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Journal of Electromyography and Kinesiology 16 (2006) 125–136
JOURNAL OF ELECTROMYOGRAPHY AND KINESIOLOGY
www.elsevier.com/locate/jelekin

Precision of measurements of physical workload during standardised manual handling. Part II: Inclinometry of head, upper back, neck and upper arms

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Received 2 November 2004; received in revised form 29 April 2005; accepted 9 June 2005

Abstract

For measuring the physical exposure/workload in studies of work-related musculoskeletal disorders, direct measurements are valuable. However, the between-days and between-subjects variability, as well as the precision of the method per se, are not well known.

In a laboratory, six women performed three standardised assembly tasks, all of them repeated on three different days. Triaxial inclinometers were applied to the head, upper back and upper arms. Between-days (within subjects) and between-subjects (within tasks) variance components were derived for the 10th, 50th and 90th percentiles of the angular and the angular velocity distributions, and for the proportion of time spent in predefined angular sectors.

For percentiles of the angular distributions, the average between-days variability was 3.4°, and the between-subjects variability 4.0°. For proportion of time spent in angular sectors, the variability depended on the percentage of time spent in the sector; the relative variability was scattered and large, on average 103% between days and 56% between subjects. For the angular velocity percentiles, the average between-days variability was 7.9%, and the average between-subjects variability was 22%.

The contribution of the measurement procedure per se to the between-days variability, i.e., the imprecision of the method, was small: less than 2° for angles and 3% for angular velocity.

Keywords: Intra-individual; Inter-individual; Exposure variability; Assembly work

1. Introduction

Physical workload (e.g., excessive and prolonged muscular load, awkward and constrained postures, and repetitive movements) has been identified as a risk factor for developing work-related musculoskeletal disorders (WMSDs) [6,24,27]. Quantitative exposure-response relations are, however, known only to a very limited extent. This lack of knowledge hampers surveillance and regulation of these risk factors, and present standards and guidelines are often expressed in qualitative, process-oriented terms [10,11]. So far, attempts to implement these standards, guidelines, and regulations have not led to a decrease in the occurrence of WMSDs.

Legislative regulation, analogue to threshold limit values (TLVs) for exposure to toxic chemicals, noise and vibration, might prove more successful. By using technical measurements, which show a better validity,

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1050-6411/$ - see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.jelekin.2005.06.009

accuracy and precision than observation methods [17,29,36,37], the scientific basis of TLVs can be improved, and compliance surveyed.

For measuring postures, uniaxial and biaxial inclinometers have been extensively used. One major advantage of inclinometry is that definitions of head, upper back, neck and upper arm postures adhere to the ISO-standard 'Ergonomics – Evaluation of static working postures' [15]. However, excessive errors may occur during inclination in arbitrary directions even when biaxial inclinometers are used [12]. Moreover, most inclinometers are based on transducers comprising moving parts, which limits their frequency response to a few Hz, and, hence, reduces their accuracy during dynamic conditions. To overcome these limitations we have developed triaxial accelerometers for whole-day ambulatory inclinometry [12], which have an accuracy and reproducibility that is independent of the direction and the magnitude of the inclination. They provide valid data under the dynamic conditions that occur during ordinary occupational work [7,12]. The instrumentation has been applied in studies of occupational work, e.g. [2,5,14,17,33].

When inclinometers are applied for characterising the physical workload, variability (in addition to that inherent in the instrument) will be introduced, e.g., due to the non-perfect reproducibility of the reference positions. Moreover, for a particular subject there will be between-days variability, due to actual differences in task requirements, as well as differences in work performance. In addition, different individuals will not perform the same task in an identical manner. The size of between-days and between-subjects variability is crucial for determining sampling strategies, e.g. in epidemiological studies [19,32] and for surveillance of TLVs [9,20–22,26].

This study is one part of a larger investigation, which also evaluated the precision of electromyography [25] and goniometry (to be published). The specific aim of the present study was to evaluate the usability of inclinometry based on triaxial accelerometers for assessing industrial tasks, in terms of precision of the method per se, as well as between-days and between-subjects variability.

2. Subjects and methods

2.1. Subjects

Six healthy, right handed, female subjects from the department staff participated in the study. Their median age was 44 (range 36–54) years, height 168 (158–173) cm, and weight 64 (58–82) kg. The Ethics Committee of Lund University approved the study, and all participants gave their written informed consent.

2.2. Work tasks

At each trial, the subjects performed three standardised work tasks in a laboratory setting. The tasks were designed to give different levels of physical exposure. The work task 'materials picking' implied collection of materials (small details as screws and wing nuts, as well as iron weights of 2.2 and 3.2 kg), for the two other tasks, transfer of the materials on carts, and downloading of the material at the workstations. 'Light assembly', assembly of table holders for desk lamps, implied handling of light objects by both hands, with an average cycle time of 24 s. 'Heavy assembly', assembly of stands for desk lamps, consisted in handling of more and heavier components with an average cycle time of 58 s. Each task was performed for about 20 min. For details, see [25].

2.3. Study design

All subjects performed at least three trials on separate days, separated by at least seven days (in addition to their first trial, which was considered to be a training occasion and therefore excluded in the analyses). Two subjects performed an additional trial, since some data in the previous trials had been lost due to technical problems. Preceding each trial, measurement equipment was applied to the subject for simultaneous measurement of muscular activity (electromyography [25]), head and upper arm movements (inclinometry, see below), and wrist movements (goniometry). In all trials, the work tasks were performed in the sequence 'materials picking', 'light assembly', 'heavy assembly'. A break of about 10 min was organised between the tasks.

2.4. Inclinometry

Inclinometers, based on triaxial accelerometers (Logger Teknologi HB, Åkarp, Sweden), were used to measure the angle relative to the line of gravity [12], for the head, upper back and both upper arms. Data were sampled at 20 Hz using a datalogger (Logger Teknologi HB, Åkarp, Sweden) [13]. These inclinometers do not have to be aligned with the orientation of the body segment; by recording of a reference position (defining 0° of inclination) and a position representing the forward direction, the co-ordinates can be transformed from the inclinometer to the body segment. The inclinometers per se have an accuracy of 1.3° and a reproducibility of 0.2° [12].

One inclinometer was placed on the forehead, another one to the right of the cervico-thoracic spine at the level of C7-Th1. For the upper arms, the inclinometer was fixed to a plastic plate (55×27 mm), which was placed along the upper arm, with the 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. For the head and upper back,