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A case study of a principally new way of materials kitting—an evaluation of time consumption and physical workload

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Abstract

This article presents a materials kitting case study, using an alternative method for materials kitting: the traditional picker-to-material principle was replaced with a material-to-picker approach. The study was made in a materials supply workshop of an automobile plant shortly after this kitting process had been introduced. The materials kitting was video recorded and the material pickers' physical exposure was assessed using ambulatory equipment to make an integrated registration of muscular activity, work postures and movements. The material pickers assessed work situations perceived as physically stressful. The materials kitting showed improved productivity as compared with other kitting methods. The study indicated that the work situation offered pickers low levels of physical exposure. The picking work was rather light but involved great repetitiveness in arm movements. The material pickers experienced the work as repetitive and having some physically stressful work situations. The integrated analyses showed: (1) that exposure in picking operations was similar to, but could be distinguished from, other work activities and (2) that picking from one type of storage package, Euro pallets, resulted in higher exposure than picking from plastic containers. More studies are needed on the implications of exposure levels in materials picking.

Relevance to industry

In the car industry, customer demands and manufacturers' strategies result in the handling of many components in production systems. Materials kitting is one way to handle this and reduce costs for space and materials in progress. Traditional kitting methods are time consuming, and work-related musculoskeletal problems are common.

Keywords: Materials kitting; Order picking; Production systems; Manual materials handling; Case study; Time consumption; Physical workload

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1. Introduction

The car industry's customers demand a wide variety of models and variants. Manufacturers thus compete by for example offering customised cars. This demand and the manufacturing strategy result in the handling of a large number of components in production systems. The problem of keeping many and varied components is met in many companies by materials kitting. A materials kit consists of all the components needed to assemble an individual product or a complete part of a product. Materials kitting is the process of producing the materials kit (Cox et al., 1995) and is often needed when parallel production flows are used to enable material feeding of workstations (i.e. to reduce costs of stocks and space for materials in progress). Kitting is also introduced in traditional line assembly as an alternative to line stocking, foremost for reasons of accuracy and less work in progress (Bozer and McGinnis, 1992).

Traditionally, materials picking is done according to a picker-to-material principle: kitting is done in a storage area where a material picker moves him/herself between material containers (storage packages) and picks materials to so-called picking packages. Such systems are generally time consuming as pickers are forced to transport themselves a great deal in the storage area. Some companies have attempted to improve picking systems by using a material-to-picker principle: storage packages are moved to material pickers who pick materials to picking packages, reducing the need for transportation. However, there is a great need to improve present picking systems in terms of their efficiency.

The physical exposure of workers must be considered when improvements are made in picking systems since work-related musculoskeletal disorders are common in manual materials handling. Manual materials handling generally involves repetitive movements and work postures with the arms abducted and elevated. These work conditions are known risk factors, especially for neck and upper limb disorders (Kourinka and Forcier, 1995).

To this time, ergonomic interventions have generally showed little success in improving musculoskeletal health (Westgaard and Winkel, 1997). One reason might be that the actions taken have been inadequate owing to a lack of quantitative data on physical/mechanical exposure (Winkel and Westgaard, 1992), although methods for assessing exposure are now available (Hansson et al., 1996; Åkesson et al., 1997; Hansson and Mikkelsen, 1997; Nordander et al., 2000).

However, in the few studies in which exposure data have been registered, it has most often been done without considering detailed levels of the production systems, e.g. tasks and work activities. In an intervention perspective, it is essential to gain knowledge on the exposure imposed by different tasks. Thus exposure data and information on work content must be registered synchronously and analysed in an integrated manner.

This paper presents a case study carried out in a production plant at a car manufacturer. The aim of the study was to make an integrated evaluation of a new kitting system in terms of time consumption and physical exposure.

2. Material and methods

2.1. The case study

The case study focused on warehouse operations in a production system for materials kitting. Two types of material kits were made in the warehouse: (1) sets of plastic containers with material and (2) material on specially designed material carts. The total work was divided into nine work tasks (picking different types of material, material transportation, quality work, etc.) that the workers rotated between on daily basis (1 day/work task). In total, 29 employees worked in the warehouse.

The kitting system studied was a minor part of the plant's total warehouse operations and was in a run-in phase. Full production in the system was started about 1 week before the study was made. The kitting system consisted of a drop area and a U-shaped picking area, where the latter consisted of two rows of height adjustable tables (between 0.3 and 1.0 m) along the two sides (see Fig. 1). The maximal batch size was 96 picking packages.

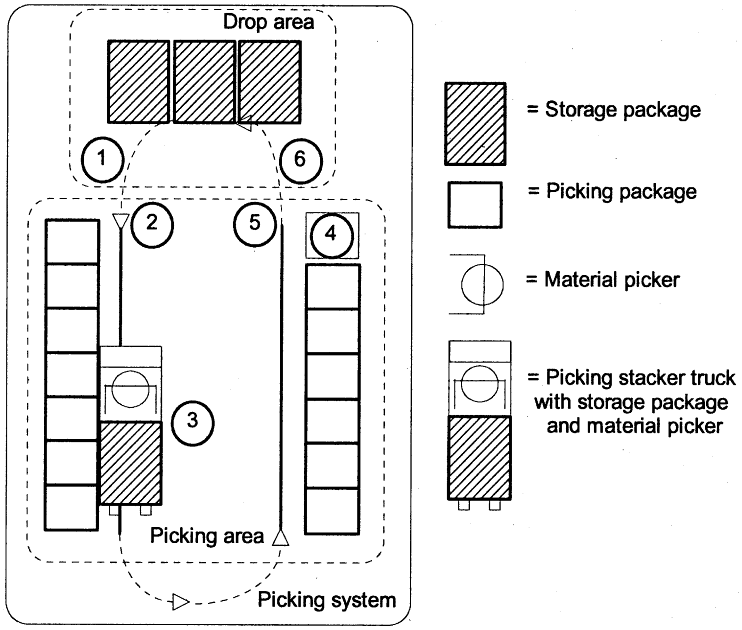

Fig. 1. Schematic layout of the picking area.

When studied, the batch size was 60 picking packages, i.e. 60 picking packages of a similar type were made. Materials were picked into picking packages (plastic containers, $0.4 \times 0.6\,\mathrm{m}^2$) placed on the tables. Two different types of storage packages were used: plastic containers ($0.4 \times 0.6\,\mathrm{m}^2$) and Euro pallets with one to four collars.

During picking, the material picker uses a rail-guided picking stacker truck manoeuvred by a foot control, thus freeing both hands for picking. The storage package is placed on the forks of the truck, the long side facing the material picker. The picking packages are exposed in a row (normally at a height of 0.9 m), with the short sides facing the material picker. Each location of a picking package is marked with an identification number corresponding to a line in a picking information list. The material picker passes the picking packages and picks parts from the storage package to the picking packages. Plastic containers are manually lifted between transportation wagons and the picking stacker truck. Pallets are lifted by the fork lift (i.e. no manual handling).

The kitting system was dimensioned for five employees: three material pickers and two workers who transported storage containers to and from the drop area in the picking system and storage racks in the warehouse. The case study focused on the material pickers' work.

A material picker's work cycle consisted of the following steps (see Fig. 1): (1) fetch a storage package from the drop area; (2) drive to the U-shaped picking area and connect the truck to the rail; (3) pick materials to picking packages along the tables in the picking area; (4) fetch a picking list of the next materials to be picked; (5) drive from the U-shaped picking area to the drop area; and (6) leave the storage package in the drop area. One or more items can be picked in a picking operation.

2.2. Study group

Four experienced material pickers participated in the study, two females, both aged 34, and two males, 44 and 47 years old.

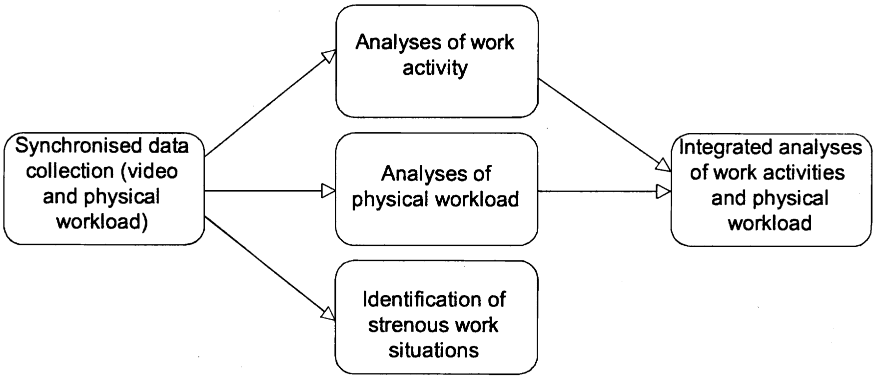

Fig. 2. Major parts of the methodology used in the case studies.

2.3. Methods

Data were collected in two ways. The material pickers were: (1) video recorded with (2) synchronised measurements of physical workload. Analyses were made from the videotapes of the content of work (work activities) and strenuous work situations (see Fig. 2). Using the results of the different analyses, integrated analyses of work activities and physical workload were made.

2.3.1. Analyses of work activities

The video-recorded work was classified according to the types of work activities the material pickers carried out. This classification was made to discriminate between necessary work and losses. The aims of the classification were to facilitate engineering-oriented analysis and to contribute to ergonomically oriented analyses of the picking systems. The activity analyses were used to estimate the efficiency of the kitting system using so-called zero-based analysis (i.e. value and non-value adding work is divided into necessary work and losses, Engström et al., 1997).

Brynzér et al. (1994) suggested four important factors for the classification of work activities in a zero-based analysis of order picking work: (1) the work activities concerning the efficiency of the system that are the most important and frequently discussed; (2) the work activities in a general picking system that relate to the necessary work; (3) whether the time length of the work activity varies with different picking system designs; and (4) whether the work activity is likely to be carried out in the picking system. The authors made a hierarchical classification on the basis of these four factors. In the present study, a modified classification of work activity groups was developed (see Table 1).

The work activities of 'grasping materials from storage package' and 'placing materials in picking package' constitute the necessary work, marked Z, while the remaining work activities are defined as losses. Z is a fixed value dependent only on the product studied, i.e. the materials kit, and not on the design or management of the production system. Z is consequently dependent only on the characteristics of the single items to be picked and is independent of an individual material picker's performance. The resource consumption is specified in percentages in the zero-based analysis, where Z is set to 100%. All real picking systems have losses. The advantage of the zero-based analysis is that comparisons can be made of the level of losses in picking systems of different designs and of these systems and reference values.

It is desirable in picking that the material picker can proceed directly to the next picking location without waiting for another material picker to move and that parts can be picked directly from the storage package and placed into picking packages without preparation (e.g. folding).

In addition to the zero-based analysis, absolute values of characteristic work activities were

Table 1
Classification of work activities of the picking system in two hierarchical levels

Work activity group	Work activities
Necessary work (Z)	Grasping materials from storage package Placing materials in picking package
Handling and transportation	Handling picking package
	Handling picking package accessories Transportation of storage package between picking locations Transportation of storage packages before or after picking Transportation of picking packages Transportation of picking package accessories Walking
Handling packaging	Marking packages Handling empty packages Material preparation
Administration and miscellaneous work	Identifying and reading
	Inspection/control Adjustment Administrative work Miscellaneous work operations
Disturbances	Miscellaneous Asking and answering Waiting

Handling is used for operations during which the material picker stands still at a picking location, i.e. at the tables with picking packages.

calculated. Z was related to each picking operation, i.e. grasping materials from storage package and placing them in the picking package. Analyses were related to characteristic variables such as types of packages, disturbances such as waiting and characteristics of materials. Time consumption was assessed for what was regarded as 'normal picking/condition', i.e. no occurrence of disturbances and no need for material preparation during the work cycle.

2.3.2. Direct measurements of physical workload

Recordings of the physical workload were made bilaterally using data loggers (Logger Teknologi HB, Åkarp, Sweden; Asterland et al., 1996). The registrations were made for a period of 4 h of working time for each material picker.

Electromyography (EMG) of the trapezius muscles and the forearm extensors was registered with a sampling frequency of 1024 Hz using surface electrodes. The electrode pairs had a centre-to-centre distance of 20 mm. For the trapezius, they were placed on the descending part of the muscles, 20-mm lateral to the midpoint of the line between C7 and the lateral acromion (Hansson et al., 1997). The electrode pair for the extensor muscles of the forearms was placed over the muscle bellies, identified by palpation while an extension of the wrist was done. The electrodes were placed at a distance of one-third of the forearm length from the elbow. For details on electrodes and skin preparation see Åkesson et al. (1997).

The muscular activity was normalised to the maximal EMG activity (MVE) provoked by maximal voluntary contractions. For the trapezius muscle, three MVCs were made as a unilateral abduction to 90° in the scapular plane and with a resistance placed proximal to the elbow. The MVCs for the extensor muscles were done as maximal hand grips in a sitting position with the forearm supported and with the hand semi-pronated and non-deviated.

Muscular activity was characterised as the root mean square of the value of the EMG signal (Hansson et al., 1997). The 10th, 50th, 90th and 99th percentiles of the amplitude distribution function (APDF) were used to describe the muscular loads (Jonsson, 1982). The proportion of muscular rest, defined as the time spent below 0.5% MVE, was also used as a measure of muscular load (Veiersted et al., 1993; Hansson et al., 2000; Nordander et al., 2000).

Postures and movements of the head, upper back and upper arms were registered with a sampling frequency of 20 Hz using triaxial accelerometers (Loggerteknologi HB, Åkarp, Sweden) to measure inclination relative to the line of gravity (Hansson et al., 2001). One inclinometer was fixed to the forehead, one to the right of the cervico-thoracic spine at the level of C7-Th1, and one to each upper arm. For the upper arms, the inclinometer was fixed to a plastic plate with a length of 55 mm and a width of 27 mm. The plate was fixed along the upper arm, with its lateral edge along a line from the lateral posterior corner of the acromion to the lateral epicondyle and the upper edge at the insertion of the deltoid muscle. This line was defined with the upper arm alongside the body and the elbow flexed at 90°.

For the head and upper back, the angles and their time derivatives of forward and sideways projections were used to describe the postures and movements (Åkesson et al., 1997). The reference positions for the head and upper back (0° of forward and sideways bending) were defined as upright standing, facing straight ahead. The forward direction of the head and upper back was defined with the subject sitting, leaning straightforward with the elbows resting on the knees and looking at the floor. For the upper arms, the elevation angle and the time derivative of the posture on the unit sphere (described by spherical co-ordinates) were used to describe the postures and the movements. The reference position for the arms was defined with the subject sitting, with the side of the body leaning towards the backrest, the arm hanging perpendicular over the backrest and with a 2-kg dumbbell held in the hand.

Wrist positions and movements were recorded (sampling frequency of 20 Hz) using biaxial electrogoniometers (XM65, Biometrics Ltd., Cwmfelinfach, Gwent, UK; Hansson et al., 1996). In addition to previously used measures, the angular acceleration was calculated from the angular velocity using the 3-point first-order central difference. The reference position (0° flexion and deviation) was defined as the angles of the wrist when the subject was standing and the arms and hands were hanging relaxed along the body. The flexion measures were used to characterise the work.

2.3.3. *Perceived physically stressful work situations*

A method for ergonomic evaluation of complex manual work called VIDAR (Kadefors and Forsman, 2000) was used to assess work situations perceived as physically stressful. The method is based on worker assessment rather than expert assessment. VIDAR uses interactive worker assessment of video recordings and requires active participation by the worker during the analysis. Technically, the method is built upon communication between a video recorder and a computer. The video film is shown on the computer terminal, and the filmed worker assesses the work by clicking on virtual controls on the computer screen whenever a situation inducing pain or discomfort arises. The worker marks affected body regions and rates perceived exertion (according to the CR-10 scale; Borg, 1982). In this way, a filmed sequence covering hours of work can be condensed into a limited number of high-priority work situations. A library is compiled in the computer, including task and worker identification data, ergonomic data and pictorial information. Data are controlled and edited in the final step of the analysis. As soon as an analysis of a video film is finished, a report is produced automatically and can be printed.

2.3.4. *Integrated analyses*

Video recordings and physiological measurements were synchronised to facilitate the integration of data on time used in different work activity groups and physical workload. This was done using a remote control unit to mark a sample in the data logger and activate a light-emitting diode at the beginning of each video recording period. When the separate analyses of time consumption and physical workload were complete, the video frame in which the data collection started was time locked to the corresponding data sample (Forsman et al., 1999, 2001). The time windows of the work activity groups were then identified and after digital synchronisation with the logger data, used to extract statistics on physical exposure. The 10th, 50th and 90th percentiles of the different exposure parameters, e.g. trapezius muscular activity, were computed for the work activity groups. The calculations were made in a specially designed Microsoft Excel program (macro) and the results were plotted in ‘integrated diagrams’. The method is described in detail by Forsman et al. (1999, 2001).

3. Results

3.1. Analyses of work activities

Analyses of work activities were made for the four material pickers. The analysis comprised a total of 858 min of work time and included 5509 picking operations. Table 2 shows the mean time/picking operation of each work activity group for each material picker. Results of the zero-based analyses are reported in Fig. 3.

Time consumption can be related to different measures such as picking operation, work cycle (i.e. one for each part number), batch of picking packages of a similar type or total batch of picking packages. The case study design made it possible to calculate figures for time used related to picking operations and work cycle. Total time

Table 2
Mean time/picking operation (s) for each work activity group for four material pickers, two male (M) and two female (F)

Work activity group	Picker 1 (M)	Picker 2 (F)	Picker 3 (M)	Picker 4 (F)
Necessary work, (*Z*)	3.1	2.4	3.4	1.7
Handling and transportation	5.2	5.3	4.6	4.3
Handling of packaging	0.3	0.2	0.5	0.2
Administration and miscellaneous work	1.0	1.3	0.8	0.5
Disturbances	1.6	0.7	0.9	0.4
Sum	11.2	9.9	10.2	7.1

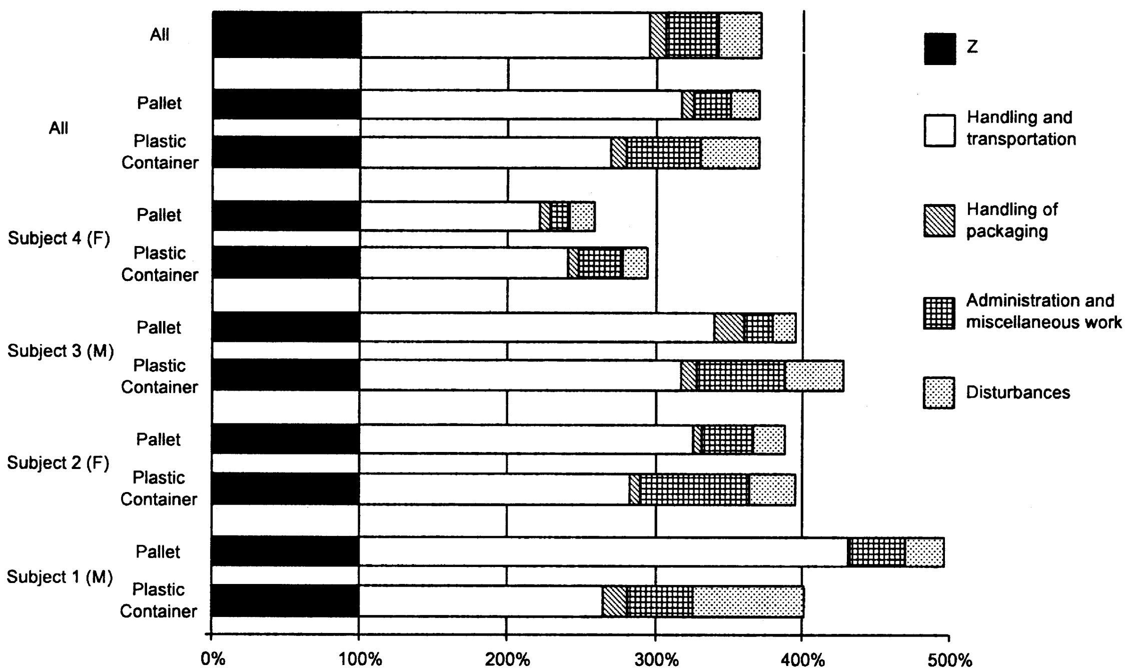

Fig. 3. Results of the zero-based analysis, displaying picking from pallets and plastic containers for each material picker and all observations.

consumption for each batch of picking packages could not be measured since we did not study all separate placements of materials/packages and batch.

The activity analysis showed that the fixed value of 'Z' was 2.5 s for each picking operation. The time increased by $\approx$1 s when it was necessary to prepare the item in the picking operation. For 'normal picking' to more than 30% of the picking packages, the time required for each picking operation, i.e. 'Z' and the work activity 'transportation of storage package between picking locations', was $\approx$5.5 s. The analysis of all observations showed that the time consumption for *each picking operation* increased considerably if picking was made to only a few picking packages (<30% of all packages). There was a waiting line at 14% of the picking operations that approximately doubled the time consumption. The analysis showed that the time required for work activities related to *each work cycle*, primarily loading and unloading storage packages, was $\approx$165 s/work cycle.

Two different storage packages were used in the kitting system. Zero-based analyses were made for each storage package type and the results indicate that picking from pallets increases the time required for 'handling and transportation' by $\approx$30%, probably owing to the larger size of the pallets (i.e. longer movement distances). The time required for 'administration and miscellaneous work' was extensive when the picking was done from plastic containers, partly owing to poor work routines, e.g. incomplete labeling of containers.

3.2. Direct measurements of physical workload

3.2.1. Muscular activity

Muscular activity during work, including all work tasks, was on average low (see Table 3). The 10th and the 90th percentile were 0.4% MVE and 10% MVE, respectively, for the right trapezius muscle. The extensor muscles' load was almost twice as high as the trapezius levels. Muscular rest was also considerably lower for the extensor muscles. There were large inter-individual differences with respect to the muscle activity for both muscles. There were also differences between the female and male material pickers. There was a larger span between the percentiles for the two men, indicating that the male pickers had a more dynamic work technique than the female pickers. Moreover, muscular rest was generally lower for the female pickers. In these pickers, muscular rest was lower for the left than for the right trapezius muscle. The 'necessary work' implied a higher muscular load in relation to the total measurement time. This was most evident for muscular rest and the 10th percentile.

3.2.2. Postures and movements

During the total measurement time, the material pickers worked half of the time with the head bent forward at an angle of >29°, the upper back bent forward >13°and the right and left arms elevated more than 32° and 30°, respectively (see Table 4). The corresponding angular velocities were 15, 11, 39 and 40°/s.

The 'necessary work' was carried out with a median of 4° further forward bending of the head, while the upper back was in almost the same posture. Moreover, the head was seldom in a neutral posture during the 'necessary work' (the 10th percentile being 21°).

A comparison of 'necessary work' and total measurement time showed that the velocities were the same with respect to the head and upper back and all percentiles. With regard to the arms, the 'necessary work' implied a somewhat lower elevation ($\approx$4°) as regards the 50th and 90th percentiles for both arms and greater dynamic demands on the right arm.

3.2.3. Wrist positions and movements

All four material pickers had a dorsiflexed position (50th percentile) of the right wrist, the average being −12° during 'necessary work' and −16° during the total measurement time (see Table 5). The right wrists were considerably dorsiflexed 10% of the time: −38° during 'necessary work' and −47° during the total measurement time. The palmar flexion was minor: it exceeded 15° during 'necessary work' for only 10% of the time and 11° during the total measurement time. In general, for all material pickers and all percentiles, the wrists were more dorsiflexed during the total

Table 3
Muscular load of the trapezius muscle and extensor muscles of the forearm during 'necessary work' (Z) and during total measurement time (4 h) for four material pickers, two male (M) and two female (F)

	Picker 1 (M)		Picker 2 (F)		Picker 3 (M)		Picker 4 (F)		All (means)	
	Z	4 h	Z	4 h	Z	4 h	Z	4 h	Z	4 h
Trapezius										
Right										
Muscular rest (% time)	10	17	7	8	2	13	2	5	5	11
Percentile (% MVE)										
10^{th}	0.5	0.3	0.6	0.5	1.7	0.4	0.8	0.6	0.9	0.4
50^{th}	4.2	2.5	1.8	1.4	7.9	6.1	2.0	2.0	4.0	3.0
90^{th}	14	12	5.7	4.7	18	18	6.3	6.9	11	10
Left										
Muscular rest (% time)	14	15	1	1	9	17	0	0	6	8
Percentile (% MVE)										
10^{th}	0.3	0.3	1.2	0.9	0.5	0.4	0.9	0.9	0.7	0.6
50^{th}	4.2	3.0	3.9	3.1	4.3	3.4	2.0	2.1	3.6	2.9
90^{th}	13	11	9.4	8.1	12	13	7.4	7.2	10	9.8
Extensor										
Right										
Muscular rest (% time)	1	3	0	0	4	5	0	0	1	2
Percentile (% MVE)										
10^{th}	2.0	1.0	5.4	4.2	1.3	0.8	2.6	2.3	2.8	2.1
50^{th}	5.8	4.1	16	14	4.5	3.7	6.5	5.2	8.2	6.8
90^{th}	15	13	35	33	11	11	16	15	19	18
Left										
Muscular rest (% time)	0	2	0	0	0	1	0	0	0	1
Percentile (% MVE)										
10^{th}	2.7	1.4	2.7	2.0	2.8	1.6	2.2	1.6	2.6	1.6
50^{th}	7.8	5.0	8.4	5.8	7.9	5.4	5.1	3.7	7.3	5.0
90^{th}	20	17	22	18	16	14	13	12	18	15

Muscular rest and the 10th, 50th and 90th percentiles are shown.

measurement time than during 'necessary work'. The inter-individual differences were most pronounced for the 10th percentiles. A similar pattern was seen for the left side. However, differences between 'necessary work' and the total measurement time were smaller.

As for movement, it was evident that the work was done with the hands in almost constant motion during 'necessary work' and the total measurement time. The hands were defined as being still for $<1\%$ of the time. Moreover, the flexion velocities were higher for the right than for the left side and for 'necessary work' as compared to the total measurement time. This was also the case for repetitiveness.

3.3. Perceived physically stressful work situations

Physically stressful work situations were identified in two work activity groups: 'necessary work' and 'handling and transportation' (see Table 6). Some of these work situations occurred a large number of times during a work day (e.g. turning the neck when manoeuvring the picker stacker truck), while others occurred only a few times during a work day (e.g. in the handling of ready picking packages). A number of identified work situations resulted from the design of the equipment, e.g. stopping the picker stacker truck in the U-shaped picking area caused a jerk, which two material pickers perceived as stressful. Other

Table 4
Postures and movements of the head, upper back and upper arms during 'necessary work' (Z) and total measurement time (4 h) for four material pickers, two male (M) and two female (F)

	Picker 1 (M)		Picker 2 (F)		Picker 3 (M)		Picker 4 (F)		All (means)	
	Z	4 h	Z	4 h	Z	4 h	Z	4 h	Z	4 h
Head										
Flexion (percentile; °)										
10th	—	—	13	5	34	12	15	0	21	6
50th	—	—	26	21	45	40	29	26	33	29
90th	—	—	38	37	58	56	45	44	47	46
Velocity (percentile; °/s)										
10th	—	—	1.8	1.5	1.9	1.9	2.2	2.0	2.0	1.8
50th	—	—	14	13	14	15	16	16	15	15
90th	—	—	49	52	56	64	52	57	52	58
Upper back										
Flexion (percentile; °)										
10th	2	−4	5	3	13	8	—	—	7	2
50th	10	8	12	12	21	18	—	—	14	13
90th	23	25	24	23	35	31	—	—	27	26
Velocity (percentile; °/s)										
10th	1.0	0.8	1.7	1.2	1.5	1.4	—	—	1.4	1.1
50th	9.8	9.4	14	12	13	12	—	—	12	11
90th	38	41	43	45	41	44	—	—	41	43
Right arm										
Elevation (percentile; °)										
10th	24	24	12	11	12	14	18	20	16	17
50th	37	38	26	29	23	27	29	36	29	32
90th	56	58	51	54	39	42	46	56	48	52
Velocity (percentile; °/s)										
10th	8.5	5.8	16	10	11	8.6	14	8.7	12	8.3
50th	41	32	66	46	49	38	54	41	52	39
90th	138	123	208	168	148	125	162	147	164	141
Left arm										
Elevation (percentile; °)										
10th	21	22	11	11	14	15	14	15	15	16
50th	35	39	22	23	25	30	23	28	26	30
90th	54	61	38	43	42	45	41	45	44	48
Velocity (percentile; °/s)										
10th	6.0	5.3	13	10	9.7	8.4	11	10	9.9	8.4
50th	29	30	57	51	39	36	45	44	42	40
90th	102	115	176	173	111	113	135	141	131	136

The 10th, 50th and 90th percentiles are shown. Values are missing for picker 1 (head) and picker 4 (back) for technical reasons.

situations resulted from certain material characteristics or the way materials were stored. Some of the identified work situations arose from a lack of work routines, such as the extra work caused by having to rearrange items in picking packages to make room for the next item to be picked.

Reasons for, and possible solutions to, problems were discussed in the interviews conducted during VIDAR. In the interviews, all studied material pickers claimed that the work in the kitting system resulted in fatigue or disorders located to the neck, shoulders and back. The VIDAR and interview

Table 5
Wrist flexion, positions and movements in the right and left wrists during 'necessary work' (Z) and total measurement time (4 h) for four material pickers, two male (M) and two female (F)

	Picker1 (M)		Picker 2 (F)		Picker3 (M)		Picker 4 (F)		All (means)	
	Z	4 h	Z	4 h	Z	4 h	Z	4 h	Z	4 h
Right wrist										
Position (percentile; °)										
10th	−42	55	−53	−72	−46	−51	−32	−32	−43	−53
50th	−20	−22	−20	−33	−20	−21	−11	−10	−18	−22
90th	7	3	14	6	6	2	9	10	9	5
Movements										
Velocity										
Below 1 °/s (% of time)	0.3	1.0	0.1	0.5	0.3	0.2	0.1	0.3	0.2	0.5
Percentile (°)										
50th	26	14	47	18	32	18	31	14	34	16
90th	125	95	183	129	129	96	119	94	139	104
Repetitiveness (MPF; Hz)	0.31	0.29	0.29	0.28	0.42	0.32	0.32	0.35	0.34	0.30
Left wrist										
Position (percentile; °)										
10th	−40	−47	—	—	−60	−59	—	—	−50	−53
50th	−21	−25	—	—	−25	−30	—	—	−23	−28
90th	5	2	—	—	1	0	—	—	3	1
Movements										
Velocities										
Below 1 °/s (% of time)	0.5	1.5	—	—	0.2	0.3	0.8	1.1	0.5	1.0
Percentile (°)										
50th	13	9	—	—	20	13	12	8	15	10
90th	77	63	—	—	100	80	57	47	78	63
Repetitiveness (MPF; Hz)	0.24	0.20	—	—	0.26	0.25	0.33	0.32	0.28	0.26

Positive values denote flexion in the palmer direction. Values are missing for the left side for pickers 2 and 4 for technical reasons.

results were summarised and used by a work group in the warehouse. The work group discussed problems and solutions in a participative way. The results of VIDAR and the interviews were thus used to improve the material pickers' work situation.

3.4. Integrated analyses

By synchronising data, it was possible to relate detailed physical workload measures to specific work activities. Analyses were made of physical workload in the different types of work activity groups and for the two types of storage packages used in the picking operations. Integrated figures are used here to illustrate time consumption and some selected physical workload parameters in different work activity groups.

3.4.1. Physical workload in relation to work activities

Results of the integrated analyses of workload related to work activities are exemplified in diagrams (see Fig. 4), in which the horizontal axis represents relative time. The bar width represents time consumption relative to 'necessary work' (Z). The vertical axes show magnitudes of different workload parameters. Each vertical value, for example the 90th percentile in muscular activity for the right trapezius muscle, is based on all time spent in the specific work activity group among all four material pickers. The shown 90th percentile is the average of the four material pickers' 90th percentile in the respective work activity group.

Fig. 4a shows that the activity of the extensor muscles is higher for all percentiles and all work activity groups as compared to the trapezius

Table 6
Subtasks perceived as physically stressful: body regions and ratings (Borg CR-10 scale)

Subtasks	Body regions (no. of answers)	Range of ratings
Necessary work (*Z*)		
Picking when picker stacker truck stops	Lower back (1)	4
	Neck (1)	2
Grasping and placing materials in general	Right hand (1)	2
Grasping the last items out of storage packages (Euro pallets)	Lower back (2)	4
	Left shoulder (2)	2–5
	Right knee (1)	4
Grasping plastic small boxes out of storage packages (plastic container)	Lower back (2)	2
	Right shoulder (1)	2
Grasping materials when picking package accessories are used	Right shoulder (1)	5
	Left shoulder (1)	5
	Right hip (1)	3
Grasping materials from plastic containers (when low)	Lower back (1)	5
	Right hip (1)	5
	Left hip (1)	5
Placing materials in the far end of picking packages	Neck (1)	5
	Right shoulder (1)	5
Placing large materials in picking packages	Right shoulder (1)	3
Placing plastic small boxes in picking packages	Right shoulder (1)	4
	Left shoulder (1)	4
	Right hip (1)	3
Rearranging items in picking packages to make room for items still to be picked	Lower back (1)	4
	Upper back (1)	4
Handling and transportation		
Transportation of storage packages before or after picking — turning the neck when manoeuvring the picking stacker truck	Neck (3)	3–4
	Right shoulder (1)	3
	Left shoulder (1)	3
Lifting heavy plastic storage packages to the picker stacker truck	Lower back (2)	2–3
	Right shoulder (1)	2
	Left shoulder (1)	2
	Right elbow (1)	3
	Left elbow (1)	3
Pulling plastic storage packages to the picker stacker truck	Right shoulder	3
Handling ready picking packages—lifting to upper or lower shelves of material wagons	Lower back (1)	4
	Upper back (1)	4

muscles. The work activity group labelled 'necessary work' had higher muscular activity values for all percentiles in relation to the other work activity groups except for the 90th percentile during 'handling packaging', which is most evident in the extensor muscles. However, this muscular activity constitutes only 8% as compared with 'necessary work' (100%).

Fig. 4b shows the postures of the head, upper back and upper arms for each work activity group. In head flexion, 'necessary work' implied the highest flexion for all percentiles. This was also the case for the upper back except for the 90th percentile during 'handling packaging'. The difference between the 10th and the 90th percentiles, which reflect the degree of constrained posture—a

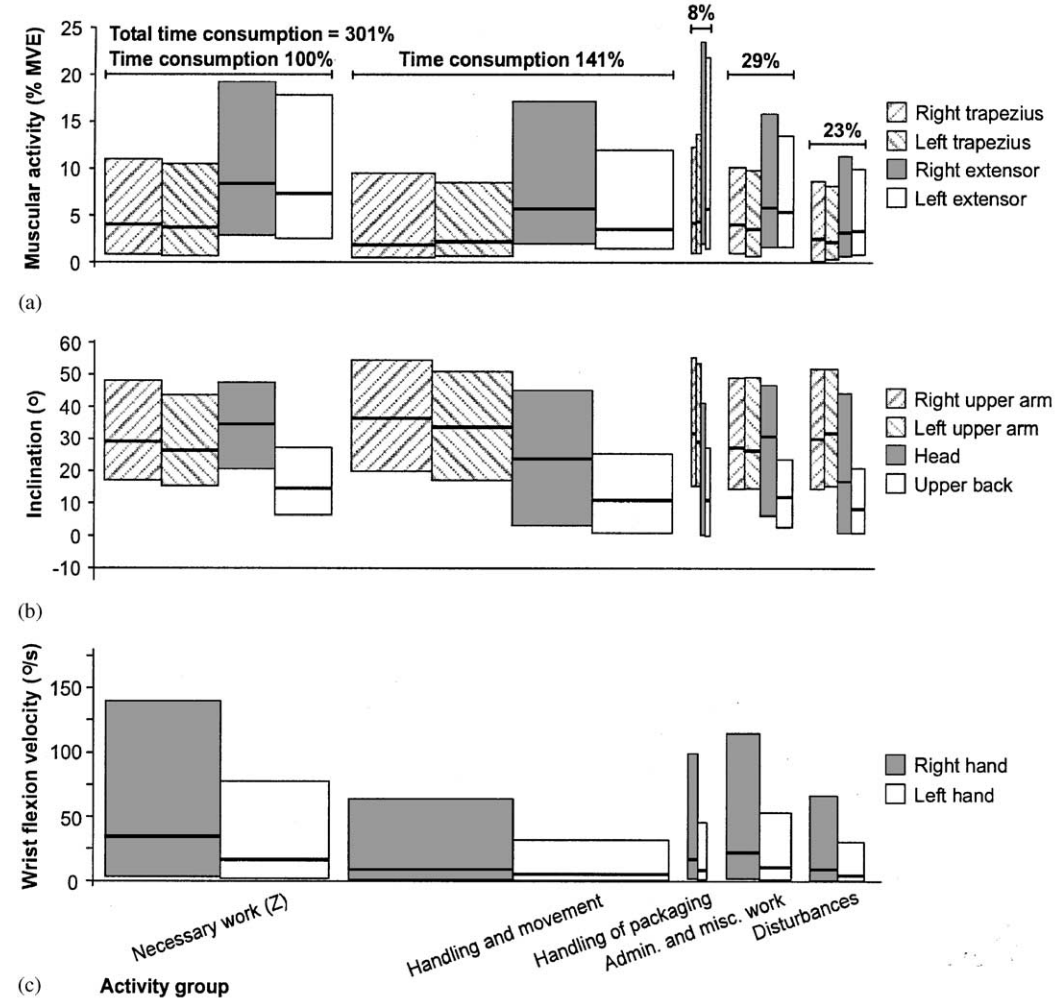

Fig. 4. The four material pickers' muscular activity, inclination and wrist flexion velocity in the work activity groups. The bar width represents the time consumption relative to the 'necessary work'. For each bar, the median level is indicated with a bold line. The upper and lower ends represent the 90th percentile and the 10th percentile, respectively.

wider distribution means a less constrained posture—showed that 'necessary work' implies a more constrained posture. In terms of the inclination of the upper arms, 'necessary work' did not generally imply an increase in elevation in relation to the other work activity groups.

Fig. 4c shows the wrist flexion velocity for each work activity group. The median velocity levels seem to be similar. The figure shows considerable differences regarding top velocities, however, where 'handling packaging', 'administration and miscellaneous work' and 'disturbances' result in high wrist flexion velocities.

3.4.2. Comparisons of picking from different storage packages

Comparisons of picking from plastic containers and Euro pallets, are shown in Figs. 5–7. The results are presented in paired relations in which ratios ('picking from Euro pallet'/'picking from

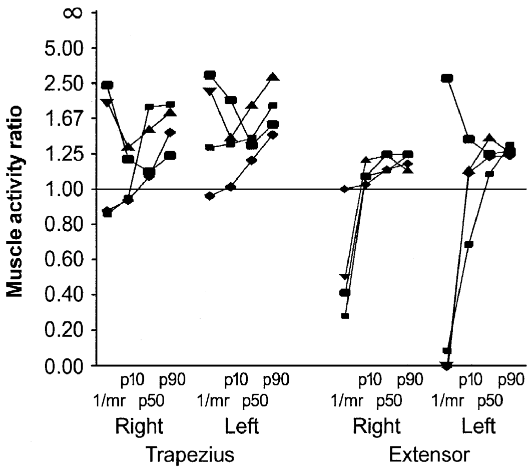

Fig. 5. The four material pickers' muscle activity ratio in the work activity 'picking from Euro pallets' is shown in relation to the work activity 'picking from plastic containers'. Muscular rest (mr; proportion of time spent with a muscular activity below a threshold level) and the 10th, 50th and 90th percentiles (p10, p50 and p90) of the muscle activity distributions are shown for the right and left trapezius and the extensor muscles in the four material pickers. The symbols represent the four material pickers.

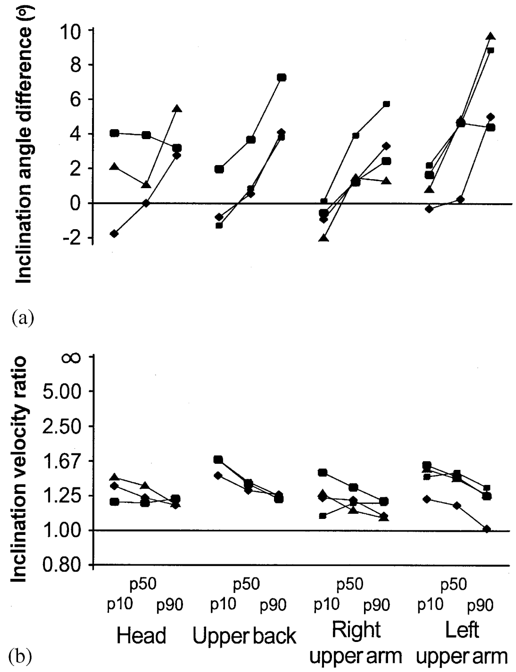

Fig. 6. The four material pickers' inclination angle difference and inclination velocity ratio. The work activity 'picking from Euro pallets' is shown in relation to the work activity 'picking from plastic containers'. The 10th, 50th and 90th percentiles (p10, p50 and p90) are shown for the head, upper back and the right and left upper arm in the four material pickers. The symbols represent the four material pickers.

plastic containers') are used for muscular load and movement and differences ('picking from Euro pallet'–'picking from plastic containers') for postures and positions. Each figure shows individual data for all four material pickers. The reference line indicates identical values for the two work activities. The ratio scale was chosen to give a symmetric presentation independent of the way in which the comparisons were made.

With respect to muscle activity, picking from pallets induced a clearly increased muscle load (see Fig. 5). However, picking from pallets resulted in lower 10th percentiles for two material pickers in the right trapezius muscle and a lower 10th percentile in the left extensor muscle for one material picker. The picture was ambiguous for muscular rest in the trapezius muscle.

With respect to postures, 'picking from pallets' was on the whole done with a more forward flexion of the head and upper back (see Fig. 6a). Picking from plastic containers induced a higher degree of inclination especially for the left arm. In terms of movements, 'picking from pallets' was done with a higher velocity for all material pickers and all regions (see Fig. 6b).

As regards wrist flexion angle, there was no clear difference in picking from the two types of storage packages (see Fig. 7). The results in Fig. 7a indicate greater differences between the material pickers than between picking from the two types of storage packages. As regards wrist flexion velocity, the results (see Fig. 7b) show that picking from pallets gave a higher velocity in general, although there were some inter-individual differences.

4. Discussion

The results of the case study show that the kitting system's productivity, in comparison with similar kitting systems, is high and has a potential

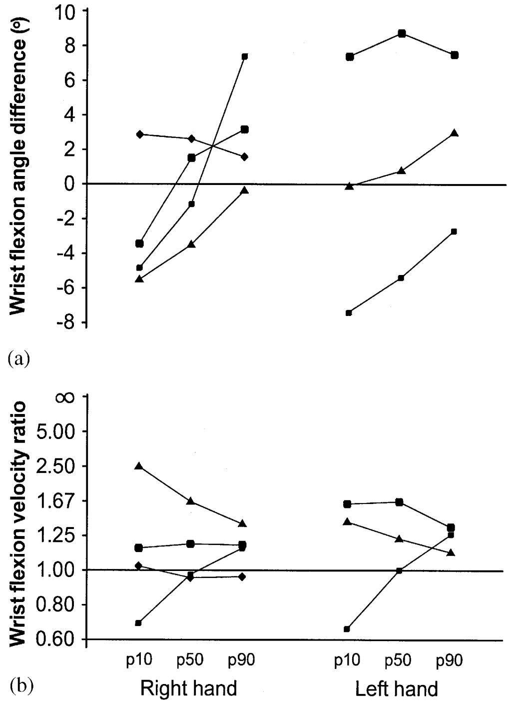

Fig. 7. The four material pickers' wrist flexion angle difference and wrist flexion velocity ratio. The work activity 'picking from Euro pallets' is shown in relation to the work activity 'picking from plastic containers'. The 10th, 50th and 90th percentiles (p10, p50 and p90) are shown for the right and left wrists in the four material pickers. The symbols represent the four material pickers.

for further improvement. A major reason for the high level of productivity was the material-to-picker principle used, which involved larger batch sizes and less need for transportation. The level of losses is rather high, however. This is partly explained by the fact that the kitting system was in a run-in phase at the time of the study. Results of a follow-up study made by the car manufacturer show a reduction in time consumption for all groups of work activities, except '*Z*'; 'handling before and after picking' was primarily reduced. There is also potential to reduce time consumption even further by technical improvements of the equipment.

In terms of ergonomics, the study indicates a work situation with low levels of physical exposure with respect to muscular activity and work postures. Results of the measurements show that the materials picking work was highly repetitive for the arms. The material pickers also experienced the work as repetitive and as containing some physically stressful work situations. These situations were in the work activity groups called here 'necessary work' and 'handling and transportation'. A comparison of Fig. 5 with the material pickers' experience of stressful work situations reflects the rather even muscular activity levels and postures in 'necessary work' and 'handling and transportation'. The work activity group 'handling packaging', with high measured levels of muscular activity, was however not among the work situations perceived as stressful by the material pickers.

The results of the comparison of the two types of storage packages (plastic containers and Euro pallets) indicate that picking material from pallets is physically more stressful than picking from plastic containers. The different measures used show a similar pattern of higher workload when picking from pallets.

The results of the comparison of work activity groups showed that the muscular activity differed to some extent. For some measures, the physical workload was higher during the necessary work (grasping and placing of materials) than for other work activity groups. However, the results of the different measures used (muscular activity, inclination of body parts and wrist flexion velocity) did not show the same pattern when the work activity groups were compared. For some measures, but not all, the necessary work required a higher workload.

Our intent in analysing workload for different work activity groups was to compile data for use in analyses of the effect of increased productivity (i.e. less time for 'losses', such as disturbances). In society, there is a view that increased productivity, and thus reduced time for 'losses', should automatically result in higher workloads for the workers. Our results do not support that view. Several aspects of physical workload important for the development of neck and upper limb disorders (Bernard, 1997) were covered in the present study. However, other factors that we did not study may also contribute, e.g. rotation of the head and upper and lower arm.

The integration of task analysis and quantitative measurement of physical workload provides information relevant to evaluations of the effect of changes in the production systems on physical workload. This can be valuable, since WMSDs are prevalent in the industry studied, and earlier interventions have not been very effective (Westgaard and Winkel, 1997). A prerequisite for the usability of this method is that the workload of the defined tasks is independent of the production system. Moreover, the exposure-response relations must be known in quantitative terms to be able to predict the risk for WMSDs in a new or modified production system. This kind of work is now in progress (e.g. Hansson et al., 2000). However, because of the strong interactions (Bernard, 1997), these relations may be complex.

We believe that integrated diagrams can be used to estimate the results of a planned intervention, such as how an increase in the proportion of time allowed for necessary work would affect parameters of the physical workload. However, the results of the integrated analyses of work activity groups and physical workload illustrate the problems in characterising exposures in work activities and selecting appropriate measures to use when analysing work. More studies are needed on appropriate measures for use in analysing work and on exposure levels in different principles for materials picking.

5. Conclusions

The results of the case study show that the kitting system's productivity, in comparison with similar kitting systems, is high and has a potential for further improvement. As a consequence of the system design, the materials picking work was highly repetitive. The workers experienced also the work as repetitive and as containing some physically stressful work situations. The results indicate that an improved productivity, i.e. reduced time for losses, should not automatically result in higher workload.

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