Ergonomics development needs in truck body design – from video analyses to solution proposals

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Abstract: Truck drivers need improvements on their work environment in ergonomics and safety issues. In this study, participative video analyses were performed to identify areas of discomfort and the risks drivers face when working outside the cab. Analyses resulted in identification of 262 discomfort and risk factors of which roughly half occurred in trucks and trailers. Due to the findings, a web questionnaire was used to investigate what kind of participative product design aspects truck body and trailer manufacturing companies apply currently. Accordingly, the need for participation is recognised but these companies lack such systematic procedures and methods. This study also introduces a procedure to utilise the identified risks and discomforts for developing the design and development requirements. The procedure has led to new solutions that are currently utilised in different interest groups’ processes. The procedure supports participation by all stakeholders and may be used in product design processes in environments where a mutual understanding is crucial for eliminating the recognised safety problems in practice.

Keywords: delivery transportation; participative ergonomics; physical discomfort; product design; psychosocial discomfort; safety; truck body; truck driver’s work outside the cab; video analysis; human factors.


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1 Introduction

Delivery truck drivers mainly work alone when travelling along their delivery routes (Shibuya et al., 2010). Nonetheless they are still in continuous contact with other people during their shift. They also need various tools when performing their duties in different loading and unloading environments that are often unpredictable and uncontrolled. According to studies by Okunribido et al. (2006), delivery truck drivers spend averagely only one third of their work day driving. Various other tasks, such as moving, maintenance and manual handling of goods fill the remainder of their work day. Thus the work environments vary greatly during the work shift (Hanowski et al., 1999; Okunribido et al., 2006). Several studies have been performed on truck drivers’ occupational safety and thus the risks and problems faced by the drivers are well recognised. They are mainly related with non-traffic work, as is shown in the studies published by Okunribido et al. (2006), Robb and Mansfield (2007), Salmoni et al. (2008), and by Shibuya et al. (2010).

1.1 Typical risks in work performed outside the cab

The economic pressure and competition between carriers has resulted in tightened delivery schedules (Braver et al., 1992) and usually the only concern when the routes and stops are planned is minimising total operation and maintenance costs (Baptista et al., 2002). Some important risk management aspects, such as accident information, are currently insufficiently utilised in Finnish transportation companies (Lind and Kivistö-Rahnasto, 2008). On the other hand, the work environments and their risks are not always easily controlled by the transportation company or organiser, particularly when it comes to customers’ premises (Bentley and Haslam, 2001; Li et al., 2008; Shibuya et al., 2010). Development in these areas can only be reached through close participation of different interest groups (Målvist and Parmund, 2008; Westgaard and Winkel, 1997).

Trucks and trailers form part of the typical work environments for drivers. Truck cabs and their ergonomics have been developed intensively (Parkinson et al., 2007; Patenaude et al., 2001) and so accidents in the sector are mainly non-traffic in nature. Instead, they are related to work performed outside the cab. Falling from a height, overexertion, repetitive motion injuries and being caught between or under objects are the most common types of accidents in the delivery transportation field (FAII, 2010; Lin and Cohen, 1997; Okunribido et al., 2006; Shibuya et al., 2010). According to a study by Shibuya et al. (2010) almost 40% of accidents result from falling. Falls can occur in various situations, for instance when ascending to or descending from the cab or truck
body or even when operating (tarping/untarping, checking or securing a load, loading or unloading, or adjusting chains/straps) at heights (McClay, 2008; Shibuya et al., 2010). The majority of falls occurs from the back of the truck, trailer or from cargo (Jones and Switzer-McIntyre, 2003). The influences of bad descending techniques are well-known and largely studied (Väyrynen et al., 1996; Fathallah et al., 2000; Patenaude et al., 2001; Giguere and Marchand, 2005). Although concurring with the observation, McClay (2008) states that trucks and trailers still provide inadequate protection against falls. In addition to the above mentioned risks, there are also other risk sources related to cargo spaces and loads, for example in load securing (Branch, 2007; Christiansen and van Dyne, 2006) and load stability (McClay, 2008).

1.2 Improvements in truck drivers’ work

All accidents and problems have their own individual effect on productivity. They can be predicted, and thus avoided through good design (Kjellén, 2000). Working environments of the delivery truck drivers generate demand for careful design of tasks, tools, jobs and work organisation. Standard ISO 6385 (2004) introduces ergonomics guidelines for designing such work systems.

Truck manufacturing companies have their own design processes which aim to provide safety in their products (Nord Nilsson, 2010). Various tools and aids such as fork lifts, carts, trolleys and hand trucks have been developed to ease the manual handling of material (Jung et al., 2005) whilst different types of ladders have been developed to ease the access to and from (ascending and descending) the cab and cargo space (McClay, 2008). Even so, many drivers ignore these aids due to for instance inexperience and poor truck design (Fathallah et al., 2000). Poor design issues may appear to the user as for instance high or too narrow steps for footing and bad handhold locations (Torma-Krajewski, 2007).

Earlier studies on truck design and ergonomics (Kinghorn and Bittner, 1995; Mack et al., 1995) have indicated that the designers had a poor understanding of the anthropometric statistics, transportation task requirements and environmental conditions under which the loads are transported. Torma-Krajewski (2007) has indicated rather similar aspects on a study on prill trucks. According to Torma-Krajewski’s (2007) study, several design features failed to meet the published standards set to ascending and descending. Traffic safety issues are emphasised also on a study of trailer designers’ attitudes by van der Burg and van Gorp (2005). They claim that designers are not interested in doing more than customers or legislation require and that customers, drivers and other stakeholders are responsible in safety issues beyond the legislation.

Trucking industry companies are essentially top-down managed companies and keen members of different value chains (Ellegaard et al., 2003) where various co-operation practices are required between the different interest groups. The ergonomic approach to product development and usability emphasises participatory, user-centred design processes where the end-users are invited to cooperate with the developers (Olsson and Jansson, 2005; Vink et al., 2008). Such participatory design processes (Visser et al., 2007) ensure that product functions are understood by the designers.

Participation optimally takes place at both the organisational and the individual levels (Wilson, 1995). The best results are often achieved when development work is performed
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1.3 Objectives

Very little research exists regarding how ergonomics and safety issues are taken into account during the design processes of truck bodies and trailers. However, to eliminate or reduce the risks and discomforts, a number of different operative design processes are required. Thus this study addresses this gap on one hand by exploring typical risks that occur in the working environments of delivery truck drivers outside the cab and on the other hand by exploring Finnish truck body and trailer manufacturing companies’ product design processes. This study utilises material gathered in a Finnish development project that was aimed at developing safety and productivity of delivery truck drivers’ work outside the cab (Reiman et al., 2010). Various participants such as national and international research partners, labour organisation, employer’s organisations, the insurance business, and companies from the fields of information and telecommunication technology (ICT) as well as truck manufacturing and transportation participated in the project.

The first objective of this study was to define the typical risks and ergonomic discomforts in truck drivers’ work performed outside the cab by analysing their work from the point of view of ergonomics. A video footage on the work performed by the project participants was filmed for the purposes of the analysis. The analysis method will be explained later in this article. The elimination and reduction of the identified risks and discomforts requires operative design and upgrade processes. Therefore, the second aim was to examine the participative product design aspects that the truck body and trailer manufacturing companies apply in their product design and upgrading processes, and the ones they disregard. Based on the findings and authors’ experiences in the project, a proposal on how future participatory design processes could be arranged is introduced.

2 Methodology

The data for this study was collected from two different sources: physical and psychosocial discomforts and risks were gathered from participative video analyses, and manufacturing companies’ design processes were explored through a web questionnaire. The research process is depicted in Figure 1. The proposal on how future participatory design processes could be arranged is formed on the basis of an analysis of this data. Hence this study is qualitative and interpretative in nature.
2.1 Video analyses

A video- and computer-based work analysis method, VIDAR (Kadefors and Forsman, 2000), was used in discomfort and risk identification and analysis. VIDAR is a participative, subjective tool for ergonomic assessments at work places. It is used for letting the employees themselves identify physically and psychosocially demanding situations and risks from previously recorded video footage of their own work (Forsman et al., 2006; Kadefors and Forsman, 2000).

The identified physical discomforts are evaluated by choosing the body regions which the physical discomfort affects with a body map. The degree of discomfort for every body region is rated from 0 to 10 on the Borg CR-10 Scale (Borg, 1982; Forsman, 2008). The psychosocial discomforts are evaluated by selecting the most fitting alternatives from a list provided in VIDAR. The list consists of nine psychosocial discomfort alternatives: time pressure, obstruction/interruption/disturbance, uncertainty, poor control, lack of response/feedback, risks, the task is emotionally demanding, the task is boring or meaningless and other. These nine discomforts include a total of 26 more specific definitions. The alternatives are mainly based on action theory from which perspective the stressors are circumstances that disturb the goal directed actions (Forsman et al., 2003).

A verbal description of the situation and its frequency during a certain period is reported for every identified discomfort. As a result, VIDAR produces a list of all identified discomforts and their descriptions for further development purposes. VIDAR version 4.1 was used in a Finnish language setting together with a laptop computer and a digital camcorder.

2.2 Questionnaire

For the purposes of the study, a questionnaire was developed, aimed at those in management of the 28 Finnish truck body and trailer manufacturing technology
companies that belong to the Federation of Finnish Technology Industries. This constituted approximately 90% of all companies of the branch in Finland. The purpose of the questionnaire was to define the participative product design aspects that Finnish truck body and trailer manufacturing companies apply in their product design processes. The questionnaire was divided in two parts. First, the respondents evaluated the importance of ten statements on a six-point scale and then they answered ten open questions.

The questionnaire was web-based and developed with the Webropol survey software. The website address for the questionnaire was distributed as a link embedded in an e-mail message and sent to the contact persons’ individual e-mail addresses. The respondents entered and submitted answers directly via a secure website.

3 Results

3.1 VIDAR analyses

The researcher followed and filmed the driver’s work outside the cab on their short haul distribution routes in late winter 2008. Nineteen professional short-haul drivers [17 male, two female; average age = 31.5, standard deviation (SD) = 9.0 years; average driving years = 8.6 years, SD = 8.0 years] volunteered to take part in the individual analyses and eight male stakeholders took part in the group analyses (Table 1). A total of about 1,500 minutes of video footage of drivers’ work was recorded and analysed.

Table 1  VIDAR results in different sessions

<table>
<thead>
<tr>
<th>Evaluator groups</th>
<th>Evaluators (N)</th>
<th>Session types</th>
<th>Physical discomforts</th>
<th>Psychosocial discomforts</th>
</tr>
</thead>
<tbody>
<tr>
<td>The driver’ group</td>
<td>Drivers (19)</td>
<td>16 individual analyses of their own work</td>
<td>130</td>
<td>67</td>
</tr>
<tr>
<td>The stakeholder group</td>
<td>Drivers’ immediate superiors (3)</td>
<td>3 group sessions</td>
<td>19</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Industrial safety group members (3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R&amp;D personnel from a cargo space manufacturer (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In total</td>
<td></td>
<td></td>
<td>149</td>
<td>113</td>
</tr>
</tbody>
</table>

The video analyses resulted in a total of 262 identifications of discomfort (Table 1). The majority of those identifications concerned physical discomforts (149 identifications; 57%) that occurred when performing tasks such as moving in and out of the cargo space and manual handling of materials. The psychosocial discomforts (113 identifications; 43%) were related to factors such as time pressure, risks or obstacles at customers’ premises, incorrectly working tools and fear of causing loss as a results of one’s own choices and actions.

The identified discomforts were divided into two classes on the basis of where they occurred:

1 courtyards and premises
2 trucks.
These classes were separated further into five categories (I–V) as shown in Figure 2 and Table 2. Examples of typical sources for discomforts in different work environment categories are depicted in Table 2.

**Table 2**  Some typical sources for discomforts in different work environments

<table>
<thead>
<tr>
<th>Work environment</th>
<th>Examples of typical discomforts and risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Courtyards and premises</td>
<td></td>
</tr>
<tr>
<td>I Customers’ premises</td>
<td>- Narrowness inside buildings due to structural design issues.</td>
</tr>
<tr>
<td></td>
<td>- Other structural design issues, such as:</td>
</tr>
<tr>
<td></td>
<td>- bad lighting solutions inside and outside premises</td>
</tr>
<tr>
<td></td>
<td>- doors opening on wrong directions on drivers’ point of view</td>
</tr>
<tr>
<td></td>
<td>- high doorsteps</td>
</tr>
<tr>
<td></td>
<td>- slipperiness, ice on the ground.</td>
</tr>
<tr>
<td></td>
<td>- Narrowness inside premises due to miscellaneous obstacles and disorder (such as rubbish bins and returning roller cages).</td>
</tr>
<tr>
<td></td>
<td>- Long distances on the courtyards.</td>
</tr>
<tr>
<td></td>
<td>- No help available during the night. That causes uncertainty in unclear situations, such as when the doors are locked, aids and tools are missing and if confronting people that should not be at the premises (e.g., burglars and drunken people).</td>
</tr>
<tr>
<td>II Home terminals</td>
<td>- Long distances inside the terminals.</td>
</tr>
<tr>
<td></td>
<td>- Bad lighting solutions.</td>
</tr>
<tr>
<td></td>
<td>- Noise from other loading units.</td>
</tr>
<tr>
<td>2 Trucks</td>
<td></td>
</tr>
<tr>
<td>III Cargo spaces</td>
<td>- Problems with securing irregularly shaped loads. Bedding points might be too small and frozen during the wintertime.</td>
</tr>
<tr>
<td></td>
<td>- Ascending and descending cargo space.</td>
</tr>
<tr>
<td>IV Tailgate loaders</td>
<td>- Heavy, high or large loads (difficult to move).</td>
</tr>
<tr>
<td></td>
<td>- Climbing on and jumping of the tail gate loader.</td>
</tr>
<tr>
<td></td>
<td>- No fall arrest systems on tailgate loaders for loads and driver.</td>
</tr>
<tr>
<td></td>
<td>- Non-functioning remote controls.</td>
</tr>
<tr>
<td>V Cabs and outwards body structures</td>
<td>- Positioning and use of in-vehicle computers.</td>
</tr>
<tr>
<td></td>
<td>- Positioning of different plugs and gas tank vary between different truck and trailers. Might require climbing on the trailer body.</td>
</tr>
<tr>
<td></td>
<td>- Cargo space supporters and their installations. Installation requires manual work and might be noisy. Practices vary between different manufacturers’ products.</td>
</tr>
</tbody>
</table>

Most of the discomforts were related to customer’s premises (37%) and home terminals (15%) (Figure 2). However, almost half of the discomforts were related to trucks and their bodies.
3.2 Questionnaire

Nineteen of 28 companies responded to the questionnaire which resulted in a survey response rate of 68%. The respondents appreciated new innovations and products, and rated these as important or highly important (Figure 3). According to the respondents’ open answers, new product ideas and innovations are end-results from internal R&D processes and from different cooperation procedures with the end-user companies. The companies are willing to allow end-users – both individuals and companies – to participate more but they lack systematic procedures and methods to actually provide the opportunity.

Figure 3 illustrates that the respondents mostly appreciated end-users and their knowledge and experiences as important aspects in manufacturing companies’ R&D processes. The end-users are commonly taken into account at the early stages of the
design processes. End-users are strongly involved in the design, testing and implementation phases in nearly half (47%) of the respondent companies. The opportunities for participation were provided by holding various kinds of interviews (42% of the companies), usability tests (26%) and by offering a possibility to give feedback. Exhibitions are another common forum for feedback collection. However, there are also companies (32%) that do not collect feedback at all from the end-users.

Safety, ergonomics and usability aspects are commonly appreciated as important or highly important in R&D processes. However, 16% of the respondents found it less important to take ergonomics and usability aspects into consideration in the early design phases. Furthermore, the usage of accident reports and databases is for most of the respondents (58%) only somewhat important during early design phases (Figure 3). Only one company uses systematically data provided by insurance companies.

The companies are very eager to utilise data that is produced by their own R&D department (Figure 4). They also perceive continuous development processes with end-user companies as very important. However, there are differences in how the companies use external data. A large proportion of the companies find it less important (37%) or not meaningful (16%) to use research data that is produced by research institutes and universities. Only two companies responded that they systematically utilised research done at institutes and universities. In addition, a majority of the companies think that it is not important to use data that is produced by occupational health care services. Only one company responded that they systematically benchmark vehicles of other businesses.

**Figure 4** The importance of different R&D data sources ($n = 19$)

<table>
<thead>
<tr>
<th>Data sources for R&amp;D</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous development with the end-user companies</td>
<td>19</td>
</tr>
<tr>
<td>Occupational health care services</td>
<td>3 (Don't know or not meaningful)</td>
</tr>
<tr>
<td>Research institutes and universities</td>
<td>1 (Don't know or not meaningful)</td>
</tr>
<tr>
<td>Own R&amp;D department</td>
<td>11 (Don't know or not meaningful)</td>
</tr>
</tbody>
</table>

### 4 Discussion

In this study, the VIDAR analysis was utilised for the first time in participative development processes of mobile work on a large scale. In contrast to this study, VIDAR
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analyses have previously been mainly used in ergonomic workplace assessments in both repetitive and complex work, but only on jobs which do not require working in varying environments. Herein, VIDAR was utilised in identifying and categorising ergonomic discomforts at different work environments for mobile workers. The identifications of discomforts and risks can be divided into two quite evenly sized work environment categories; firstly trucks and secondly open spaces and customer and home terminal premises. Both categories need their own development actions and participative design approaches, but some of the improvements can be achieved by small modifications on working methods and attitudes. These include aspects such as:

• changing working methods from carrying to pushing or pulling
• accommodating the three point contact rule (three of four limbs are in contact with vehicle at all time) when ascending or descending
• setting the load on as back as possible on the tailgate loader
• utilising more widely already existing tools and aids.

To disseminate these practices, stronger efforts and also training for the drivers are needed. Working environments could also be easily improved with relatively small enhancements on, e.g.:

• floor and ground materials and their slipperiness
• signals and guidance material
• lighting solutions
• general order and cleanliness.

Different feedback channels between drivers and customers could also be efficient and quite easily executable solutions on collecting risk and defect factors and distributing good practices. VIDAR could be used also for these purposes. As in this study, VIDAR identifications served as visualised definitions of work-related problems. These definitions were utilised in diversified development sessions at a macro level for defining different development needs and also at a micro level for visual definitions of individual problems. At a macro level the drivers’, middle management’s, cargo space designers’, end-users’, ergonomists’ and other stakeholders’ shared design sessions led to the development of ICT-based tools that could be utilised in evaluating different work environments and also drivers’ actions. However, the testing of this tool is still running. On a micro level the sessions led to a number of practical improvement proposals for issues such as container supports and their safe installation and lighting issues inside cargo spaces. Currently, these proposals are included in a cargo space manufacturing company’s R&D processes.

According to the answers to the questionnaire, the manufacturing companies lack systematic tools and procedures for ergonomics and user-centred design. As found in the literature review, ergonomics and safety aspects should be emphasised more vigorously from the early concept and design stages. VIDAR could be an incredibly useful tool in enabling participation, as it provides concrete visualisation of the problems. In this study, different interest groups participated in the analyses for facilitating user-centred design in a new and effective way. Furthermore, the participation of other stakeholders such as occupational health care experts, customers and safety authorities’ at some level should
be considered. However, the VIDAR process is rather time consuming, and thus the participants should be carefully selected separately for each case.

4.1 Proposal on how participative design processes could be arranged

Accident information and accident statistics analyses provide accurate micro and macro level data of accidents. However, they are currently insufficiently utilised in the transportation field. Accident information and analysis data should be more carefully considered in transportation companies’ safety management procedures as well as in user-centred design. Some key problem entities can be identified and highlighted through accident data analyses allowing further analyses to be directed in the right areas. The problem areas and the tasks in which they occur can be video recorded and further analysed with VIDAR or another other video-based method. The results from VIDAR analyses can be utilised in various ways. Key identifications can be highlighted when illustrating definite ongoing and temporary problems for further discussions and also when outlining more wide-ranging development needs on a macro level.

The strength of VIDAR is that it visualises problems and thus offers concrete basis for improving work systems. Through visualisation researchers and design professionals are able to learn about the users’ work environments. Figure 5 illustrates a proposal on how future participative design processes could be arranged. The proposal is based on the findings of the study and the authors’ experiences during on the project. More research is needed for determining the best way for its implementation and its cost-effectiveness in different cases.

Figure 5  Simplified illustration of the proposal
According to the proposal, statistical analyses and VIDAR analyses could be utilised for defining problems and development needs. This can take place at a company level or on a larger scale. Participation of different interest groups in different tasks should be evaluated on a case-specific basis. Naturally, other subjective and objective tools and methods should not be forgotten. Each type of tool and method contains errors and disadvantages which are characteristic to it, so the most reliable overview is gained by effectively using all available tools.

All relevant stakeholders should be identified and observed in the design processes. Safety and good ergonomics are not achieved simply by following a set of development methods. They must be planned and built into a product by considering different user-centred aspects at all stages. Maybe in the future the ‘design for safety’ and ‘design for ergonomics’ aspects will be studied and introduced.

Video analyses should be considered not only as a technique for participation, but as a productive methodology in development processes. In this study, the time spent on acquiring video data from the drivers’ work domain established a common ground and a better understanding about the work context between the stakeholders, though the work context was in general well-known for all. The authors believe that the visual expression of the work environment was important in creating an atmosphere where drivers’ and other stakeholders’ contributions were taken into account seriously and tacit knowledge could be collected. Based on the experience with this research, the authors argue that the video assisted analysis method supports the concurrent participation of all stakeholders from the very beginning of the development project.

4.2 Validity of the research

The validity of the subjective VIDAR method remains unconfirmed. Some yet unanswered questions related to the size and homogeneity of the subject groups and to the point of time of the analyses (in parallel with the video recording, immediately afterwards or later) were raised during the study. Still, even though the VIDAR analyses were made during a short time period (late winter 2008) the results confirm that problems faced by delivery truck drivers reported in the literature review are significant.

When utilising ‘self-confrontation’ methods the extent to which the video recordings reflect the natural behaviour of the participants or whether they are influenced by the recording must be considered. Kadefors and Forsman (2000) noticed in VIDAR research that the behaviour of the research subjects may change. Still they argued that a more significant risk related to the reliability of studies of this type is that subjects may change their standards and angle of analysis during the analysis phase. Also, after having done a great amount of video recordings of workers performing their routine work, the authors’ experience is that subjects hardly change their behaviour because of the recording.

The questionnaire was reviewed by two additional researchers and one expert from the transportation industry. The external review of the questionnaire establishes that it is not biased and that the questions were valid for this research. The questionnaire was sent to almost all Finnish truck body and trailer manufacturing companies resulting in a response rate of 68%. The very high survey response rate also confirms the validity of the quantitative section of the questionnaire. The qualitative section of the questionnaire was intended to capture the unique perspectives of the manufacturers. The responses are rather subjective in nature and thus they must be interpreted cautiously.
5 Conclusions

This study discusses the often forgotten issue of the safety of truck drivers’ work environments outside the cab. According to subjective video analyses performed for this study, the daily risks and discomforts encountered by drivers when performing different tasks are caused by both the obstacles at premises and the design features of the truck bodies and trailers.

According to the results of this study and the literature review, all safety aspects are not fully taken into account in truck body and trailer design as far as work outside the cab is concerned. Currently used product design methods and tools are not sufficient for identifying potential risks in truck drivers’ work. For example, accident information and data analyses could be utilised more profoundly when recognising different ongoing and temporary risk sources. Ongoing risks should be especially highlighted and brought to the designers’ knowledge. Video analyses produce visual recording of the work environment outside the cab and associated risks. Visualised problem definitions allow designers, manufacturers and end-users to use a common language and create risk free work environment for delivery truck drivers in their work outside the cab.

User-centred approaches are required alongside traditional design processes for unimpaired human performance. Participation could be emphasised by allowing not only end-users but also occupational health care, safety and ergonomic experts to participate in the problem definition through video analyses and in product design processes by utilising visual problem definitions. VIDAR is an easy to use and suitable method for producing visual problem definitions for such purposes besides traditional ergonomic workplace assessments.

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