacturing. In general, there were no significant relationships between the symptoms for each body section and physical risk factors. Table 5 shows the percentage of perceived physical exertion for three types of

Table 2
Musculoskeletal symptoms for two cycle times in truck assembly workers at the time of filling out the questionnaire.

	All respondents				Same respondents				P-value[a]
	Cycle time A (n = 15)		Cycle time B (n = 21)		Cycle time A (n = 11)		Cycle time B (n = 11)		
	n	%	N	%	n	%	n	%	
Neck, VAS[b] ≥ 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

[a] Mac Nemar exact test for 11 operators who responded for both cycle times.
[b] Visual analog scale for pain.

Table 3
Organizational ergonomic characteristics for two cycle times reported by truck assembly workers.

	All respondents				Same respondents				P-value
	Cycle time A (n = 15)		Cycle time B (n = 21)		Cycle time A		Cycle time B		
	n	%	N	%	N	%	n	%	
During a typical workday, work rate imposed by:									
Technical constraints (mandatory screwdriver, or tools etc.)	12	80	15	71	9	75	8	67	1.00[a]
Immediate dependence on the work of one or more colleagues	7	47	14	67	6	50	9	75	0.38[a]
Inter-section activity (inter working group, inter cluster, logistics, etc.)	9	60	13	65	7	64	8	73	1.00[b]
Following safety procedures	15	100	17	81	12	100	9	75	NA[a]
Following production procedure	14	93	19	100	11	100	11	100	NA[b]
Permanent (or at least daily) monitoring or control by hierarchy	6	40	8	40	4	33	5	42	1.00[a]
Following or monitoring computerized process (Production Process)	8	53	11	52	8	67	8	67	NA[a]
Workload necessities									
Exceeding normal hours	5	33	11	52	4	33	7	58	0.38[a]
Shortening or skipping a meal	3	20	0	0	2	18	0	0	NA[b]
Missing a break	1	7	0	0	1	9	0	0	NA[b]
Working too fast for an operation that requires care	7	47	5	25	5	45	3	27	0.63[b]
Abandoning a task to do another unplanned activity	3	20	2	11	2	18	2	18	NA[b]
NOT completing an activity	3	20	2	10	2	18	1	9	1.00[b]

NA: Not Applicable.
[a] Mac Nemar exact test for 12 operators who responded for both cycle times.
[b] Mac Nemar exact test for 11 operators who responded for both cycle times.

Table 4
Subjective assessment of physical ergonomic risk factors for two cycle times reported by truck assembly workers.

	All respondents				Same respondents				P-value	Reference Data[c] (n = 362)	
	Cycle time A (n = 15)		Cycle time B (n = 21)		Cycle time A		Cycle time B				
	n	%	N	%	n	%	n	%		n	%
Repeating same action (≥4 h/day)	4	27	3	14	2	17	2	17	1.00[a]	139	39
Neck flexion (>4 h/j)	3	20	2	10	2	17	1	8	1.00[a]	137	38
Neck extension (>4 h/j)	0	0	0	0	0	0	0	0	NA[a]	8	2
Arms at or above shoulder level (≥2 h/day)	5	33	5	24	3	25	2	17	1.00[a]	55	15
Arms abducted (≥2 h/day)	8	53	11	52	5	42	4	33	1.00[a]	81	22
Holding the hand behind the trunk (≥2 h/day)	0	0	2	10	0	0	2	17	NA[a]	21	6
Elbow flexion/extension (≥2 h/day)	12	80	13	62	9	75	7	58	0.63[a]	173	48
Pronation/supination movements (≥2 h/day)	9	64	8	38	6	55	3	27	0.38[b]	95	26
Putting elbow on the rigid surfaces (≥2 h/day)	1	7	2	10	1	8	1	8	NA[a]	83	23
Wrist bending in extreme postures (≥2 h/day)	7	47	11	52	5	42	5	42	1.00[a]	188	53
Pressing with the base of the palm (≥2 h/day)	5	33	1	5	4	33	0	0	0.13[a]	48	13
Holding tools or objects in a pinch grip (≥2 h/day)	11	73	9	43	8	67	5	42	0.25[a]	104	29
Use of vibrating hand tools (≥2 h/day)	6	40	8	38	4	33	4	33	1.00[a]	84	23
Back Flexion/twisting (≥2 h/day)	15	100	15	75	11	100	8	73	NA[b]	198	55
Back Flexion/twisting (≥4 h/day)	2	13	0	0	2	18	0	0	NA[b]	41	11
Carrying 1–10 kg (≥4 h/day)	4	27	3	14	3	25	2	17	1.00[a]	31	10
Carrying 10–25 kg (≥4 h/day)	2	13	0	0	2	17	0	0	NA	9	3
Handling 1–4 kg (≥4 h/day)	7	47	6	29	5	42	3	25	0.50[a]	64	20
Handling loads >4 kg (≥4 h/day)	3	20	3	14	1	8	1	8	NA[a]	36	11
Push pull (≥2 h/day)	3	20	2	17	2	17	2	17	1.00[a]	76	21

NA: Not Applicable.
[a] Mac Nemar exact test for 12 operators who responded for both cycle times.
[b] Mac Nemar exact test for 11 operators who responded for both cycle times.
[c] Data from epidemiologic study among blue-collar operators in the manufacturing and assembly industries in a French region (Pays de la Loire).

Table 5
Perceived physical exertion force ≥15 according to Borg scale reported by truck assemblers on Friday and Monday for three types of working day workload.

	Friday						Monday					
	Low workload workday		Typical workday		High workload workday		Low workload workday		Typical workday		High workload workday	
	n	%	n	%	n	%	n	%	n	%	n	%
Cycle Time A (n = 15)	1	7	3	20	9	60	0	0	3	20	10	67
Cycle Time B (n = 20)	1	5	2	10	12	60	0	0	2	13	12	75

One subject was absent at the time of interviews for cycle time B.

working day on Friday and Monday. More than 60% of the operators reported perceived physical exertion equal or greater than 15 (hard) for high workload days on Friday and Monday for both cycle times. There was no significant difference between perceived physical exertion on Friday and Monday. The situation was similar for both cycle times.

3.3. Psychosocial factors

Table 6 presents psychosocial factors, including high psychological demands, low decision latitude and low social support. In this study, 79% of operators in cycle time A and 90% of the subjects in cycle time B reported low decision latitude. Psychological demands were also reported to be relatively high in both cycle times. Therefore the job strain that was derived from these two dimensions was 43% for cycle time A and 62% for cycle time B. Fig. 1 shows the patterns of job strain between study populations in both cycle times. It was shown that 40% of the people in cycle times A and 62% of them in cycle time B were classified in the high strain zone (lower right), 33% in cycle time A and 29% of people in cycle time B in the passive zone (lower left), 13% and 10% of people in cycle times A and B in the low strain zone (upper left) and 7% in cycle time A in the active zone (upper right). None of operators in cycle time B were classified in active zone. Low decision latitude and high psychological demands of reference data were reported by 70% and 41%, respectively. Another dimension investigated was social support. Twenty-five percent of subjects in cycle time B reported low social support whereas 53% of operators in cycle time A complained of low social support. Iso-strain was reported by 10% of subjects in cycle time B and 21% of subjects in cycle time A. Mac Nemar's exact test did not show any difference between the two cycle times. Low social support was reported to be higher in reference data than in cycle time B (48% of people complained low social support). Iso-strain was therefore higher in the reference data than in truck assembly operators for cycle time B.

4. Discussion

The purpose of this study was to evaluate subjectively three dimensions of the ergonomic approach in a truck assembly manufacturing plant. Physical, organizational and psychosocial risk factors were evaluated by self-reported methods for the two cycle times (11 min and 8 min). The operators also reported their musculoskeletal symptoms. The results of the study showed that musculoskeletal symptoms were more frequent in the upper limbs (shoulders/elbows/wrists) and lower back. The prevalence of symptoms in the lower limbs was low. Although the operators reported fewer symptoms in cycle time B (8 min) than in cycle time A (11 min), the results were not significantly different for the same respondents in the two cycle times. The reason might be related to the low number of subjects who were included in the study. Upper limb and lower back symptoms were frequent complaints in other studies in automotive assembly industries. Johansson et al. reported that the neck, shoulders, lower back and hands were complained of frequently by truck assemblers although the symptoms for short (6 or12 min) and long (20 or 45 min) cycle times were reported to be similar (Johansson et al., 1993). Engstrom et al. reported a high prevalence of musculoskeletal symptoms in the Volvo manufacturing industry, with the exception of the lower limbs (Engström et al., 1999). Widanarko et al. showed that neck/shoulder, wrists, arm/elbow and lower back were most common areas of complaint in a study of 3000 participants with different occupations (Widanarko et al., 2014, 2015; Widanarko, 2013). All these results are consistent with our findings and indicate the prevalence of upper limb musculoskeletal disorders in manufacturing assemblers.

Exposure to shoulder risk factors is common in automotive manufacturing assembly, particularly in the truck assembly industries. When comparing this study with epidemiologic reference data in France, shoulder risk factors were more frequent in our study. This was to be expected because the tasks to be accomplished in truck assembly require elevation of the arms in excess of 60° depending on truck size. In the study by Johansson et al., 39% of truck assemblers reported arm elevation above shoulder level (Johansson et al., 1993). Engstrom et al. reported that 35% of assembly operators were exposed to arm elevation above shoulder level two hours or more per day (Engström et al., 1999). In his ergonomic evaluation by direct measurement methods for forty-three types of work, Hansson et al. reported the highest levels for shoulder risk factors (arm elevation) among automotive assemblers (Hansson et al., 2010). All of these results are consistent with our results as the study population reported 33% and 24% arm elevation (>90°) for cycle times A and B, respectively. Arm abduction (<90°) that represents moderate exposure to shoulder risk factors was reported by more than half of the operators in both cycle times. To our knowledge there are few self-reported studies reporting moderate exposure to shoulder risk factors. However, accumulation of moderate and high workload shoulder risk factors will generate shoulder disorders.

Exposure to elbow and hand/wrist risk factors was also common, although it was reported less frequently for cycle time B. Elbow flexion and pronation/supination of the forearm were relatively high in both cycle times. Many tasks in assembly workstations required the use of electrical or manual screwdrivers and these actions involved pronation/supination of the elbows. Furthermore, the elbow is usually bent during assembly tasks. Bending the wrist usually happened when operators used handheld power tools to tighten screws and nuts. Other tasks such as

Table 6
Subjective assessment of psychosocial risk factors for two cycle times reported by truck assembly workers.

	All respondents				Same respondents				P-value	Reference Data[c] (n = 362)	
	Cycle time A (n = 15)		Cycle time B (n = 21)		Cycle time A		Cycle time B				
	n	%	N	%	n	%	n	%		n	%
High psychological demands	8	53	13	62	6	50	8	67	0.69[a]	147	41
Low decision latitude	11	79	19	90	9	75	11	92	0.50[a]	249	70
Job strain	6	43	13	62	5	42	8	67	0.38[a]	98	28
Low social support	8	53	5	25	5	45	5	45	NA[b]	170	48
Isostrain	3	21	2	10	2	18	2	18	1.00[b]	52	15

NA: Not Applicable.
[a] Mac Nemar exact test for 12 operators who responded for both cycle times.
[b] Mac Nemar exact test for 11 operators who responded for both cycle times.
[c] Data from epidemiologic study among blue-collar operators in the manufacturing and assembly industries in a French region (Pays de la Loire).

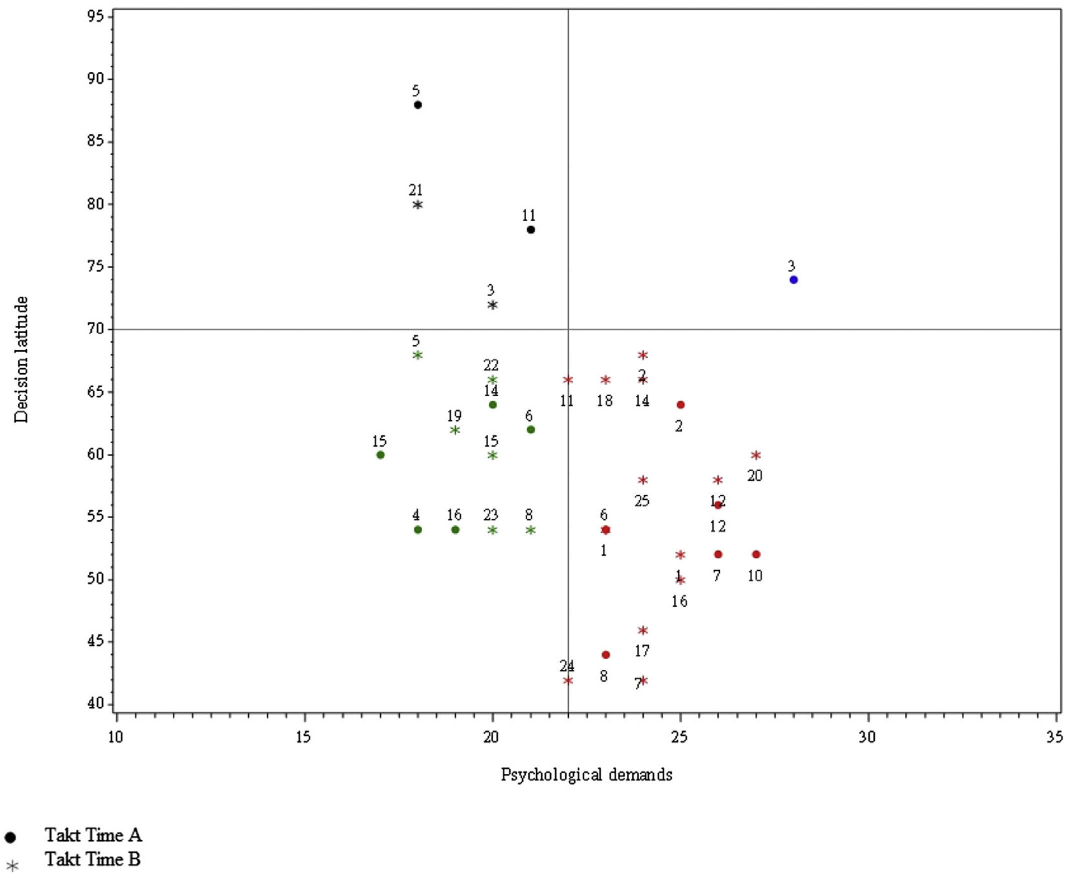

Fig. 1. Job strain derived from psychological demand and decision latitude dimensions for two Takt times.

pushing a wagon also involved wrist bending. The operators usually gripped light and thin objects (1–2 kg) such as supports, pumps etc with pinching or squeezing actions. These activities contain main ergonomic risk factors for elbows/hands/wrists and more than half of the subjects reported exposure to these risks. Exposure to elbow and hand/wrist risk factors in reference data was as frequent as our findings in truck assemblers, but pronation/supination movements and pinching grip were less often reported. Other studies reported a high prevalence of elbow/hand pain in automotive assemblers because of workloads and few attempts to reduce elbow/hand risk factors. When using screwdrivers routinely, the screwdriver's weight and reaction forces produced at the end of tightening were reported to be the main reasons for elbow/hand/wrist complaints in previous studies (Engström et al., 1999; Byström et al., 1995; Zetterberg et al., 1997). Other reasons for the high prevalence of elbow/hand/wrist disorders might be related to accumulative working with hands during the working day. Most claims involving musculoskeletal illness in an European truck assembly plant over the last 20 years were related to elbow disorders.

Back flexion for more than two hours/day was reported by all subjects in cycle time A and more than half of the operators in cycle time B. Although extreme back flexion occurred less frequently for truck assembly, the operators habitually bent their backs forward slightly, along with exertion force for performing their tasks. Back risk exposure reported by the operators was fairly high and it seems that they overestimated their exposure. However, the prevalence of lower back symptoms was also high in the study population and in the reference data. A possible reason for back risk factors is handling heavy parts and components. In our study the operators usually handled components ranging from 5 kg to 15 kg, depending on the workstation. About half of the operators in both cycle times handled materials or tools for more than 4 h/day. The percentage of material handling was reduced in the new cycle time, although the difference was not significant. As reported in other studies, handling heavy components, frequent standing/walking with little opportunity to sit down are other reasons for the high prevalence of low back disorders among truck assemblers that we also observed in our study (Fredriksson et al., 2001; Johansson et al., 1993; Engström et al., 1999). Perceived physical exertion force was relatively similar in both cycle times. However, for a typical workday perceived exertion force (≥15) was reported more frequently in cycle time A than in cycle time B. Other studies showed that the Borg rating is not only an index of physical activity but also an indicator of psychological factors (Borg, 1990; Josephson et al., 1996). Our hypothesis in this study was that operators might perceive an increase in physical exertion on Fridays compared to Mondays. However, we found that the perceived physical exertion was identical on Fridays and Mondays for both cycle times. The exertion perceived on high workload days was much more than on other types of work day. A high load workday was defined in this study as a day when the operators had to assemble difficult truck options. Therefore, the distribution of truck options in the assembly line should be more carefully considered by engineers. Loading up the line imbalance by truck options might expose operators to extra perceived physical exertion (fatigue).

The operators in cycle time B reported less exposure to physical risk factors than those in cycle time A. Statistical tests did not show a significant difference, which might be related to the small numbers in the study population. The possible reasons why the operators' subjective assessment decreased in the new cycle time might be related to the technical/engineering improvements, reorganization and new design workstations. Four new workstations were created in the new system and high risk tasks were distributed between different workstations. Furthermore, some technical improvements such as using a lifting tool at the mudguard station and changing the design of the unlocking system in the "bumper assembly on chassis" station were incorporated which also reduced risk factors in the new system. Although the new cycle time reduced the content of each workstation because of shorter time, performing fewer unacceptable tasks (high risk) meant that the operators had felt better in the new cycle time. Furthermore, the new concept was not completely changed and most alterations were related to balancing, reorganization and modification.

In this study organizational characteristics were evaluated according to two main categories, i.e. work rate and workload. The assemblers reported more complaints regarding work rate compared to workload. Operators reported a high percentage of work rate imposed by mandatory use of tools, screwdrivers, lifting devices, etc, in both cycle times. In an assembly plant, assemblers must use different tools (sometimes more than 8 screwdrivers and torque wrench during one cycle time) and this causes extra movement and memorization of use of the right tool. Furthermore, following the standards and assembly procedures was reported by nearly all of the operators in both cycle times. For each workstation there were approximately three truck options with different assembly procedures that the operators had to follow. Each assembler worked in at least four different workstations during the day, and therefore had to memorize and follow many instructions regarding each truck option and workstation. The combination of these organizational constraints with physical risk factors could increase the risk of musculoskeletal disorders (Widanarko et al., 2014, 2015). However, the organizational factors that were imposed by workload such as exceeding normal hours of work, working too fast and unplanned activity were reported to be low in both cycle times. In contrast to another study where time constraints were reported by assemblers, in our study the operators were satisfied with the time organization as few subjects reported missing break, having short meals or skipping meals, working too fast, etc. The possible reason for this was the structure and organization of the assembly line in our study in which each workstation had its own support post (known as variant position in the factory) for helping the operators (Widanarko et al., 2014; Johansson et al., 1993).

Various reports have shown an association between psychosocial risk factors at the workplace and musculoskeletal symptoms (Widanarko et al., 2014, 2015; Widanarko, 2013; Johansson et al., 1993; Engström et al., 1999). In our study the operators in both cycle times reported high levels of psychological demand and low decision latitude. The reference data also showed that low decision latitude and high psychological demand were common psychosocial factors in blue-collar operators in France. However, the percentage reported was less than in our study. In the assembly line, there is naturally a low possibility for active learning or motivation for creativity and developing new behaviors. Operators' stress and strain is therefore increased due to low decision latitude and high psychological workload. Job stress and strain in the workplace could influence musculoskeletal disorders due to muscle tension and result in behavior changers as workers might report more musculoskeletal symptoms (Carayon et al., 1999; Bongers et al., 2002). On the other hand, social support, another dimension of psychosocial factors, was reported to be satisfactory by more than 70% of the subjects in cycle time B. This dimension was developed in the new cycle time and it was better compared to reference data. It is interesting to note when this dimension was considered, the final calculated percentage of iso-strain decreased significantly and it was lower than the reference data. It can be concluded that it is possible to reduce strain by good social support, although, due to the nature of operations and processes in the assembly plant, it is difficult to match high decision latitude and to decrease psychological demands. In general the importance of managing psychosocial risk factors is highlighted in other studies because the combination and interactive effect of this risk factor along with high physical workload not only increase the risk of musculoskeletal outcomes but also influence productivity and the quality of products (Falck and Rosenqvist, 2012).

5. Conclusions

The findings of this study showed that potential physical risk factors mainly involving the upper limbs were significant among truck assembly operators. Most subjects reported risk factors for elbows, shoulders and hands/wrists, and the percentages of WR-MSDs symptoms reported in the upper limbs were also considerable. Perceived physical exertion increased on the high workload working day. However, it was not considerable on the typical and low workload working days. Perceived physical exertion was not different for Mondays and Fridays for assemblers. Our results showed that, although low decision latitude and high psychological demands were common psychosocial risk factors among our subjects, good quality social support reduced the strain. Reorganization with taking into account ergonomic approach reduced musculoskeletal symptoms and physical risk factors in the new cycle time but the difference from the initial concept was not significant.

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