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Industrial development of car disassembly - ergonomics and system performance

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An integrated analysis of ergonomics and time consumption in Swedish 'craft-type' car disassembly

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Abstract

Car disassembly is at the edge of extensive rationalisations due to increased legislative demands for recycling. This study focused on (1) assessing current mechanical exposures (physical work loads) for comparison with future rationalised systems, with particular emphasis on time aspects, (2) analysing disassembly work in terms of time consumption and exposures in constituent tasks as defined by a loss analysis technique, and (3) predicting the consequences of car disassembly rationalisation for mechanical exposures. The study showed that disassembly implied pronounced circulatory loads, and that more walking and higher lumbar peak loads were found than in studies of assembly work. Value-adding tasks comprised 30% of the total working time, and implied higher postural exposures for the head, arm, trunk and wrist, as well as less opportunities to recover, as compared to non-value-adding tasks. Organisational-type rationalisations can be expected to increase the time spent in value-adding work, thus increasing local exposures for the average worker, while a concurrent increase in mechanisation level might reduce circulatory exposures, the amount of walking, and peak lumbar loads.

Keywords: Rationalisations; Disassembly production systems; Mechanical exposures

1. Introduction

Swedish car disassembly companies have recently been investigated in a qualitative explorative study (Kazmierczak et al., 2004). Dismantlers, manufacturers and authority stakeholders described current production systems as 'craft-type', facing modest competition and showing good profitability. Work was described to contain a wide variety of tasks and considerable periods of set-up time. The respondents did not report any major musculoskeletal problems in the trade or any particular long-term sick leave. This statement could not, however, be validated due to the lack of specific disorder databases for this occupational group. While 'craft-type' production may offer more variation and autonomy to the individual operator than serial mass production (Eklund and Berggren, 2001), it might also imply larger whole-body exposures and higher peak loads due to its low level of mechanisation.

A new EU directive (The European Parliament, 2000/53/EU) now restricts the use of some materials and stipulates minimum reuse and recovery rates for end-of-life vehicles (ELVs, i.e. cars that have reached the end of their useful life). Thus, wastes from ELV must be reduced to 15% of the total car weight by the year 2006 and to 5% by 2015. This implies disassembly of more parts and materials that are not commercially attractive today. For production to stay profitable in spite of

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increased time spent in non-value adding tasks, comprehensive rationalisations are anticipated. During recent decades, most car assembly plants ('forward factories') have adopted lean production strategies (Womack et al., 1990; Docherty and Huzzard, 2003; Metall Report, 2003). A similar rationalisation is now expected in the 'backtrack factories' processing large volumes of ELVs (Kazmierczak et al., 2004).

Forward car factories have a long tradition of rationalisations to improve productivity, quality and profitability. Radical rationalisations may lead to excessive job strain and possibly to an increased occurrence of musculoskeletal disorders (Landsbergis et al., 1999). A common major aim in rationalisation is to make more efficient use of time through changes in work organisation. This may be pursued by a work intensification (Brödner and Forslin, 2002), e.g. elimination of rest pauses and a reliance on short-cycle tasks in serial processes. On the other hand, technological rationalisations may reduce whole body exposures and peak loads through increased mechanisation (Attebrant et al., 1995).

The resulting changes in mechanical exposure may be complex, and may be anticipated to cause for example a reduction in rest pauses. Thus, a working day may become less 'porous' in the sense that there are fewer opportunities to recover physically and mentally. Changes in 'porosity' occur in the time domain of exposure, as opposed to the intensity or level domain. While metrics describing exposure levels are often discussed in the ergonomic literature, there is a paucity of methods and parameters for assessing changes in time aspects of exposure (Wells et al., 1997; Mathiassen and Christmansson, 2004).

This study was a follow-up of our explorative study (Kazmierczak et al., 2004). It aimed at (1) assessing current mechanical exposures (physical work loads) for comparison with future rationalised systems, with particular emphasis on time aspects, (2) analysing disassembly work in terms of time consumption and exposure in constituent tasks as defined by a loss analysis technique, and (3) predicting the consequences of car disassembly rationalisation for mechanical exposures.

2. Material and methods

2.1. Subjects

The 13 car disassembly plants from which chief managers had participated in our previous exploratory interview study (Kazmierczak et al., 2004) were approached again; five of them expressed interest in engaging in the present follow-up study. A total of 10 healthy disassembly male workers (two from each company) participated (median age 39 yr (range 21–57 yr), weight 78 kg (range 73–88 kg), stature 177 cm (range 165–186 cm)). All subjects were right-handed and had a minimum of 1 year of work experience in car disassembly (1–10 yr).

2.2. Methods

Data were collected during an ordinary working day by means of video recordings and direct technical measurements of mechanical exposure. Work activities were obtained in real-time from the videos and task-specific exposures were obtained from the direct measurement files as described below.

2.2.1. Work activities

The average video recording time was 6.15 h (range 5.2–6.5 h) for the 10 subjects. Recordings were interrupted during lunch and two coffee breaks (1–2 h per work day). Work activities were documented for all recorded hours.

Categorisation of work tasks in the job was based on an exhaustive list of coded work activities. The categorisation scheme was set up with the assistance of an experienced engineer (Table 1). The task categories were defined so as to differentiate between necessary work (value-adding, direct work) and losses according to the so-called zero-based analysis (Engström and Medbo, 1997). Periods of disturbances caused by the researchers were identified and excluded from further analyses.

The activities were grouped into four main task categories (Table 1): (I) *direct work* (value-adding tasks including disassembly); (II) *material/tool handling* (including handling car parts and tools); (III) *casual tasks* (e.g. administrative tasks, walking without handling, work-related communication and cleaning); and (IV) *unplanned breaks*, including non-organised pauses and disturbances.

To secure a good reliability of the activity assessment, two researchers initially made independent analyses of 4 h of video recordings. Minor differences were detected, which were resolved in consensus discussions. Using the refined activity definitions as a basis, only one researcher proceeded with the analysis of the remaining recordings.

2.2.2. Mechanical exposures

Inclinometers were used to record the sagittal flexion/extension angles of the head and trunk and the right upper arm elevation relative to the line of gravity. The inclinometers were placed on the subjects according to Hansson et al. (2001). Zero angles were assessed from recordings of a relaxed reference position made prior to work (Hansson et al., 2001).

Wrist positions in the flexion-extension and ulnar-radial planes were recorded using biaxal electrogoniometers (XM65, Penny and Giles Biometrics Ltd.,

Table 1
Classification of tasks and work activities

Tasks	Activities	Description
Direct work	Disassembly	Principal activities in disassembly, e.g. unscrewing and screwing parts, hammering, drilling; includes reaching for a tool during disassembly
Material/tool handling	Handling of tools	Any tool activity, e.g. mounting, fixing, preparing, holding tools; walking with a forklift; adjusting car lift; fixing gloves
	Handling of parts	Placing a part in stock; manual inspection of parts, placing parts on the forklift; packaging
Casual tasks	Administration–VDU	Computer work; printing labels for registration of parts; looking into bar code folder
	Administration—other	Writing notes on car parts; placing labels on parts; writing numbers on cars; visual and manual inspection of car
	Walking without materials handling	
	Work–related communication	Two or more workers discussing issues related to the work
	Cleaning	Preparation of the workplace; cleaning at the end of the workday; spreading sawdust; trashing materials
Unplanned breaks	"Disturbances"	Waiting for a car to be placed on a lift; looking for, e.g. tools, parts, a phone
	Other pauses	Smoking; private phone calls; making coffee; hand cleaning and drying; social communication with co–workers

Gwent, UK; Hansson et al., 1996). The two goniometer end-blocks were attached to the dorsal face of the hand at the third metacarpal bone and to the distal dorsal side of the fully pronated forearm, respectively. The recordings of work tasks were preceded by a mobility test and a reference position recording as described by Hansson et al. (1996). Inclinometer and goniometer data were sampled at 20 Hz per channel using data loggers (Logger Teknologi HB, Åkarp, Sweden; Hansson et al., 2003). Registrations were made for an average period of 8.3 h per worker (range 7.5–9 h). Both recordings included lunch and coffee breaks. Goniometer measurements were not possible in one subject for technical reasons. Off-line, data were transferred to a personal computer, processed and analysed. Postures and movements for each activity category were obtained by synchronising video and exposure recordings (Christmansson et al., 2002; Forsman et al., 2002).

For the purpose of estimating 'peak' loads on the low back, the situations judged to be most critical to the back were selected from the video recordings of each worker and processed in a biomechanical model of the lumbar spine (Norman et al., 1998).

Exposure at the job level was also assessed by the following parameters: heart rate (HR), number of steps and low back peak loads. HR was recorded during the entire working day (breaks included) using a telemetric electrocardiograph system logging an average value every 5th second (Polar Vantage NV ™, Polar Electro OY, Finland; Bao et al., 1996). The overall HR average throughout the work day and the corresponding heart rate ratio (HRR) were assessed. HRR was calculated as $100*(HR_{work}-HR_{rest})/(HR_{max}-HR_{rest})$, where HR_{max} was calculated as $210-(0.662 \times \text{age})$ (Bruce et al., 1974) and HR_{rest} was set to 60 beats per minute (bpm) (Wigaeus Hjelm et al., 1995). The total number of steps taken during the entire working day was measured with a pedometer (Fitty 3 Electronic, Uttenreuth, Germany; Selin et al., 1994).

Basic observations were made on the basis of the video recordings of product variation (old, worn out ELV cars, or newer insurance cars) and production cycle time. Both measures are simple expressions of 'similarity', i.e. the extent to which the same operations are repeated over and over again in the job (Moore and Wells, 1992; Kilbom, 1994; Mathiassen, 2003).

For the purpose of estimating 'peak' loads on the low back, the situations judged by the first author to be most critical to the back were selected from the video recordings of each worker and processed in a biomechanical model of the lumbar spine to give the compression force, the reaction shear force, and the moment at the L4/L5 joint (Norman et al., 1998). Inclinometer and goniometer data on arm elevation, head and trunk flexion/extension and wrist postures were processed further to give the exposure parameters shown in Table 2.

Posture levels were expressed through the 10th, 50th, 90th and 99th percentiles of the cumulative posture distribution, that is the APDF (Jonsson, 1982). Limits for "neutral" and "extreme" postures of the head, trunk and arm were set according to the draft standard on working postures (European Standard, 2002). For wrist postures, limits were based on normative data on the maximal movement envelope (Platzer, 1984). Together, the set of parameters in Table 2 operationalise all three conceptual dimensions of exposure: level, frequency and duration (Winkel and Mathiassen, 1994; Mathiassen and Christmansson, 2004).

Table 2
Exposure variables and parameters for posture and velocities, based on inclinometer and goniometer recordings

Concept	Operational variables	Definition of parameters[a]
POSTURE		
LEVEL		
General distribution	Percentiles of the cumulative posture distribution	10th, 50th, 90th, 99th
Rest	Percent time in a neutral posture	*Neutral* Arm: $<20°$ *and* velocity $<5°/s$ Head: 0–20° *and* velocity $<5°/s$ Trunk: 0–20° *and* velocity $<5°/s$ Wrist: inside an ellipse with major flexion axis–20 to 20° *and* minor deviation axis–10 to 10°, *and* velocity $<5°/s$
Extreme	Percent time in an extreme posture	*Extreme* Trunk: $<0°$, *or* $>60°$ Arm: $>60°$ Head: $<0°$, *or* $>60°$ Wrist: flexion $<-60°$ *or* $>60°$; *or* deviation $<-10°$, *or* $>30°$
FREQUENCY		
Micro–recovery frequency	Number per minute of substantial periods in a neutral posture	*Substantial* Period duration > 3s *Neutral* As above
VARIATION		
Level diversity	Percentile range	Difference 10th–90th percentile
VELOCITY		
LEVEL		
General distribution	Percentiles of the cumulative velocity distribution	10th, 50th, 90th, 99th
Low (static periods)	Percent time at low velocities for substantial periods	*Substantial* Period duration > 3s *Low* Trunk: $<5°/s$ Arm: $<5°/s$ Head: $<5°/s$ Wrist: flexion *and* deviation $<5°/s$
High	Percent time at high velocities	*High* Trunk: $>90°/s$ Arm: $>90°/s$ Head: $>90°/s$ Wrist: flexion $>90°/s$; deviation $>60°/s$

[a]Positive angle directions correspond to increasing head and trunk flexion, arm elevation from the line of gravity, palmar wrist flexion, and ulnar wrist deviation.

2.2.3. Statistics

Group results were described by medians. Exposure differences between work tasks were analysed using Friedmann's non-parametric statistical test for repeated measures, followed by a post-hoc test for the specific exposure differences between direct work and each of the other three tasks (Siegel and Castellan, 1988). In the statistical analysis of the back posture percentiles, time in neutral, time in extreme, and micro-recovery frequency were excluded in two subjects for technical reasons.

3. Results

3.1. Job exposures

In general, an operator was responsible for all dismantling tasks on a particular car. About 25% of the total working time was devoted to old ELV, while newer 'insurance' cars, typically crashed in accidents, occupied the remaining time. Based on our video recordings, the mean cycle time while disassembling an

ELV car was about half an hour while insurance cars took 3–16 h to dismantle, depending on the number of valuable parts.

Job exposures according to the technical recordings are shown in Table 3.

3.2. Task distribution

Fig. 1 illustrates the task distribution in the disassembly job. Value-adding tasks (direct work) comprised about 30% of the total working time. The largest proportion of the time, almost 40%, was devoted to material and tool handling, i.e. tasks that were an integrated part of work procedures but did not add to the value of the product.

3.3. Task exposures

3.3.1. Posture percentiles

Post-hoc Friedmann tests showed that direct work (value-adding tasks) implied a more pronounced arm elevation at the 50th, 90th and 99th percentiles than casual tasks and unplanned breaks (in both cases $p<0.01$, Fig. 2). The head was bent backward more than 20° during 10% of the value-adding working time (Fig. 2). The median head flexion angle during value-adding tasks was 30° as compared to 6° during unplanned breaks ($p<0.01$). For the trunk, direct work implied more extension at the 10th percentile level than during unplanned breaks and casual tasks (in both cases $p<0.05$, Fig. 2). Trunk flexion was also more pronounced at the 90th percentile level during value-adding tasks than during unplanned breaks ($p<0.01$) and casual tasks ($p<0.05$). Value-adding tasks tended to imply more ulnar deviation and flexion of the wrist than casual tasks and unplanned breaks, although a statistical confirmation was obtained only for the 90th ($p<0.05$) and 99th ($p<0.01$) deviation percentile and 50th and 99th flexion percentile ($p<0.05$; difference between value-adding and casual tasks).

Fig. 2 also illustrates that the posture range, i.e. the difference between the 10th and 90th posture percentiles, was larger in value-adding work than in casual tasks and unplanned breaks for all investigated body parts (in both cases $p<0.01$).

3.3.2. Time in neutral (rest) and extreme postures

Fig. 3 (left panel) shows the proportion of time spent in neutral postures with, at the most, a very slow movement for the arm, head, trunk and wrist. Value-adding tasks implied the shortest time spent in a neutral posture for all investigated body regions. However, strong statistical support was found only for a difference between value-adding tasks on the one hand, and casual tasks and unplanned breaks on the other (arm, $p<0.001$; trunk, $p<0.01$; head, $p<0.01$).

The right panel in Fig. 3 illustrates the proportion of time spent in extreme postures for the arm, head, trunk and wrist. For the arm, direct work was associated with a longer time spent in extreme postures than casual tasks and unplanned breaks ($p<0.01$). For the head, a significant difference was found between value-adding tasks and material handling ($p<0.05$), as well as value-adding and casual tasks ($p<0.01$).

3.3.3. Velocity percentiles

The angular velocity distributions for the arm, head, trunk and wrist for each task are illustrated in Fig. 4. Value-adding tasks tended to imply higher velocity percentiles for all investigated body regions. Significant differences were found between value-adding tasks and unplanned breaks and casual tasks for the arm 10th and 99th percentiles ($p<0.01$ in both cases). For the wrist significant differences were found between value-adding tasks vs. casual tasks and unplanned breaks for the 10th and 90th percentiles, both in deviation and flexion–extension ($p<0.05$).

3.3.4. Time at low and high velocities

Proportions of time spent at low and high velocities are shown in Fig. 5. Low velocities (i.e. "static" postures) occurred less in value-adding tasks than in the other tasks, while unplanned breaks showed the largest occurrence of low velocities (difference between value-adding and unplanned breaks: $p<0.01$ for the arm, trunk and wrist; difference value-adding vs. casual tasks: $p<0.01$ for the arm and $p<0.05$ for the trunk).

Value-adding tasks showed a larger occurrence of high velocities than unplanned breaks for the arm ($p<0.01$). There was also a high-velocity difference between value-adding and casual tasks for wrist deviation and flexion-extension (in both cases $p<0.01$).

3.3.5. 'Micro-recovery' frequency

Fig. 6 shows the frequency of long periods spent in a neutral posture ('micro-recovery' frequency; for definition see Table 2). According to this parameter, value-adding tasks provided fewer recovery periods than unplanned breaks for the head ($p<0.01$) and trunk ($p<0.05$). A difference for the wrist was found between value-adding and casual tasks ($p<0.01$).

4. Discussion

The main findings of this study were that (1) direct work (value-adding tasks) comprised only 30% of the total working time, (2) value-adding tasks implied higher postural exposures of the head, arm, trunk and wrists compared to non-value-adding tasks, (3) circulatory exposures and walking were substantial and, (4) high low back peak loads occurred.

Table 3
Job exposure. Group medians and range (in brackets, $n = 9$–10) of (Table 3(a)) HHR, number of steps and peak lumbar load parameters, and (Table 3(b)) postures and velocities for the arm, head, trunk and wrist

(a)	Median	(Range)
Heart rate ratio (HRR%)	31	(20–45)
Number of steps	1668	(874–2302)
Lumbar peak loads		
Compression force, N	3645	(2890–6735)
Reaction shear force, N	526	(318–827)
L4/L5 moment, Nm	205	(142–386)

(b)

Postures	Arm	Head	Trunk	Wrist dev		Wrist flex
10th percentile, °	13.9 (8.5–24.3)	−13.7 (–22.0 to −0.22)	−6.0 (−11.5 to −0.08)	−10.8 (−39.0 to −5.6)		−27.6 (−52.0 to −12.4)
50th percentile, °	32.0 (22.0–41.5)	19.5 (5.5–38.0)	10.1 (0.3–12.3)	3.6 (–12.4–12.9)		−5.2 (−15.5–3.8)
90th percentile, °	72.1 (52.0–79.2)	53.3 (36.7–60.0)	40.2 (37.4–59.0)	16.3 (8.5–31.1)		11.0 (6.8–25.2)
99th percentile, °	115.0 (87.2–135.0)	75.3 (59.4–82.9)	73.2 (65.3–82.7)	27.4 (20.1–45.2)		37.5 (20.2–42.0)
Time in neutral, %	4.0 (0.5–11.5)	5.0 (2.7–6.8)	9.5 (4.9–21.9)		6.5 (1.5–61.2)[a]	
Time in extreme, %	15.4 (6.2–22.0)	46.5 (39.0–58.2)	27.9 (14.0–51.0)	34.8 (7.2–89.2)		0.5 (0.0–5.9)
Frequency of 'micro–recovery' periods, min^{-1}	0.5 (0.1–1.6)	0.7 (0.4–1.1)	1.5 (0.6–2.5)		1.9 (0.2–3.7)[a]	
Percentile range (10th–90th), °	56.0 (43.5–65.5)	61.1 (55.0–76.0)	47.0 (44.3–65.0)	32.5 (25.7–47.5)		41.9 (23.0–62.8)
Velocities						
10th percentile, °/s	2.4 (1.5–4.2)	2.7 (2.2–3.5)	2.0 (1.3–2.4)	0.9 (0.4–1.4)		1.3 (0.5–1.6)
50th percentile, °/s	23.4 (18.8–35.2)	19.2 (17.0–23.7)	15.1 (13.3–22.8)	9.6 (5.2–16.7)		15.2 (9.5–20.6)
90th percentile, °/s	101.0 (85.4–136.2)	82.5 (70.0–104.0)	69.4 (64.8–86.7)	54.0 (31.1–92.3)		81.1 (48.1–103.2)
99th percentile, °/s	250.0 (204.1–331.7)	204.5 (166.2–266.7)	175.5 (154.0–205.0)	136.0 (86.4–235.0)		220.9 (144.1–266.8)
Time at low velocities, %	1.5 (0.2–4.3)	0.1 (0.0–1.3)	0.8 (0.1–3.0)		4.1 (2.4–13.9)[a]	
Time at high velocities, %	12.3 (8.9–20.2)	8.4 (5.8–12.6)	6.0 (5.0–9.4)	8.3 (2.9–18.4)		8.4 (2.7–12.6)

[a]Both wrist deviation and flexion were used to compute these parameters.

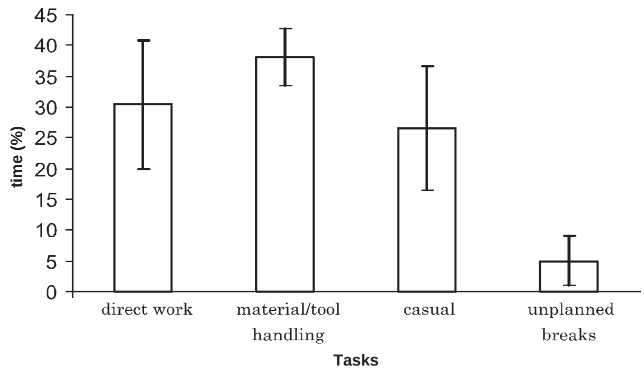

Fig. 1. Mean time proportion (percent) of the four task categories in car disassembly ($n = 10$). Bars show standard deviation between individuals.

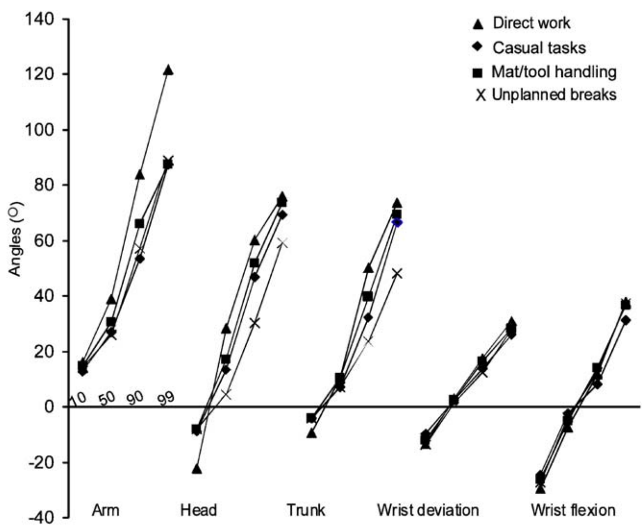

Fig. 2. Group medians of arm, head, trunk and wrist postures ($n = 9-10$) according to task. The 10th, 50th, 90th, and 99th percentiles are shown for all body regions.

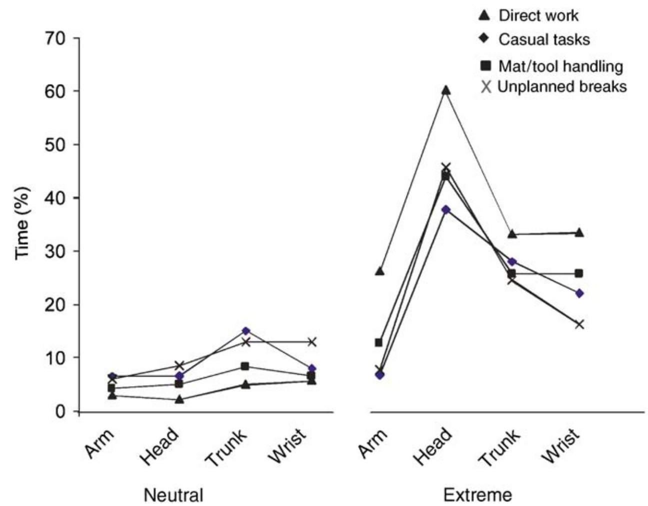

Fig. 3. Group median ($n = 9-10$) of the time proportion (percent) spent in neutral (left panel) and extreme (right panel) postures (cf. Table 2) for arm, head, trunk and wrist, according to task.

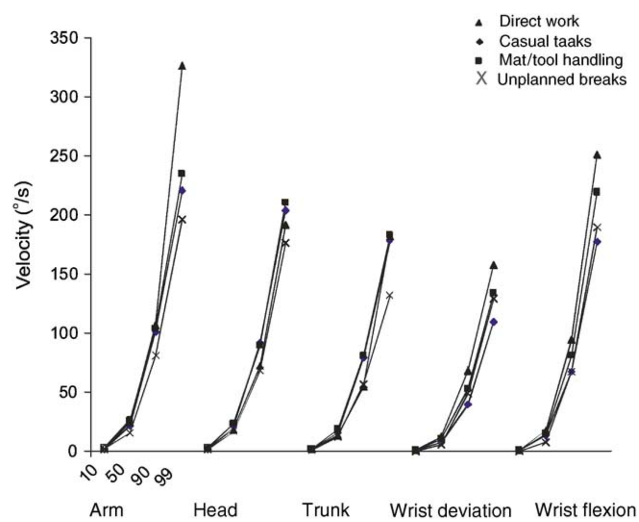

Fig. 4. Group medians of arm, head, trunk and wrist angular velocities ($n = 9-10$) according to task. The 10th, 50th, 90th, and 99th percentiles are shown for all body regions.

4.1. Methodological considerations

4.1.1. Companies and subjects

The Swedish Car Recyclers Association (SBR) comprises two main categories of companies (1) those disassembling mainly crashed "insurance" cars, and (2) those focusing on old worn out ELVs. The present study included companies where, in average, about 75% of the number of disassembled cars were 'insurance' cars and 25% old ELVs (Kazmierczak et al., 2004). Since the disassembly time per car was shorter for old ELVs, the overall proportion of work time for these cars was even less than 25%. However, it will probably increase in the future due to legislative demands implying more dismantling tasks on old ELVs. Although the investigated companies focused on 'insurance' cars, we believe that they were representative even for companies concentrating on old ELVs, in terms of company size and production volume per year. While the duration of a complete car disassembly differed between insurance cars and old ELVs, the relative proportions of different tasks as well as the task exposures were considered by both researchers and subjects to be similar. We thus believe that our results on these variables are representative of both types of cars.

The subjects agreeing to participate in the measurements did not, according to observations by the researchers, differ in any systematic way from the general population working at the investigated compa-

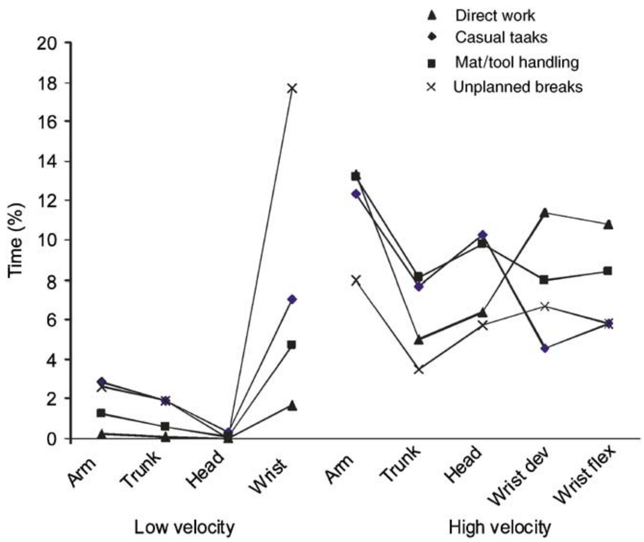

Fig. 5. Group median ($n = 9-10$) of time proportion (percent) spent at low (left panel) and high (right panel) velocities (cf. Table 2) for arm, trunk, head and wrist, according to task.

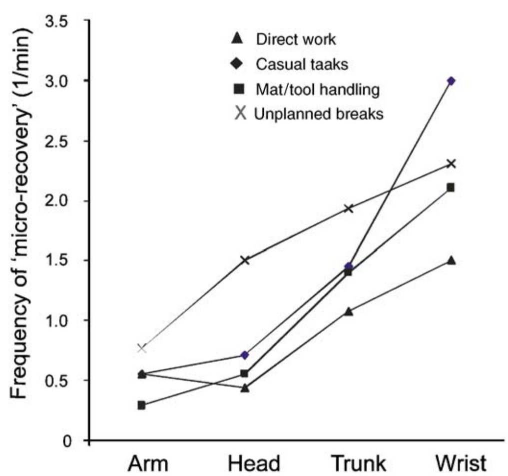

Fig. 6. Group median frequency (min^{-1}; $n = 9-10$) of 'micro-recovery' periods (cf. Table 2) for arm, head, trunk and wrist according to task.

nies with respect to work tasks and personal characteristics. Also, the measurement days were reported to be "typical" working days by all subjects.

4.1.2. Exposure parameters

A major aim of most rationalisations is to make the use of time more efficient (Brödner and Forslin, 2002). Thus, time patterns of exposure can be expected to change in a future rationalisation of car disassembly, in addition to changes in exposure levels, due, e.g. to increased mechanisation levels. Time aspects of exposure, such as frequencies and variation across time, are strongly suspected to be important to the risk of developing musculoskeletal disorders (Winkel and Westgaard, 1992; Kilbom, 1994). Therefore, a thorough description of exposures needs both parameters describing time aspects and those covering level aspects (Wells et al., 1997; Mathiassen and Christmansson, 2004). In studies of rationalisation, it is especially important to emphasise all three main dimensions of exposure: level, frequency and duration (Winkel and Westgaard, 1992; Winkel and Mathiassen, 1994), as well as their interactions. Traditionally, studies of ergonomic epidemiology and interventions have concentrated on the level dimension (e.g. "static", median and peak postures derived from the cumulative exposure distribution, or neutral and extreme postures) (e.g. Winkel and Mathiassen, 1994; Westgaard and Winkel, 1997). Thus, mechanical exposure variables describing time aspects occur to a smaller extent in the literature than metrics for amplitude.

One class of time dimension variables describe the frequency content of exposures. This was documented for instance in power spectrum analysis of postures (Hansson et al., 1996), occurrence of short pauses in the EMG signal (Veiersted et al., 1990), frequency of changes in posture between certain angle sectors (Kilbom and Persson, 1987), and relative time spent without interruption in specific exposure categories, i.e. exposure variation analysis (EVA; Mathiassen and Winkel, 1991). In the present study, the frequency dimension was assessed through the occurrence per minute of "substantial" periods (more than 3 s) in a neutral posture. This parameter was intended to reflect the extent and timing of opportunities to recover. Thus, it resembles the "long gap" frequency parameter suggested for expressing rest patterns in muscle activity (Jensen et al., 1993).

Frequency of posture changes can be one expression of posture "variation". Lack of variation has been pointed out as a risk factor, comprising mechanical as well as psychological elements (e.g. Hagberg et al., 1995). As another simple measure of variation in exposure, we assessed exposure range measured by the difference between the 10th and 90th posture percentiles. Furthermore, the extent of variation was assessed through the proportion of time spent at a low movement velocity for more than 3 s in succession, i.e. in "static" postures.

The task categories were defined according to an engineering approach focusing on value-adding activities vs. losses. Exposure profiles were derived for each major task category in the job. As illustrated below in Section 4.3., this enhances the usability of the results in a proactive intervention approach by facilitating predictions of what might happen in the course of rationalisations that change the time proportions of value-adding and non-value-adding tasks.

4.2. Exposures in current car disassembly

4.2.1. Job exposures

The median HRR for a full day of disassembly work was 31%. According to Jørgensen (1985), 30% of the HRR may be a reasonable upper limit over an 8-h workday for mixed physical work with manual handling tasks. Thus, the present disassembly work implied substantial circulatory exposures. This seemed partly to be due to extensive walking. The disassembly workers walked 1668 steps/h, which is more than previously reported for furniture removers (in average 1381 steps/h; Karlqvist et al., 1994) and truck engine assemblers working in upright positions (739 steps/h; Neumann, personal communication).

The peak reaction shear force for disassembly (526 N) and the peak moment (205 N) were both higher than corresponding results from assembly performed in upright postures: 465 and 182 N, respectively (Norman et al., 1998). The average lumbar peak compression for the disassembly workers (3645 N) exceeded the limit for lifting tasks (3400 N) recommended by NIOSH (Waters et al., 1993).

4.2.2. Task exposures

Task exposures have been documented in terms of posture and velocity percentiles in several settings (e.g. Ohlsson et al., 1994; Åkesson et al., 1997; Balogh et al., 1999; Hansson et al., 2000). However, below we compare our data only with industrial assembly work, emphasising our focus on prediction of future rationalisation effects.

The value-adding tasks in disassembly implied higher arm elevation (Fig. 2) than found in cases of assembly of sewing machines (Bao et al., 1996) and material kitting work (Christmansson et al., 2002). The corresponding arm angular velocities (Fig. 4) were, however, considerably lower in value-adding disassembly compared with material kitting (median velocities 23 and 52°/s, respectively). Explanations for that might be that disassembly work is often performed, e.g. under, inside, or on a car that is placed high up on a lift; this type of work cannot be performed with very fast arm movements.

Disassembly workers had their heads bent backward more than 20° during 10 percent of the value-adding working time (Fig. 2). This may be due to work performed under cars. In general, disassembly seemed to imply less forward flexed head postures than electro-mechanical assembly work (Aarås et al., 1988). However, disassembly was associated with faster movements of the head than material kitting (Christmansson et al., 2002).

The trunk was in a neutral posture half of the time in value-adding disassembly tasks (Fig. 2) while it was more flexed (50th percentile: 14°) in sewing machine assembly (Bao et al., 1996) and material kitting (Christmansson et al., 2002). However, 90th percentile postures of the trunk were more extreme in disassembly than in sewing machine assembly and material kitting. The value-adding tasks in disassembly implied similar 10th and 50th percentile velocities of the trunk as found in material kitting (Christmansson et al., 2002), but a higher 90th percentile velocity.

The time distribution of wrist flexion–extension in disassembly (Fig. 2) was similar to results from automobile assembly workers in a study by Hägg et al. (1997). However, the wrist posture range in disassembly was less than in material kitting (Christmansson et al., 2002). This also applies to wrist velocities (Fig. 4).

Value-adding disassembly tasks implied a shorter time spent resting in a neutral posture than non-value adding tasks for the arm, head, trunk and wrists, and a larger time proportion spent in extreme postures (Fig. 3). Value-adding tasks also exhibited fewer opportunities to recover in a neutral posture without moving (Fig. 6). Low velocities (indicating "static" postures) occurred less in value-adding tasks than in the other activities (Fig. 5). Thus, value-adding tasks implied, in general, to a greater extent than non-value-adding tasks, exposures that are suspected to be associated with risk for developing musculoskeletal disorders.

4.3. Expected rationalisation effects

The investigated companies are likely to survive on the market due to active development plans including, e.g. certification, investments in new technologies, and modernisation (Kazmierczak et al., 2004; http://www.sbrservice.se).

It seems justified to expect that future rationalisations in car disassembly will change the time proportions of activities, including an increase in the time spent in value-adding tasks. In addition, technological changes of this value-adding disassembly work may cause its exposure to closer resemble assembly work. Based on the above reasoning, future value-adding disassembly work may thus imply less awkward postures but higher movement velocities than today, as well as less backward bending of the head and slower head movements. As concerns the back, more bent median trunk postures can be expected, but smaller peak angles and velocities. An increase in the proportion of value-adding tasks towards values observed in manufacturing (Bao et al., 1996; Engström and Medbo, 2003) might lead to less opportunities for recovery, as suggested by the less "porous" exposure profile of direct work as compared to other task categories in the job.

5. Conclusions

We documented exposures in the total job as well as in value-adding and non-value adding tasks in car disassembly—an industry on the edge of major rationalisations. The results supported our hypotheses from a prior explorative study that present disassembly can be characterised as 'craft-type' work, implying high circulatory exposures, a large number of steps and high peak lumbar loads. However, 'local' exposures, estimated as postures and velocities of the trunk, head and upper arm were in general lower than in modern assembly work.

Non-value-adding tasks comprised a large proportion of the working day, and they also offered less risky exposures than value-adding tasks. Future organisational rationalisations are expected to increase the proportion of value-adding tasks. This may increase risk for developing musculoskeletal disorders. On the other hand, technological rationalisations (i.e. increased mechanisation) may lead to reduced cirvulatory stress and lower lumbar peak loads.

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