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Diversity and variation in biomechanical exposure: What is it, and why would we like to know?

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Abstract

Trends in global working life suggest that the occurrence of jobs characterized by long-lasting low-level loads or repetitive operations is increasing. More physical "variation" is commonly believed to be a remedy against musculoskeletal disorders in such jobs. One aim of the present paper was to shortly review the validity of this conviction. An examination of the available epidemiologic literature pointed out that the effectiveness of initiatives like job rotation or more breaks is weakly supported by empirical evidence, and only for short-term psychophysical outcomes. Only a limited number of studies have been devoted to physical variation, and concepts and metrics for variation in biomechanical exposure are not well developed. Thus, as a second objective, the paper proposes a framework for investigating and evaluating aspects of exposure variation, based on explicit definitions of *variation* as "the change in exposure across time" and *diversity* as "the extent that exposure entities differ". Operational methods for assessing these concepts are also discussed.

Keywords: Breaks; Job rotation; Physical workload

1. Variation and diversity in contemporary work

Contemporary working life in the industrialized world is characterized by several trends that have a profound influence on the physical load (biomechanical exposures) of workers in general and the variability of these loads in particular.

Companies in industry as well as in the service sector increasingly outsource segments of their production, including administrative and supportive tasks, to sub-contractors, and rationalize the remaining core production towards a larger reliance on automation and information technology (Docherty et al., 2002). These actions would be expected to result in fewer and more similar work tasks, and a general move towards lower and less varying exposure levels in those tasks.

An additional trend in industry points to increasing implementation of (neo-)tayloristic production principles with a strong focus on eliminating time losses. This suggests that jobs will show fewer opportunities for variation and recovery through discretionary or unplanned breaks, and a larger occurrence of short-cycle, repeated operations.

During production peaks, companies often hire temporary workers that are assigned to easy, standardized tasks (Neumann et al., 2002), thus leaving a smaller selection of tasks for the long-term employees. Both worker groups might thus experience biomechanical exposures with limited variation during these periods.

Increasing flexibility of work in time and space is still another trend (Aronsson, 1999), in particular in occupations with a strong representation of tasks that can be solved using modern communication tools. This particular trend suggests that exposure differences between work and leisure diminish, and hence that individuals experience a more uniform exposure profile across the day(s).

All of the above trends indicate that working life is changing in a direction that will result in less exposure variability to workers. However, it is generally believed by the scientific community (Kilbom, 1994; Bongers, 2001) as well as by legislators (Swedish National Board of Occupational Safety and Health, 1998; CEN, 2001) that "variation" in biomechanical exposure is beneficial to musculoskeletal health and well-being, and that it increases

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job satisfaction (Rissén et al., 2002; Jarvi and Uusitalo, 2004). Interventions promoting variation are often recommended (Fallentin et al., 2001) and even implemented (Davis and Jorgensen, 2005), especially for jobs characterized by "static" loads and postures, like computerized office work, or by "repetitive" work operations, like short-cycle assembly work in industry. Suggested initiatives include more diversified tasks in the job, as obtained through job enlargement or job rotation, as well as increased break allowances.

On the basis of a literature review, the present paper discusses the validity of the conviction that more "variation" is an effective remedy for improved musculoskeletal health in certain jobs. Realizing the lack of a conceptual framework, the paper also proposes basic definitions of the concepts *diversity* and *variation* in the context of biomechanical exposure, and discusses operational measures of these variables. While the paper raises several issues that would deserve a thorough review and re-appraisal, its principal aim is only to draw attention to these issues and set a stage for further discussion.

2. Diversity, variation, health and well-being

Several physiologic hypotheses have been proposed of why certain exposure patterns would, in the long term, lead to musculoskeletal disorders (Visser and Van Dieën, 2006). Most of these theories imply that posture and load variation is beneficial to health. In particular, proper recovery of muscles is believed to be of crucial importance for avoiding disorders. In that context, the generic purpose of exposure variation is to give populations of motor units that would otherwise be overloaded an opportunity to relax. This can be achieved by moving activity to other muscles outside or within the same synergy (Palmerud et al., 1998), or to other regions within the same muscles (Mathiassen and Winkel, 1990), or maybe even to other motor units within the same region (Westad et al., 2003). In occupational practice, the issue is then to identify tasks and activities that promote utilization of these degrees of freedom in motor performance.

However, the importance of exposure variation as compared to cumulative exposure or exposure peaks depends on the physiologic response under consideration, and the tissue. For instance, visco-elastic strain failure of lumbar disks depends more strongly on load levels than on the frequency of loading (van Dieën and Toussaint, 1997). In contrast, muscular fatigue development is highly sensitive to load variation even if the average load level is kept constant (Mathiassen, 1993), and both the timing and size of load changes is important. Thus, in occupational settings, relationships between biomechanical exposure variation and health can be expected to differ depending on the target outcome; and in those cases where variation is, indeed, important, no uniform answer can be expected as to how much and which kind of variation would be most appropriate.

Epidemiologic studies (Bernard, 1997; Buckle and Devereux, 1999; Sluiter et al., 2001) have documented that job exposures described as "monotonous", "static", or "repetitive" are associated with increased risks for a number of upper extremity musculoskeletal disorders, as compared to more "varying" jobs. However, postures, loads and their time aspects are, in general, superficially described in the investigated job(s), with a predominance of methods based on self-reports or expert judgment. The character and extent of variation has rarely been addressed. A few studies comparing occupations in the context of repetitive tasks have, indeed, assessed variation using observations or direct measurements, but, for some reason, with less accurate methods in the population with "varying" tasks than in the group considered to be at risk (e.g., Nordander et al., 1999). The majority of epidemiologic studies compare occupations that differ more in exposure than what would be feasible to achieve within a particular job, even with radical modification. Thus, ergonomics epidemiology offers only vague suggestions regarding the possible health effects of more variation within different jobs, as well as on what health-promoting patterns of variation might look like.

In ergonomics intervention research, the most frequently studied manipulation of biomechanical variation is to introduce more breaks in repetitive or static work. The interest in rest breaks is shared by ergonomists (Konz, 1998) and engineers (Bechtold et al., 1984), largely on the basis of an abundant literature demonstrating that periods of rest dramatically alleviate fatigue in isometric and isotonic contractions.

An increased allowance of scheduled breaks has been confirmed by some field studies of office work (Hagberg and Sundelin, 1986; Henning et al., 1997; Galinsky et al., 2000; McLean et al., 2001; van den Heuvel et al., 2003) and meat processing (Dababneh et al., 2001) to lead to less discomfort; the effect on productivity was ambiguous. In these studies, the added breaks corresponded to between 2% and 8% of total working hours, that is, noticeably less than the total duration of discretionary and scheduled breaks in ordinary work, which seems to be in the order of 10–20% of the working day excluding lunch (Nordander et al., 2000; Svendsen et al., 2005). Furthermore, when more scheduled breaks are introduced, discretionary breaks may decrease (Hagberg and Sundelin, 1986), and the scheduled breaks may be perceived as annoying due to their interference with work flow (Henning et al., 1997). How a certain overall duration of scheduled breaks is split up and distributed across the working day seems to be of minor importance to fatigue (Rohmert and Luczak, 1973; Dababneh et al., 2001) and perceived exertion (Beynon et al., 2000), with the exception of breaks being so short that muscles do not get the time to relax.

Laboratory and semi-field studies of assembly work (Sundelin, 1993; Mathiassen and Winkel, 1996) and office tasks (McLean et al., 2001) have confirmed that subjects prefer protocols with breaks over continuous work even if average work pace is maintained. However, the studies could not show that breaks had conclusive effects on physiologic fatigue. As an attractive explanation proposed by McLean et al. (2001), exposure during work could per se be so varying that a small additional contribution through the breaks would have marginal effects. This idea is based on the notion that a possible significance of breaks might not be related to their contents of *rest*, but rather to their influence on overall exposure *variation*.

As an alternative to scheduled rest breaks, some studies have investigated the effect of increasing the allowance for discretionary breaks, either without limitation (office work; Rohmert and Luczak, 1973; Henning et al., 1989) or maximized to a total of 24 min per day (meatpacking; Genaidy et al., 1995). In all of these studies, signs of fatigue appeared even with breaks. One reason may be that the increased break allowance was used only to a limited extent. Thus, in the meatpacking study by Genaidy et al. (1995), workers took out only about 5% of the allowance, presumably because stronger drivers than health and comfort guided their choice of work schedules. In any case, discretionary breaks will be effective only if exposure during the breaks differs from that during work. Some studies have indicated that breaks are, indeed, associated with less vigorous exposures than work (Nordander et al., 2000; Kazmierczak et al., 2005; Svendsen et al., 2005), but that the difference may not be particularly prominent in sedentary occupations such as ordinary office work (Fernström and Åborg, 1999; Mathiassen et al., 2003a). Notably, a "break" can, for equally good reasons depending on the context, be interpreted as a period with deviating (typically low) exposure, or as a purposeful period of non-work, be it scheduled or discretionary, or even as any period of non-work, including unexpected disturbances in production. Obviously, exposure during the break, and hence its value as a source of variation, depends on this interpretation.

For occupations exhibiting long-term, low-level exposures, increased variation may more effectively be obtained through increased activity than through more rest. Thus, introducing gymnastics exercises into office work has been investigated (Sihvonen et al., 1989; Sundelin and Hagberg, 1989; Henning et al., 1997; van den Heuvel et al., 2003), as well as mixing repetitive assembly tasks with lifting activities (Mathiassen and Winkel, 1996). In some of these studies, subjects preferred the alternative activities to a similar allowance of passive rest, while other studies failed to show this difference. None of the studies assessed the effect on disorders. Physical training programs at the workplace, which often contain regular activities during working hours and thus imply an altered exposure time-line, have so-far been of limited success in improving job satisfaction and absenteeism (Proper et al., 2002). As for the break allowance programmes discussed above, compliance has proved to be a major, critical issue in interventions promoting work-site physical activity (Silverstein et al., 1988), and strong incentives from the organization is most likely a mandatory requirement.

Job rotation, and the related initiatives task rotation, job enlargement and job enrichment are frequently recommended interventions in the ergonomics literature, in particular for jobs dominated by "repetitive" or "static" tasks. While a common rationale is the conviction that an increased physical and mental variation will be beneficial to health (Kilbom, 1994), job rotation may also be advocated for the purpose of reducing the overall exposure level (Jonsson, 1988). Surprisingly few studies have, however, been devoted to the possible effectiveness of these initiatives.

In a field study of refuse collectors, Kuijer et al. (1999) showed that workers who shifted within a day between two of the three major work tasks of truck driving, street sweeping, and refuse collection experienced less fatigue than workers only doing one of the tasks. In a prospective study, however, more low-back complaints were found in a group rotating between collecting and truck driving as compared to workers only collecting refuse (Kuijer et al., 2005). Other musculoskeletal disorders showed similar occurrences in the two groups. The risk that job rotation may impair health at the group level has been demonstrated also in a simulation study by Frazer et al. (2003). These results emphasize that the effectiveness of job rotation in a particular setting depends intimately on the shape of the relationship between the dominant exposure determinants of risk and the disorders they may cause. If the relationship is U-shaped, job rotation may reduce disorders at the group level, if not, the intervention can be indifferent or even detrimental.

A few additional papers have documented natural, company-initiated interventions with an emphasis on redistribution of tasks among individual workers. In a study of supermarket employees, rotation between seated cashiers' work and more mobile tasks, for instance at the delicatessen counter, resulted in less musculoskeletal complaints than doing cashiers' work alone, but only with scanner-type counters that did not require manual entry of prices (Hinnen et al., 1992). If traditional check-out counters were used, alternative tasks were perceived as annoying. The impact of the rotation scheme on those employees at the delicatessen counter that were derived of some of their tasks was not studied. A similar setting was studied by Rissén et al. (2002). Supermarket cashiers that were also allowed to work in other shop departments experienced the job rotation to be positive in several aspects, but no effects were found on disorders.

In an office reorganization studied by Fernström and Åborg (1999) workers became less specialized and the proportion of desk tasks, as opposed to computer work, was generally increased. However, exposure levels did not change, presumably because the available tasks in the production system had similar exposures. Exposure variation was not assessed for individual workers.

As part of a rationalization in the fish-processing industry (Ólafsdottir and Rafnsson, 1998), workers got more specialized on either short-cycle tasks or packing operations than before. The prevalence of musculoskeletal disorders in the upper extremities increased after the change. This was ascribed to decreased variation in the jobs, but variation was only evaluated by expert judgment.

Introduction of a team-based production system for assembling cars was studied by Christmansson et al. (1999). While the new organization implied considerably better opportunities for the workers to change between assembly and administrative tasks than the former, little changed in workers' perception of their psychosocial work environment, and musculoskeletal health did not improve. According to the authors, a probable explanation was that the reorganization was not accompanied by sufficient education, and that the employees therefore perceived the new organization as stressful. Again, variation was only assessed on the basis of expert judgment.

In summary, limited empirical evidence from working life supports that feasible interventions focusing on more biomechanical exposure variation are, indeed, beneficial to musculoskeletal health. Obviously, this does not oppose that variation can, indeed, be important. Neither does it per se disqualify current guidelines on diversity and variation. Rather, the lack of evidence emphasizes the need for studies that explicitly focus on exposure variation and health-related outcomes in different occupations, and studies that further investigate the feasibility and effectiveness of interventions that manipulate variation at the levels of organizations and individuals. Further progress on this line of research would be greatly facilitated by a consistent conceptual framework covering variation and diversity in exposure, as well as related issues such as "static" and "repetitive".

3. What is diversity and variation?

According to the Concise Oxford English Dictionary (Thompson, 1995), *vary* means "make different" or "undergo change," and *variation* is described as "the act or an instance of varying" or "departure from a former or normal condition." Thus, "variation" is intimately associated with change, implicitly across time. In the context of biomechanical exposures, a reasonable definition of the concept *variation* would then be "the change in exposure across time." With this definition, *variation* focuses on an exposure time-line in terms of how much and how fast exposure changes and whether it exhibits patterns of self-similarity, such as regularly recurring elements. Variation does not, however, deal with overall averages of exposure levels; neither does it consider the gross duration of exposure. An individual worker's exposure can be characterized with respect to its variation, as can a "product cycle exposure" (Bao et al., 1996), i.e. the exposure associated with manufacturing one complete product, for instance along an assembly line.

Other terms than "variation" have been used in the literature to describe time aspects of biomechanical exposures, "static" probably being the one used most frequently. While several disparate operational definitions have been proposed for "static", most of them share the idea that "static" work is characterized by postures and/or muscle activity changing only slowly across time. Thus, the proposed definition of *variation* includes "static" work as a special case of (limited) change in exposure. Also, "repetitive" work will refer to particular cases of variation, whether it stands for "similar work tasks performed again and again" (Kilbom, 1994) or "the frequency and rate of … changes [of body parts in space]" (Hagberg, 1992).

While *variation* refers to features in an individual exposure time-line (Fig. 1), it does not consider exposure similarities or discrepancies between different exposure entities, as defined for instance by tasks, jobs, occupations, or (within the individual) days or cycles. The term *diversity* is suggested to serve this purpose. According to the Concise Oxford Dictionary, "diversity" means "variety" or "a different kind", and in biology the term is used to describe the extent that species differ, for instance in a certain natural environment. Thus, in the context of biomechanical exposures, *diversity* is suggested to be defined as "the extent that exposure entities differ", the corresponding adjective being *diverse*, with the antonyms "similarity" and "similar". According to this definition, exposure entities can be diverse with respect to any biomechanical exposure variable, including those describing variation. For instance, two tasks may be *diverse* in the sense that they differ in mean exposure at the group level, or in the sense that movement frequencies differ. Likewise, two consecutive work cycles performed by a particular worker may be similar with respect to cycle time, while at the same time being more diverse in terms of the proportion of muscular rest.

Obviously, *variation* and *diversity* are closely connected concepts. A job composed of several diverse tasks, that is, tasks differing in exposure, will probably offer a sizeable

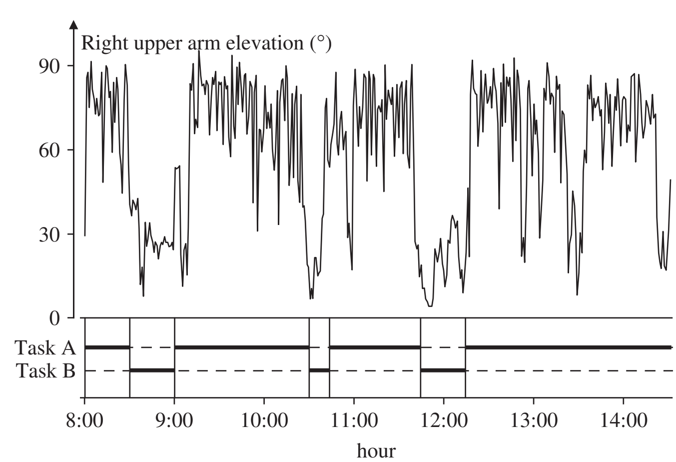

Fig. 1. Time-line of minute-to-minute averages of the right upper arm elevation angle for an individual performing two tasks, A and B.

exposure variation for the worker. At the level of production systems, substantial task diversity is a prerequisite that jobs with variation can be constructed at all. Thus, task diversity is a core determinant of "Exposure Latitude" in a production system (Bao et al., 1996).

Another term of widespread use, in particular in the statistical literature on sampling of occupational exposures, is exposure *variability* (Loomis and Kromhout, 2004; Burdorf, 2005). While being closely related to the proposed definition of diversity, the term "exposure *variability*" is suggested to be restricted to quantitative expressions of dispersion with a basis in descriptive statistics, such as variance, standard deviation or mean-square error. This limitation is consistent with the use of exposure variability in occupational epidemiology as a general term including dispersion within days within subject, between days within subject, between subjects, between tasks, between jobs. Thus, exposure variability parameters are candidates for operational expressions of diversity (cf. Section 4), but diversity can be assessed in other ways as well.

Table 1
Descriptive exposure data for the recording of upper arm elevation shown in Fig. 1

	Job	Task A	Task B
W_t	·	0.82	0.18
m_j, m_t	57.3	64.9	22.2
s_{wj}, s_{wt}	25.1	20.4	10.2
C_{Tm}	0.82	·	·
C_{Ts}	0.62	·	·

Data are shown for the entire recording (job), as well as for the two tasks A and B.
W_t, task time proportion in the recording; m_j, m_t, mean exposures of job and tasks in the recording, °; s_{wj}, s_{wt}, standard deviation of job and task exposures in the recording, °; C_{Tm}, diversity of task mean exposures, i.e. m_t. Estimated using Eq. (2), on the basis of a gross within-task between-subjects standard deviation of individual means (i.e. s_{St}) of 10° (cf. Table 5 in Mathiassen et al., 2003b); C_{Ts}, diversity of within-task within-subject standard deviations of exposure, i.e. s_{wt}. Estimated using Eq. (2), on the basis of a gross within-task between-subjects standard deviation of s_{wt} of 4° (unpublished data from the study reported by Mathiassen et al., 2003b); ·, not applicable.

4. Measuring variation and diversity

While methods for assessing biomechanical exposure levels are well developed in the ergonomics literature, less attention has been paid to measuring exposure diversity and variation in consistent and standardized ways (Mathiassen and Christmansson, 2004). The proposed definition of *variation*—"the change in exposure across time"—implies that the issues of how fast and how much a particular exposure changes, and whether it exhibits recurring, similar elements, all qualify as aspects of variation.

A variety of methods have been proposed for assessing how fast or often a biomechanical exposure changes, that is, its properties in the frequency domain. Procedures range from rather simple ones, such as counting of motions during a specified time period (Colombini, 1998), and observing the number of times per hour that extremities move between certain angle sectors (Kilbom and Persson, 1987), to approaches requiring advanced equipment for data collection and processing, such as estimating the frequency of muscle activity sequences below (Veiersted et al., 1990) or above (Mork and Westgaard, 2005) certain thresholds, or assessing key parameters from the frequency spectrum of posture recordings (Ohlsson et al., 1994). Notably, since movements are equivalent to changes in posture across time, parameters describing movement speed reflect the frequency contents of the corresponding posture recordings.

The aspect of "how much" an exposure changes across time has received less attention in terms of quantification than "how fast". A considerable body of literature refers to "static" work or "constrained postures", with the implicit message that exposure changes little across time, but quantitative descriptors of how "static" or "constrained" the work might be are rare. A particularly simple expression of "how much" is the overall exposure range, for instance measured through the difference between the 5th and 95th percentiles of the cumulated exposure distribution (the APDF; Jonsson, 1988). A related approach, which is more consistent with procedures suggested below for assessing diversity, is to determine the variance (or, equivalently, the standard deviation) of the overall exposure distribution (Table 1). One advantage of this metric is that the overall within-subject within-job variability, s^2_{wj}, in a combination of tasks can be estimated on the basis of information about each of the tasks:

$$s^2_{wj} = \sum\nolimits_t W_t\left[(m_t - \sum\nolimits_t W_t m_t)^2 + s^2_{wt}\right], \qquad (1)$$

where Σ_t indicates summation across tasks, and W_t, m_t and s^2_{wt} are the time proportion, mean exposure and within-subject exposure variance of task t, respectively. Thus, Eq. (1) connects traditional, task-based analysis in ergonomics (Dempsey and Mathiassen, 2006) with an epidemiologic job-oriented view on exposure (Mathiassen et al., 2003a). Eq. (1) might even with some caution (Mathiassen et al., 2003b) be used to predict exposure variability for an individual on the basis of average task data from relevant groups. Several studies have reported task exposures in the context of task diversity in a job (e.g. Finsen et al., 1998; Hye-Knudsen et al., 2004), but the implications in terms of overall exposure variation in the job have not been estimated on a quantitative level.

While the metrics discussed above give separate answers to "how often" or "how much" exposure changes, the exposure variation analysis (EVA; Mathiassen and Winkel, 1991) attempts to capture both aspects at the same time. EVA assesses the proportion of work time spent in uninterrupted sequences within specified exposure level categories, classifying the sequences according to their duration (Table 2). Thus, an EVA shows how often exposure changes according to the exposure magnitude. Several modifications of EVA have already been proposed (Mathiassen and Winkel, 1996; Anton et al., 2003; Larivière et al., 2005), and an interesting line of further development would be to implement a "continuous EVA", that is, the instantaneous rate of change in exposure as a function of the exposure level at that point in time (Fig. 2). This plot provides the marginal distributions answering "how much" and "how fast" exposure changes, while at the same time showing, for instance, whether slow changes (indicating "static" work) occur at extreme exposure levels.

Metrics for diversity, that is, "the extent that exposure entities differ", or its antonym similarity, are not well developed in ergonomics (Moore and Wells, 1992; Mathiassen and Christmansson, 2004). When it comes to diversity within a particular exposure time-line, substantial attention has been paid to whether similar elements or "blocks" of exposure occur at regular intervals, that is, in a "repetitive" pattern. As with "static" and "constrained" exposures, many studies have been devoted to "repetitive" work with little or no consideration as to measuring the extent of "repetitiveness". Many of these studies have been concerned with cyclic tasks, and thus have used the cycle time as a proxy for (lack of) diversity in the job, whether it be estimated from production data or observations (Silverstein et al., 1986; Neumann et al., 2002). A few studies have assessed the periodicity of movements on basis of the posture power spectrum (Radwin and Lin, 1993; Ohlsson et al., 1994). However, the assumption of a near-perfect cycle-to-cycle similarity in repetitive work is not trivial. Both postures and muscle activation vary between repetitions of controlled, short-cycle tasks in the laboratory (Kjellberg et al., 1998; Mathiassen et al., 2002, 2003b). This motor variability seems to increase in occupational settings (Möller et al., 2004), and it is probably influenced by production factors as well as by personal traits (Gaudart, 2000; Mathiassen et al., 2003b). Notably, diversity can be assessed for parameters reflecting any of the three main dimensions of posture: amplitude, frequency, and duration (Möller et al., 2004), and even for complete exposure blocks (Winter and Yack, 1987).

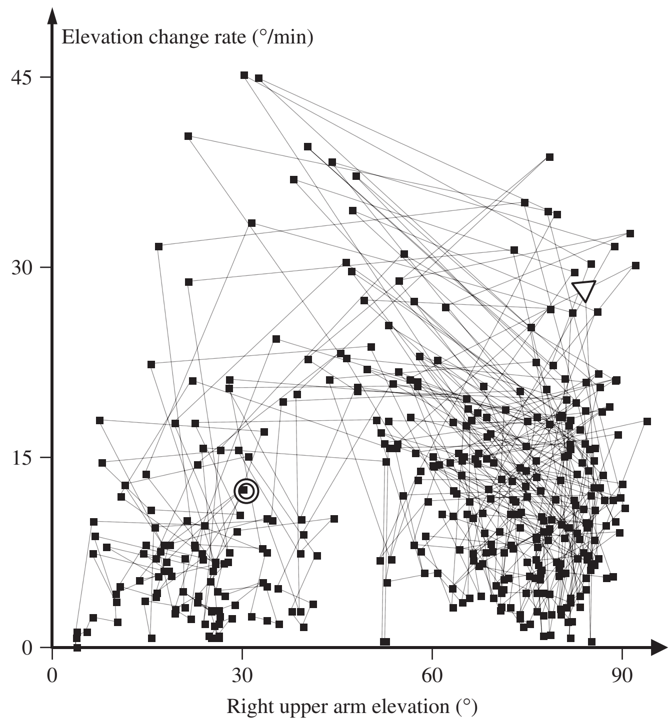

Fig. 2. Consecutive minute-to-minute relationship between right upper arm elevation and its instantaneous change rate for the recording in Fig. 1. Triangle, double circle: first and last minute, respectively.

Table 2
Exposure Variation Analysis of the recording of upper arm elevation shown in Fig. 1

	Sequence duration (min)					
Posture interval (°)	0–1	1–3	3–7	7–15	15–31	All
0–15	2.3	1.3	0.0	2.0	0.0	5.6
15–30	2.6	8.7	1.8	0.0	4.1	17.1
30–45	3.8	1.8	3.1	0.0	0.0	8.7
45–60	7.7	3.6	1.0	0.0	0.0	12.3
60–75	9.5	11.5	1.0	0.0	0.0	22.0
75–90	6.6	19.4	7.2	0.0	0.0	33.2
90–105	1.0	0.0	0.0	0.0	0.0	1.0
All	33.5	46.3	14.1	2.0	4.1	100.0

The value in a cell shows the percentage of total time spent in a particular posture interval (row), and in uninterrupted sequences of a specified duration (column). For example, during 3.6% of the analyzed work, the arm was elevated between 45° and 60° in sequences lasting between 1 and 3 min.

If exposure is distributed in a random fashion across time, the exposure variance between blocks of exposure will be expected to decrease in a direct, inverse relation to the length (duration) of the blocks (Mathiassen et al., 2003a). Thus, the issue of whether "similar" blocks of exposure occur in the exposure time-line comes down to analyzing if the block-to-block variance deviates from expected values at any particular block length larger than the basic analysis time unit (quantum length; Mathiassen et al., 2003a) in the original exposure recording. In work consisting of cyclically repeated tasks, the cycle time offers an obvious candidate for a block length that should be analyzed with respect to (lack of) exposure diversity (Möller et al., 2004). In non-cyclic tasks, or for work containing more than one task, the block length must be defined in terms of a time period, e.g., minutes (Mathiassen et al., 2003a) or hours (Westgaard et al., 2001). It might then be appropriate to retrieve the block-to-block variance as a function of the block length (Fig. 3). The shape of this relationship can, for instance, be analyzed using techniques originating in complexity theory, for the purpose of disclosing patterns of autocorrelation and self-similarity (Glenny et al., 1991). Obviously, this will also assess cycle-to-cycle diversity in

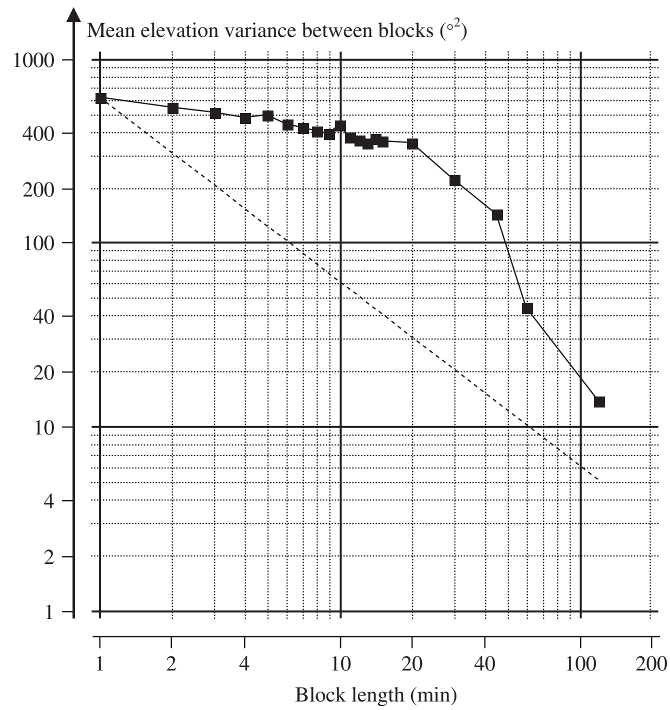

Fig. 3. Variance between mean right upper arm elevations in time blocks of increasing length, cut from the recording in Fig. 1. Dashed line: expected, linear relationship (log–log plot) between variance and block length for randomly distributed exposures.

cyclic work, since the average cycle time appears as a special case of block length. Keeping track of the time-line in a "continuous EVA" plot (Fig. 2) offers another challenging opportunity for identifying periods of self-similarity in exposure. None of these approaches have so far been tested on biomechanical exposures.

While diversity within an exposure time-line is an aspect of exposure variation, diversity beyond the individual concerns the extent that tasks, jobs, occupations or groups differ in exposure. The idea of using standard statistical dispersion measures of relevant exposure parameters as metrics for diversity can be generalized to include even these issues. This approach is attractive because it can be practiced using well-known statistical mixed-model procedures for deriving variance components, which are, to some extent, part of standard analysis of data dispersion (Loomis and Kromhout, 2004; Burdorf, 2005). Thus, the diversity among groups or conditions can be assessed in absolute terms using the appropriate mean-squared error (MSE), or by indices that also fulfil the reasonable request of being sensitive to whether conditions differ consistently among individuals. As an example, the diversity between tasks in a production system can be expressed as (Mathiassen et al., 2005)

$$C_{\mathrm{T}} = \mathrm{MSE}_{\mathrm{T}} / \left[\mathrm{MSE}_{\mathrm{T}} + s^2_{\mathrm{S}t}\right] \quad (2)$$

with $\mathrm{MSE}_{\mathrm{T}}$: mean-squared error between tasks; $s^2_{\mathrm{S}t}$: gross exposure variance between subjects within task, including within-subject components. This index, which can be assessed for any exposure parameter (Table 1), can take values between zero and 1, the former when task exposure means are exactly equal, and the latter when task exposure means differ, but all individuals share the same exposure in each particular task.

The statistical precision of the proposed variance-based diversity metrics can be assessed by analytical algorithms (Mathiassen et al., 2003b) or by empirical re-sampling techniques, such as bootstrapping (Mathiassen et al., 2002).

5. Conclusions

More physical variation is commonly suggested to be an effective intervention against musculoskeletal disorders in jobs with low-level, long-lasting loads or repetitive operations. The present literature review points out that the empirical evidence for this conviction in intervention studies or epidemiology is weak. Some studies have shown beneficial effects of increased break allowances on short-term discomfort, while very few studies have been aimed at the long-term effects of initiatives like job rotation or job enlargement, and with inconsistent results. Further progress of research in this field is restrained by the present lack of a consistent conceptual framework for discussing and assessing aspects of exposure "variation".

In response to the latter insight, two distinct concepts are suggested: *variation* defined as "the change in exposure across time", and *diversity* meaning "the extent that exposure entities differ". Variation can then be assessed using variables expressing how much and how fast a particular exposure changes, and whether it exhibits recurring elements. Some candidates for appropriate measures can be found in the literature, but further development is needed, in particular with respect to recurring time patterns. Metrics for diversity are even less developed, but a promising idea is to base them on traditional statistical expressions of dispersion, such as standard deviations.

Using this conceptual and methodological framework as a stepping stone, there is a need for studies that can show in which occupational settings more exposure variation is an appropriate intervention and what an optimal variation might be in those settings. This research should, for instance, be devoted to answering what an adequate collection of tasks in a production system might look like in terms of proportions and exposure diversity, and what the promoters—at the level of individuals and systems—would be for creating jobs with good variation from these tasks.

Furthermore, there is a need for controlled experiments that can establish and explain the physiological and psychophysical effects of different sources of physical and mental variation, so as to feed working life interventions and help explaining their results.

References

Anton, D., Cook, T.M., Rosecrance, J.C., Merlino, L.A., 2003. Method for quantitatively assessing physical risk factors during variable noncyclic work. Scand. J. Work Environ. Health 29, 354–362.

Aronsson, G., 1999. Influence of worklife on public health. Scand. J. Work Environ. Health 25, 597–604.

Bao, S., Mathiassen, S.E., Winkel, J., 1996. Ergonomic effects of a management-based rationalization in assembly work—a case study. Appl. Ergon. 27, 89–99.

Bechtold, S.E., Janaro, R.E., DeWitt, L.S., 1984. Maximization of labor productivity through optimal rest-break schedules. Manage. Sci. 30, 1442–1458.

Bernard, B., 1997. Musculoskeletal Disorders and Workplace Factors. NIOSH Publication 97-141, second ed. US Department of Health and Human Services, Cincinnati, OH.

Beynon, C., Burke, J., Doran, D., Nevill, A., 2000. Effects of activity-rest schedules on physiological strain and spinal load in hospital-based porters. Ergonomics 43, 1763–1770.

Bongers, P.M., 2001. The cost of shoulder pain at work. BMJ 322, 64–65.

Buckle, P., Devereux, J., 1999. Work-related neck and upper limb musculoskeletal disorders. Issue 201, Luxembourg, European Agency for Safety and Health at Work.

Burdorf, A., 2005. Identification of determinants of exposure: consequences for measurement and control strategies. Occup. Environ. Med. 62, 344–350.

CEN, 2001. EN 1005-3. Safety of Machinery—Human Physical Performance—Part 3: Recommended Force Limits for Machinery Operation. Comité Européen de Normalisation (CEN), Bruxelles.

Christmansson, M., Fridén, J., Sollerman, C., 1999. Task design, psychosocial work climate and upper extremity pain disorders—effects of an organisational redesign on manual repetitive assembly jobs. Appl. Ergon. 30, 463–472.

Colombini, D., 1998. An observational method for classifying exposure to repetitive movements of the upper limbs. Ergonomics 41, 1261–1289.

Dababneh, A.J., Swanson, N., Shell, R.L., 2001. Impact of added rest breaks on the productivity and well being of workers. Ergonomics 44, 164–174.

Davis, K., Jorgensen, M., 2005. Ergonomics. Pros and cons of job rotation as a means of reducing injury costs. J. Occup. Environ. Hyg. 2, D1–D3.

Dempsey, P.G., Mathiassen, S.E., 2006. On the evolution of task-based analysis of manual materials handling, and its applicability in contemporary ergonomics. Appl. Ergon. 37, 33–43.

Docherty, P., Forslin, J., Shani, A.B., 2002. Creating Sustainable Work Systems: Emerging Perspectives and Practice. Taylor & Francis, London.

Fallentin, N., Viikari-Juntura, E., Wærsted, M., Kilbom, Å., 2001. Evaluation of physical workload standards and guidelines from a Nordic perspective. Scand. J. Work Environ. Health. 27 (Suppl. 2), 1–52.

Fernström, E.A.C., Åborg, C.M., 1999. Alterations in shoulder muscle activity due to changes in data entry organisation. Int. J. Ind. Ergon. 23, 231–240.

Finsen, L., Christensen, H., Bakke, M., 1998. Musculoskeletal disorders among dentists and variation in dental work. Appl. Ergon. 29, 119–125.

Frazer, M.B., Norman, R.W., Wells, R.W., Neumann, W.P., 2003. The effects of job rotation on the risk of reporting low back pain. Ergonomics 46, 904–919.

Galinsky, T.L., Swanson, N.G., Sauter, S.L., Hurrell, J.J., Schleifer, L.M., 2000. A field study of supplementary rest breaks for data-entry operators. Ergonomics 43, 622–638.

Gaudart, C., 2000. Conditions for maintaining ageing operators at work—a case study conducted at an automobile manufacturing plant. Appl. Ergon. 31, 453–462.

Genaidy, A.M., Delgado, E., Bustos, T., 1995. Active microbreak effects on musculoskeletal comfort ratings in meatpacking plants. Ergonomics 38, 326–336.

Glenny, R.W., Robertson, T., Yamashiro, S., Bassingthwaighte, J.B., 1991. Applications of fractal analysis to physiology. J. Appl. Physiol. 70, 2351–2367.

Hagberg, M., Sundelin, G., 1986. Discomfort and load on the upper trapezius muscle when operating a wordprocessor. Ergonomics 29, 1637–1645.

Hagberg, M., 1992. Exposure variables in ergonomic epidemiology. Am. J. Ind. Med. 21, 91–100.

Henning, R.A., Sauter, S.L., Salvendy, G., Kreig, E.F., 1989. Microbreak length, performance, and stress in a data entry task. Ergonomics 32, 855–864.

Henning, R.A., Jacques, P., Kissel, G.V., Sullivan, A.B., Alteras-Webb, S.M., 1997. Frequent short rest breaks from computer work: effects on productivity and well-being at two field sites. Ergonomics 40, 78–91.

Hinnen, U., Läubli, T., Guggenbühl, U., Krueger, H., 1992. Design of check-out systems including laser scanners for sitting work posture. Scand. J. Work Environ. Health 18, 186–194.

Hye-Knudsen, C.T., Schibye, B., Hjortskov, N., Fallentin, N., 2004. Trunk motion characteristics during different patient handling tasks. Int. J. Ind. Ergon. 33, 327–337.

Jarvi, M., Uusitalo, T., 2004. Job rotation in nursing: a study of job rotation among nursing personnel from the literature and via a questionnaire. J. Nurs. Manage. 12, 337–347.

Jonsson, B., 1988. The static load component in muscle work. Eur. J. Appl. Physiol. 57, 305–310.

Kazmierczak, K., Mathiassen, S.E., Forsman, M., Winkel, J., 2005. An integrated analysis of ergonomics and time consumption in Swedish 'craft-type' car disassembly. Appl. Ergon. 36, 263–273.

Kilbom, Å., Persson, J., 1987. Work technique and its consequences for musculoskeletal disorders. Ergonomics 30, 273–279.

Kilbom, Å., 1994. Repetitive work of the upper extremity: part II—the scientific basis (knowledge base) for the guide. Int. J. Ind. Ergon. 14, 59–86.

Kjellberg, K., Lindbeck, L., Hagberg, M., 1998. Method and performance: two elements of work technique. Ergonomics 41, 798–816.

Konz, S., 1998. Work/rest: part II—the scientific basis (knowledge base) for the guide. Int. J. Ind. Ergon. 22, 73–99.

Kuijer, P.P.F.M., Visser, B., Kemper, H.C.G., 1999. Job rotation as a factor in reducing physical workload at a refuse collecting department. Ergonomics 42, 1167–1178.

Kuijer, P.P.F.M, van der Beek, A.J., van Dieën, J.H., Visser, B., Frings-Dresen, M.H.W., 2005. Effect of job rotation on need for recovery, musculoskeletal complaints, and sick leave due to musculoskeletal complaints: a prospective study among refuse collectors. Am. J. Ind. Med. 47, 394–402.

Larivière, C., Delisle, A., Plamondon, A., 2005. The effect of sampling frequency on EMG measures of occupational mechanical exposure. J. Electromyogr Kinesiol. 15, 200–209.

Loomis, D., Kromhout, H., 2004. Exposure variability: concepts and applications in occupational epidemiology. Am. J. Ind. Med. 45, 113–122.

Mathiassen, S.E., 1993. The influence of exercise/rest-schedule on the physiological and psychophysical response to isometric shoulder-neck exercise. Eur. J. Appl. Physiol. 67, 528–539.

Mathiassen, S.E., Christmansson, M., 2004. Variation and autonomy. In: Delleman, N., Haslegrave, C., Chaffin, D. (Eds.), Working Postures and Movements—Tools for Evaluation and Engineering. CRC Press, London, pp. 330–366.

Mathiassen, S.E., Winkel, J., 1990. Electromyographic activity in the shoulder–neck region according to arm position and glenohumeral torque. Eur. J. Appl. Physiol. 61, 370–379.

Mathiassen, S.E., Winkel, J., 1991. Quantifying variation in physical load using exposure-vs.-time data. Ergonomics 34, 1455–1468.

Mathiassen, S.E., Winkel, J., 1996. Physiologic comparison of three interventions in light assembly work: reduced work pace, increased break allowance and shortened working days. Int. Arch. Occup. Environ. Health 68, 94–108.

Mathiassen, S.E., Burdorf, A., van der Beek, A.J., 2002. Statistical power and measurement allocation in ergonomic intervention studies assessing upper trapezius EMG amplitude. A case study of assembly work. J. Electromyogr Kinesiol. 12, 27–39.

Mathiassen, S.E., Burdorf, A., van der Beek, A.J., Hansson, G.-Å., 2003a. Efficient one-day sampling of mechanical job exposure data—a study based on upper trapezius activity in cleaners and office workers. Am. Ind. Hyg. Assoc. J. 64, 196–211.

Mathiassen, S.E., Möller, T., Forsman, M., 2003b. Variability in mechanical exposure within and between individuals performing a highly constrained industrial work task. Ergonomics 46, 800–824.

Mathiassen, S.E., Nordander, C., Svendsen, S.W., Wellman, H.M., Dempsey, P.G., 2005. Task-based estimation of mechanical job exposure in occupational groups. Scand. J. Work Environ. Health 31, 138–151.

McLean, L., Tingley, M., Scott, R.N., Rickards, J., 2001. Computer terminal work and the benefit of microbreaks. Appl. Ergon. 32, 225–237.

Moore, A.E., Wells, R., 1992. Towards a definition of repetitiveness in manual tasks. In: Mattila, M., Karwowski, W. (Eds.), Computer Applications in Ergonomics, Occupational Safety and Health. Elsevier, New York, pp. 401–408.

Mork, P.J., Westgaard, R.H., 2005. Long-term electromyographic activity in upper trapezius and low back muscles of women with moderate physical activity. J. Appl. Physiol. 99, 570–578.

Möller, T., Mathiassen, S.E., Franzon, H., Kihlberg, S., 2004. Job enlargement and mechanical exposure variability in cyclic assembly work. Ergonomics 47, 19–40.

Neumann, W.P., Kihlberg, S., Medbo, P., Mathiassen, S.E., Winkel, J., 2002. A case study evaluating the ergonomic and productivity impacts of partial automation strategies in the electronics industry. Int. J. Prod. Res. 40, 4059–4075.

Nordander, C., Ohlsson, K., Balogh, I., Rylander, L., Pålsson, B., Skerfving, S., 1999. Fish processing work: the impact of two sex dependent exposure profiles on musculoskeletal health. Occup. Environ. Med. 56, 256–264.

Nordander, C., Hansson, G.-Å., Rylander, L., Asterland, P., Unge Byström, J., Ohlsson, K., Balogh, I., Skerfving, S., 2000. Muscular rest and gap frequency as EMG measures of physical exposure: the impact of work tasks and individual related factors. Ergonomics 43, 1904–1919.

Ohlsson, K., Hansson, G.-Å., Balogh, I., Strömberg, U., Pålsson, B., Nordander, C., Rylander, L., Skerfving, S., 1994. Disorders of the neck and upper limbs in women in the fish processing industry. J. Occup. Environ. Med. 54, 826–832.

Ólafsdottir, H., Rafnsson, V., 1998. Increase in musculoskeletal symptoms of upper limbs among women after introduction of the flow-line in fish-fillet plants. Int. J. Ind. Ergon. 21, 69–77.

Palmerud, G., Sporrong, H., Herberts, P., Kadefors, R., 1998. Consequences of trapezius relaxation on the distribution of shoulder muscle forces: an electromyographic study. J. Electromyogr Kinesiol. 8, 185–193.

Proper, K., Staal, B.J., Hildebrandt, V.H., Van der Beek, A.J., van Mechelen, W., 2002. Effectiveness of physical activity programs at worksites with respect to work-related outcomes. Scand. J. Work Environ. Health 28, 75–84.

Radwin, R.G., Lin, M.L., 1993. An analytical method for characterizing repetitive motion and postural stress using spectral analysis. Ergonomics 36, 379–389.

Rissén, D., Melin, B., Sandsjö, L., Dohns, I., Lundberg, U., 2002. Psychophysiological stress reactions, trapezius muscle activity, and neck and shoulder pain among female cashiers before and after introduction of job rotation. Work Stress 16, 127–137.

Rohmert, W., Luczak, H., 1973. Ergonomische Untersuchung von Teilzeit-Schichtsystemen und Pausen bei informatorischer Arbeit. Int. Arch. Arbeitsmed. 31, 171–191.

Sihvonen, T., Baskin, K., Hänninen, O., 1989. Neck-shoulder loading in wordprocessor use. Int. Arch. Occup. Environ. Health 61, 229–233.

Silverstein, B., Armstrong, T., Longmate, A., Woody, D., 1988. Can in-plant exercise control musculoskeletal symptoms. J. Occup. Med. 30, 922–927.

Silverstein, B.A., Fine, L.J., Armstrong, T.J., 1986. Hand-wrist cumulative trauma disorders in industry. Br. J. Ind. Med. 43, 779–784.

Sluiter, J.K., Rest, K.M., Frings-Dresen, M.H.W., 2001. Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. Scand. J. Work Environ. Health 27 (Suppl. 1), 1–102.

Sundelin, G., 1993. Patterns of electromyographic shoulder muscle fatigue during MTM-paced repetitive arm work with and without pauses. Int. Arch. Occup. Environ. Health 64, 485–493.

Sundelin, G., Hagberg, M., 1989. The effects of different pause types on neck and shoulder EMG activity during VDU work. Ergonomics 32, 527–537.

Svendsen, S.W., Mathiassen, S.E., Bonde, J.P., 2005. Task-based exposure assessment in ergonomic epidemiology—a study of upper arm elevation in the jobs of machinists, car mechanics, and house painters. Occup. Environ. Med. 62, 18–26.

Swedish National Board of Occupational Safety and Health, 1998. Ergonomics for the Prevention of Musculoskeletal Disorders. AFS 1998:1. Swedish National Board of Occupational Safety and Health, Stockholm.

Thompson, D., 1995. Concise Oxford English Dictionary, 11th Ed. Oxford University Press, Oxford.

van den Heuvel, S.G., de Looze, M.P., Hildebrandt, V.H., 2003. Effects of software programs stimulating regular breaks and exercises on work-related neck and upper-limb disorders. Scand. J. Work Environ. Health 29, 106–116.

van Dieën, J.H., Toussaint, H.M., 1997. Evaluation of the probability of spinal damage caused by sustained cyclic compression loading. Human Factors 39, 469–480.

Veiersted, K.B., Westgaard, R.H., Andersen, P., 1990. Pattern of muscle activity during stereotyped work and its relation to muscle pain. Int. Arch. Occup. Environ. Health 62, 31–41.

Visser, B., Van Dieën, J.H., 2006. Pathophysiology of upper extremity muscle disorders. J. Electromyogr Kinesiol. 16, 1–16.

Westad, C., Westgaard, R.H., De Luca, C.J., 2003. Motor unit recruitment and derecruitment induced by brief increase in contraction amplitude of the human trapezius muscle. J. Physiol. 552, 645–656.

Westgaard, R.H., Vasseljen, O., Holte, K.A., 2001. Trapezius muscle activity as a risk factor for shoulder and neck pain in female service workers with low biomechanical exposure. Ergonomics 44, 339–353.

Winter, D.A., Yack, H.J., 1987. EMG profiles during normal human walking: stride-to-stride and inter-subject variability. Electroenc. Clin. Neurophysiol. 67, 402–411.