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Uncertainty in monetary cost estimates for assessing working postures using inclinometry, observation or self-report

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ABSTRACT

Objective: To assess uncertainty in cost estimates for collecting posture data by inclinometry, observations and self-report.

Method: In a study addressing physical workloads at a paper mill, costs were calculated for measuring postures of twenty-eight workers during three shifts. Uncertainty in costs was assessed for all three methods as the range between an assumed best case (lowest cost) and worst case (highest cost) using scenario analysis.

Results: The cost for observation was larger, but also more uncertain (€16506 and €89552 in the best and worst case, respectively) than that of inclinometry (€7613 - €45896). Self-report costs were both lower and less uncertain (€3743 - €23368).

Conclusions: The extent of uncertainty in cost estimates implies that observation could be *less* expensive than inclinometry, e.g., in a scenario where experienced observers could use existing software, while inclinometers would have to be purchased. We propose adding uncertainty assessments to cost estimates when selecting a method for measuring working postures, and offer guidance in how to proceed in a specific setting.

1. Introduction

Costs for collecting biomechanical exposure data in working life are rarely considered and reported in the literature (Mathiassen et al., 2013; Rezagholi et al., 2012; Rezagholi and Mathiassen, 2010; Trask et al., 2007). Nevertheless, the cost of collecting and processing exposure data is an essential issue to consider when designing a study under a given budget. This includes deciding on which measurement method to apply, such as whether to assess working postures using direct technical measurements, observations, or workers' self-reports (e.g. Teschke et al., 2009). A few studies have developed comprehensive cost models for assessing and comparing costs associated with measuring postural exposures. Trask et al. (2012) showed that inclinometry was more expensive in use than observation and self-report when *collecting* posture data in industrial environments, in terms of costs borne by the researchers. However, the cost of data *processing* was larger for observation, followed by inclinometry and self-report (Trask et al., 2013). While contributing to understanding the components and sizes of fixed and variable costs associated with assessing postures and, in extension, other biomechanical exposures, neither of the studies addressed the uncertainty of the reported cost estimates.

However, any cost estimate is associated with uncertainty. The extent of uncertainty generally increases with the complexity of the cost estimate, as uncertainty in each added cost component will add to the uncertainty of the total cost estimate. In business economics, analysis of the uncertainty of an estimated cost for implementing a project is a standard element in the process of decision making, in the endeavor to optimally allocate resources. In the context of determining biomechanical exposures in occupational research, information on the uncertainty of individual cost components, such as the cost associated with purchasing equipment or the cost of rating postures from video stills, can support informed decisions of which method is preferable in a specific situation (Beevis, 2003). For example, if the researcher has access to inclinometers (Hansson et al., 2001) as well as previously developed software for extracting exposure variables from the raw recordings, then inclinometry may be the method of choice for assessing working postures. If, on the other hand, trained observers are easily accessible and only short periods of work need be analyzed, observation may be preferable. To the authors' knowledge, no previous study has assessed the uncertainty of total costs and individual cost components when assessing biomechanical exposures in working life using different methods.

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Therefore, the aim of this study was to assess uncertainty in estimates of costs associated with collecting and processing data on working postures using inclinometry, observations from video, and self-reports. To that end, we applied a comprehensive cost model proposed by Trask et al. (2014) to data collected at a paper mill (Heiden et al., 2017).

2. Materials and methods

2.1. Design and participants

The study was based on data collected at a Swedish paper mill during 2011. Twenty-eight out of 55 workers with full-time jobs and no modified duties were randomly selected to participate. In total, exposure data were collected during 84 full shifts using three different methods: inclinometry, observation of video and self-report. All participants were informed about the study both verbally and in writing, and signed an informed consent to participate. The study was conducted in accordance with the declaration of Helsinki and approved by the Regional Ethical Review Board in Uppsala (2011/026).

2.2. Measurements of physical workload

A detailed description of the biomechanical exposure measurements can be found in Heiden et al. (2017). In short, for the inclinometry measurement, the VitaMove triaxial accelerometer system (2M Engineering, Veldhoven, The Netherlands) was used to measure the workers' trunk and upper arm postures relative to the line of gravity at 32 Hz throughout the shifts. The inclinometers were attached to the trunk between the shoulder blades and on the upper arms over the medial deltoid. During the shift, a camera operator followed the worker in order to capture the worker's trunk and upper arm postures on camera. The videos were subsequently analyzed by trained observers providing ratings of work tasks, manual materials handling, gross body postures, as well as trunk and arm inclination for the full shift, based on video stills selected at regular intervals. At the end of each shift, the workers were asked to rate their workload and gross body posture during the shift in an electronic questionnaire.

Both inclinometer and observation data were processed in order to obtain the following metrics for each shift: 1) median trunk and upper arm angle, 2) proportion of time with neutral trunk (0–20°) inclination and, 3) proportion of time with neutral upper arm inclination (< 20°). From the self-report data, the occurrence of extreme gross body postures during the shift was calculated (Heiden et al., 2017).

2.3. Cost model and cost components

Total cost () was calculated for each measurement method using the model developed by Trask et al. (2014). Equation (1) presents this overall cost model with fixed ($\check{C}$) and variable ($\dot{C}$) cost components.

$$C_{TM} = \check{C}_A + \check{C}_E + \check{C}_R + \check{C}_S + \check{C}_T + \dot{C}_D + \dot{C}_M + \dot{C}_{R-worker} + \dot{C}_{R-meeting} + \dot{C}_V + \dot{C}_H \quad (1)$$

Fixed cost components are defined as costs that do not depend on the size of the data set, such as the cost associated with purchasing a measurement device. Variable cost components, on the other hand, do depend on the study size, and can be assessed by multiplying a so-called unit cost, i.e. the cost associated with obtaining one measurement unit, by the corresponding number of units collected in the study. In the present study, measurement units could be shift, worker and worksite meeting, depending on the cost component as detailed in section 2.4.The contents of each individual cost component is summarized in Table 1, and a detailed description of the model (equation (1)) and its cost components can be found in Trask et al. (2014).

2.4. Assessment of costs

Total costs were assessed for a study with the design and size of the original paper mill study (Heiden et al., 2017), in which postures were assessed for a total of 84 full shifts, distributed among 28 workers. In this study, costs were, to a large extent, associated with researchers devoting time to different tasks during the planning and implementation of the study, such as meetings, support to staff collecting data in the field, observing videos, and data processing ($\check{C}_A$, $\check{C}_R$, $\check{C}_S$, $\check{C}_T$, $\dot{C}_D$, $\dot{C}_M$, $\dot{C}_{R-worker}$, $\dot{C}_{R-meeting}$, $\dot{C}_V$). Time allocated to these tasks was meticulously tracked, following procedures described in Trask et al. (2013). Essentially, the researchers wrote down the time spent on each task. These times were then multiplied by the hourly salary of the staff, calculated as monthly salary according to information from the employer, including social taxes, divided by the number of working hours per month. Thus, hourly salary ranged from €12.8 for observers to €19.1 for junior staff, €23.9 for the consultant implementing the electronic self-report questionnaire, and €36.7 for the participating senior researcher (currency rate as per 22nd June 2017). University overhead costs (OH) on salaries were not included, since OH may vary widely between different organizations.

Administrative costs, $\check{C}_A$, of the study came with the design and implementation of the project, including documentation, budgeting and internal correspondence required in all phases of data collection and processing. The total time spent on administration tasks were 103 h for inclinometry, 158 h for observation and 81 h for self-report. Thus, administrative costs differed between methods; making up 23.9% of the total cost for inclinometry, 14.9% for observation, and 40.9% for self-report. The costs for purchasing equipment and software, $\check{C}_E$, was quite low as the study had already access to the most expensive equipment needed, such as the inclinometers. However, some equipment had to be procured, such as backup disks, as specified in the supplementary material. The fixed cost related to recruitment of workers, $\check{C}_R$, was calculated on basis of the time spent by the research team in meeting employer and union representatives at the paper mill (40 man-hours), and this entire cost was allocated to each method since it would, arguably, be required even for data collections using only one of the methods. The cost, $\check{C}_S$, of building a database and developing and/or modifying software for data processing included costs for developing the self-report questionnaire, modifying and testing software for observation and processing of inclinometer recordings, as well as building the exposure database that was used for all three measurement methods. The cost of preparations and training, $\check{C}_T$, included the time required to train the hired junior staff, which had no prior experience of the measurement methods, in the on-site data collection procedures (135 man-hours). The cost of onsite data acquisition, $\dot{C}_D$, was calculated from the time used in tasks such as measurement (693 man-hours), support to data collectors (2 man-hours), downloading and backing up data (in total 72 man-hours), and basic processing of data (168 man-hours); specific cost assessments are presented in the supplementary material. The cost of processing data, $\dot{C}_M$, included observation time (280 hrs for all 84 shifts), time spent by a senior researcher supporting the observers (0.5 hrs), processing of posture ratings (46 hrs), and processing of raw inclinometer data (143.5 hrs). The variable cost of recruiting workers, $\dot{C}_{R-worker}$, $\dot{C}_{R-meeting}$, was based on time spent by a senior researcher on communicating with 28 individual workers (5 hrs), and attending six worksite meetings (15 hrs). As with the fixed costs of recruitment above, the total variable cost associated with recruitment was allocated fully to each measurement method. The costs of commuting to the worksite, $\dot{C}_V$, was based on the total travel time (118 hrs) reported by the research team for the entire data collection. The full cost of commuting was assigned to each of the measurement methods. In the actual paper mill study, no overnight accommodations, $\dot{C}_H$, were needed, since the mill was situated within a short distance from the residence of the research team (1 h single trip).

Thus, the total cost of the study was calculated as the sum of all