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Validity of fixed-interval observations for postural assessment in construction work

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Abstract

While observing six simulated construction tasks in the field, trained analysts recorded arm, trunk and leg postures categorically with two fixed-interval observational protocols. Observations were compared to measurements obtained with an electronic postural assessment system coupled with video analysis. The electronic postural assessment system consisted of electronic inclinometers to measure upper arm posture, knee flexion and trunk flexion, coveralls to house the inclinometer wiring, and an eletrogoniometric system to measure trunk lateral bending and twisting. Video analysis included frozen-frame analysis that corresponded to the moment of observation and simulated real-time analysis. Measurements were made on five male participants who each performed three tasks representative of construction laborers' work. Agreement among the observational and reference methods was generally high, although significant differences in measured frequency of exposure existed for knee flexion, trunk lateral bending and trunk twisting. The results suggest that, under appropriate conditions, discrete observations can be used to obtain reasonably accurate estimates of exposure frequency for broad categories of certain body postures. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In a review of over 600 epidemiologic studies, the National Institute for Occupational Safety and Health (NIOSH) reported that there was strong evidence for causal relationships between awkward postures and neck/shoulder disorders, a combination of physical ergonomic exposures and upper extremity disorders, and lifting and whole body vibration and back disorders (US Department of Health and Human Services, 1997). In spite of such findings, some remain skeptical about the work-relatedness of musculoskeletal disorders. This is mainly because of conflicting study results and major flaws in many studies (e.g., lack of control for confounders). Poor characterization of exposures is an important factor that contributes to both of these limitations. Valid and precise measurements of numerous independent variables are needed to help clarify the relationships between occupational exposures and musculoskeletal health outcomes, as well as to document changes in exposure associated with the introducing workplace interventions.

Musculoskeletal problems are common among workers in the construction industry. In 1992 the construction industry had the highest frequency of work-related injuries and illness among all economic sectors, with 13.1 cases per 100 full-time workers (US Department of Labor, Bureau of Labor Statistics, 1994a). During this year, there were over 10,000 new cases of non-fatal occupational illness reported in the construction industry, 21% of which were associated with repeated trauma (US Department of Labor, Bureau of Labor Statistics, 1994b). Since this time, there has been a steady decrease in the incidence rate of work-related injuries and illnesses among construction workers, but in 1997 the incidence rate was second only to manufacturing (US Department of Labor, Bureau of Labor Statistics, 1998).

Epidemiologic studies have demonstrated associations between construction work and musculoskeletal disorders of the back and the upper and lower extremities (e.g., Burkhart et al., 1993; Damlund et al., 1982;

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Holmstrom et al., 1993; Latza et al., 2000; Riihimäki et al., 1990; Stenlund et al., 1993). However, exposure data for most of these studies are limited to trade or job title and provide little information about which work-related risk factors contribute most to the excess risk of musculoskeletal problems in this industry.

Construction workers having the same job title may have different levels of exposure to physical ergonomic stressors because the duration and distribution of job tasks for individual workers may vary among workers and from day to day. The lack of quantitative exposure data is, in part, because construction work generally requires workers to perform multiple tasks with long variable work cycles, making cycle-based ergonomic assessment methods and laboratory simulations of job tasks impractical. Exposure assessment methods designed to quantify the long-term physical requirements are needed to improve epidemiologic and intervention research in construction and other similar types of non-routinized types of work.

Work sampling is a methodology that has been used by industrial engineers for approximately 60 years to quantify the proportion of time that workers or machines devote to different work activities (Pape, 1992). Modified forms of work sampling have been applied to studies of jobs where cycle-based ergonomic exposure assessment methods could not be used easily (e.g., Karhu et al., 1981; Mattila et al., 1993; Ryan, 1989; Wickstrom et al., 1985). For these types of assessments, observations about working postures or manual handling are usually made at fixed intervals throughout a representative work period. Observations are often made on categories of exposure, and the proportion of time recorded for each exposure category is the ratio of the number of observations recorded for the category to the total number of observations. PATH (Posture, Activities, Tools and Handling), a fixed-interval observational approach, has been developed specifically to characterize the proportion of time workers spend in awkward postures, handling loads, and performing manual materials handling (MMH) and other activities within job tasks, as well as the frequency distribution of job tasks during non-routinized types of work (Buchholz et al., 1996).

Observational methods, such as PATH, offer the advantages of providing data on multiple exposures collected simultaneously, over long time periods, and can be used with little disruption to the work. There is, however, some uncertainty about the validity of observations for postural assessment. Some studies have found relatively poor-to-moderate agreement when fixed-interval observational approaches were compared to more sophisticated measurement systems (e.g., Burdorf et al., 1992; De Looze et al., 1994).

The objective of this study was to examine the validity of PATH and a simplified version of PATH for the assessment of trunk, shoulder and knee postures in construction work. Comparisons were made between both observational approaches and discrete reference measurements, between observational and continuous-direct measurements, and between PATH and simplified PATH.

2. Methods

2.1. Study site and subjects

The study took place at a laborers' training grounds that closely resembled a typical construction site, equipped with a construction trench, utilities pit, truck, asphalt and dirt surfaces, and a variety of building materials (e.g., bricks, blocks, boards). Five male college students were brought to the study site to simulate 3 of 6 construction job tasks. The order in which subjects performed each of the 3 tasks was randomly assigned.

2.2. Job tasks

The six construction job tasks were designed to facilitate a wide range of body postures, including work above the shoulders as well as below the knees. The job tasks were: (1) carrying wood beams into and out of a construction pit, (2) shoveling and moving crushed rock, (3) sweeping and shoveling dirt, (4) drilling concrete, (5) spreading mortar on concrete, and 6) moving bricks and concrete blocks. The tasks were considered representative of laborers' work based on information obtained in a survey of a union construction laborers and from researchers' field observations on highway construction sites. While the construction tasks were described in detail to each subject, the exact way in which individuals performed the task was not controlled, allowing conditions that more closely resembled real construction work.

2.3. Measurement methods

2.3.1. Observations

Both the full PATH and simplified PATH methods required observers to record postures in categories that had been modified from the Ovako Working Posture Analysing System (OWAS) (Karhu et al., 1977, 1981). These included three categories of upper arm posture (elbows below shoulder height, 1 elbow at or above shoulder height, both elbows at or above shoulder height), nine categories of leg posture (neutral or standing with knees bent $< 35°$, standing with 1 leg in air, standing with knees bent $\geqslant 35°$, walking, squatting, kneeling, sitting on chair, sitting on ground, and climbing/descending), and five categories of trunk posture (neutral, flexion $\geqslant 20°$ and $< 45°$, degrees, flexion $\geqslant 45°$, lateral bending $\geqslant 20°$ or twisting $> 20°$, and flexion $\geqslant 20°$ with lateral bending or twisting $\geqslant 20°$). The judgment of trunk

postures involved estimating the position of the shoulders relative to the hips in the sagittal (trunk flexion), frontal (trunk lateral bending) and transverse (trunk twisting) planes.

Both methods involved recording observations using a data collection template and computer-scannable data collection sheets. Categories of variables listed on the data collection template included: worker identification number, task, body postures, weight handled, MMH activities, general activities, task specific activities, tools/equipment and hand postures. For the simplified version of PATH, the observer used the template but was required to record only the worker identification number, task performed, and body postures during each observation. The simplified version was evaluated to determine what, if any, improvement in accuracy could be gained by reducing the cognitive demands of an individual observation. For the full PATH method, all relevant variables on the template were considered during each observation.

The observers were experienced PATH coders, had received the same 30-hour course in PATH data collection (including multiple evaluations of inter-rater agreement) and had collected PATH data together on several occasions. During previous studies, tests of inter-observer reliability for PATH posture codes were usually high, with the proportion of agreement exceeding 0.90 for shoulder postures and 0.80 for leg and trunk postures (Buchholz et al., 1996).

2.3.2. Reference system

The reference measurements were obtained with the use of an electronic postural assessment system, consisting of 7 accelerometers (AD05 0-5G, 2.5×10^{-4} sensitivity, PN#960424, Desktop Laboratories, Inc., 1996), a lumbar motion monitor (LMM) (Chattanooga Group, Inc., 1996), and videotape recordings (Table 1).

The accelerometers were used to measure upper arm postures (heights of elbows relative to shoulders), and knee and trunk flexion. When placed on the body segments, the accelerometers can be used to approximate a body segment's orientation during static or isokinetic (constant velocity) conditions, because, for these circumstances, the voltage output is a function of their orientation to gravity. Measures of knee flexion were predicted from differences in voltage between the accelerometers located on the upper and lower leg. The measurement of knee flexion required calibration of the electronic inclinometers to individual subjects. This system was lightweight and non-restrictive of joint motion, allowed nearly simultaneous and continuous measurement of multiple body postures, and was shown to estimate reliably the same categories of arm, trunk and leg postures (Paquet, 1998).

The LMM is an electrogoniometer that provides static and dynamic measurements of lumbar flexion, twisting and lateral bending. It was selected because of its demonstrated validity (Marras et al., 1992) and usability in the field (Marras et al., 1993, 1995). Because the LMM was designed to estimate lumbar rather than trunk postures, a pilot study that involved 5 subjects who maintained varying degrees of trunk twisting and side bending was conducted to determine how well measurements of lumbar posture predicted trunk postures (Paquet, 1998).

Measurements of trunk side bending were made by aligning a weighted inclinometer with the thoracic region of the spine and measurements of trunk twisting (shoulders relative to hips) were made with a protractor that was mounted on the floor. The study showed that trunk twisting and side bending could be predicted reasonably well with a relatively simple calibration procedure that involved making measurements with the trunk bent laterally 0 and 20° to each side and twisted 20° to each side. This calibration procedure was used in this study.

Table 1
Reference postural measurements made at fixed intervals and continuously during the simulated construction tasks

Exposure	Fixed-interval measurements	Continuous measurements
Shoulder posture	The mean electronic inclinometer (EI) measurements collected at 50 Hz over a period of 0.5 s before and after observation	EI measurements collected at 2 Hz throughout the entire task
Leg posture	Frozen frame video analysis at the instant of observation to identify standing, walking, kneeling, squatting and climbing. For standing postures, mean difference between EI measurements for upper and lower legs collected at 50 Hz over a period of 0.5 s before and after the work-sampling observation used to identify knee flexion $\geqslant 35°$	Simulated real-time analysis to identify standing, walking, kneeling, squatting and climbing. For standing postures, difference between EI measurements for upper and lower legs collected at 2 Hz used to identify knee flexion $\geqslant 35°$
Trunk flexion	EI data collected at 50 Hz over a period of 0.5 s before and after observation	EI data collected at 2 Hz throughout the entire task
Trunk lateral bending and twisting	Lumbar motion monitor (LMM) measurements collected at 60 Hz over a period of 0.5 s before and after observation	LMM measurements collected at 60 Hz over a period of 5 s before and after observation (1/3 of the task)

The reference values for leg postures were obtained by observation of videotape. The video analysis included frozen-frame evaluation of leg postures at the moment that each observation was made and the simulated real-time analysis system (Keyserling, 1986) to estimate the frequency and total duration of standing walking, kneeling and sitting postures. Knee flexion of at least $35°$ was determined by evaluating the electronic inclinometer data for the knees on videotape frames where standing was the identified leg posture.

2.4. Fitting

The electronic inclinometers were strapped tightly in line with the subject's arms and perpendicular to the subject's legs with Velcro, elastic bands and tape. One inclinometer was attached to each upper arm slightly lateral to the biceps and in line with the arm. Two inclinometers were attached to the lateral sides of the upper and lower legs and were approximately horizontal when the subject stood with the legs straight. A portable data logger (Tattletale, Model 5F, Onset Computer Corporation, 1993) was secured inside the coveralls. The LMM was secured over the coveralls in line with the lumbar region of the spine. An electronic inclinometer was secured to the upper base of the LMM over the thoracic region of the spine and was close to horizontal when the subject stood erect.

2.5. Data collection

After each subject was fitted with the instrumentation, the inclinometers and LMM were calibrated. Before each task, the subject was given a set of written and oral instructions outlining the construction work to be completed. The tasks were performed in random order and all work areas were assembled prior to the study so that the observers had very little time to anticipate which task was to be performed.

While each subject performed a task, 2 observers made PATH observations at staggered one-minute intervals, so that one PATH observation was recorded every 30 s. A third observer made simplified PATH observations every 30 s at the same moment that the PATH observations were made. For each observation, a verbal countdown of "5, 4, 3, 2, 1, CODE" was given, and the observers recorded the PATH variable categories at the moment of "CODE". Observers remained approximately 10 m from the subjects during data collection, as would be typical during data collection in the field.

Inclinometer data were collected continuously throughout the task (at 2 Hz for 28 s of each half-minute and at 50 Hz for a 2-s interval that included the instant of PATH and simplified PATH coding). The increased sampling rate was designed to improve the precision of the electronic inclinometers at the moment that observations were made.

LMM data were collected at 60 Hz for 10-s periods beginning 5 s before and ending 5 s after each PATH observation, providing measurements of trunk lateral bending and twisting for 20 s of each minute during the task. Data were transmitted directly from the LMM to a personal computer via digital telemetry.

Each worker was videotaped continuously throughout the task so that leg postures could be later identified with the frozen-frame analysis and simulated real-time methods. The frozen-frame video analysis required the video to be paused on the auditory cue of "CODE" that corresponded to the instant that the work-sampling measurements were taken, and the presence of standing, kneeling, squatting or walking postures on the videotape was recorded. For the real-time simulated analysis, the sequence and duration of these leg postures were recorded continuously throughout the tasks.

The videotape, electronic measurements and work-sampling observations were synchronized with a stopwatch so that measurements could be compared directly between the methods. The stopwatch and the data logger were activated simultaneously. The stopwatch was used to determine the appropriate time to activate the LMM.

Each task was performed for approximately 15 min. After the task was completed, the data in the portable data logger were downloaded to a personal computer. The data logger and the stopwatch were then re-activated, and the subject proceeded to the next task.

2.6. Data management

The electronic calibration and measurement data were converted to ASCII format. The calibration data were used to develop posture prediction equations. The electronic inclinometer and LMM ASCII files for each job task were imported into spreadsheets. The appropriate prediction equations were then applied to each of the measurements to obtain the shoulder, leg and trunk postures. These included the knee flexion and trunk lateral bending and twisting equations developed from the calibration of individual subjects and third-order polynomial prediction equations for arm and trunk flexion that did not require calibration.

For the discrete reference measurements, electronic data collected from 0.25 s before until 0.25 s after each observation were averaged. The standing postures recorded in the frozen-frame video analysis were cross-referenced with electronic inclinometer data of the upper and lower leg to distinguish between neutral and flexed standing postures. The reference and observational data were matched at each observation.

For the continuous reference measurements, and the frequencies of shoulder, knee and trunk flexion categories were determined for the entire continuous sampling period taken at 2 Hz for each task. The average frequency of trunk lateral bending and twisting categories predicted

with the LMM were also used for the entire sampling period (1/3 of each task). For the video analysis, frequencies of each leg posture determined with the simulated real-time analysis were used.

The raw observational work-sampling data were manually keyed into a spreadsheet and were converted into an ASCII file. The posture frequencies for each subject during each task were calculated with SAS (SAS Institute, Inc., 1992).

2.7. Data analysis

For the individual observations, the frequencies of different trunk-, arm- and leg-posture categories recorded with both observational approaches were compared to the fixed-interval measurements recorded with the electronic inclinometers, LMM and video. The chi-square statistic was used to determine whether the frequencies of exposure categories differed among the methods using SAS Proc Freq. The agreement among the methods was evaluated with two statistics: proportion of agreement ($P(a)$) and kappa (k) coefficient, which corrects for chance agreement (Siegel and Castellan, 1988). For the fixed-interval observations, the 95%-confidence intervals, calculated for exposure frequencies using an equation derived from work-sampling methods (see Pape, 1992), were compared to the continuous reference measurements. The reference measure was considered to differ significantly when it was outside the 95%-confidence interval of the fixed-interval measures.

3. Results

3.1. Shoulder postures

There were 463 electronic inclinometer, 461 simplified PATH and 457 PATH fixed-interval recordings made on

shoulder postures. There were no significant differences in the frequency of exposure to the three shoulder posture categories among the three methods (chi square on 4 d.o.f. = 3.1, $p = 0.54$). The frequency of the fixed-interval measurements also closely approximated the continuous measurements of shoulder postures (Fig. 1).

Agreement in the frequency of arm-posture categories was extremely high for all three fixed-interval methods ($P(a) \geqslant 0.93$ and $k \geqslant 0.74$), with the strongest agreement between the electronic inclinometers and simplified PATH method (Table 2). The observational recordings and fixed-interval reference measurements differed most often when one arm was recorded at or above shoulder height with the electronic inclinometers. In this case, 20% (4 of 20) of the simplified PATH observations and 40% (8 of 20) of the PATH observations were in a different category, equally divided between both arms above and both arms below the shoulders.

3.2. Knee postures

There were 463 reference, 462 simplified PATH and 459 PATH fixed-interval recordings made on the leg postures. Overall, there were significant differences in the frequency of exposure to leg-posture categories among the methods (chi square on 12 d.o.f. = 24.3, $p = 0.02$). While the frequencies of kneeling and climbing postures were almost identical among the methods, larger differences were observed in the frequency of walking, knee flexion and neutral leg postures, with significant differences among methods for only exposure to standing with legs straight (chi square on 2 d.o.f. = 12.5, $p = 0.002$). Compared to the fixed-interval reference measures, the observational methods over-estimated the frequency of standing with the legs straight and slightly under-estimated walking and knee flexion. The frequency of leg postures estimated with simplified PATH was consistently closer to the reference measurements than the full PATH method. The frequency of exposure obtained with
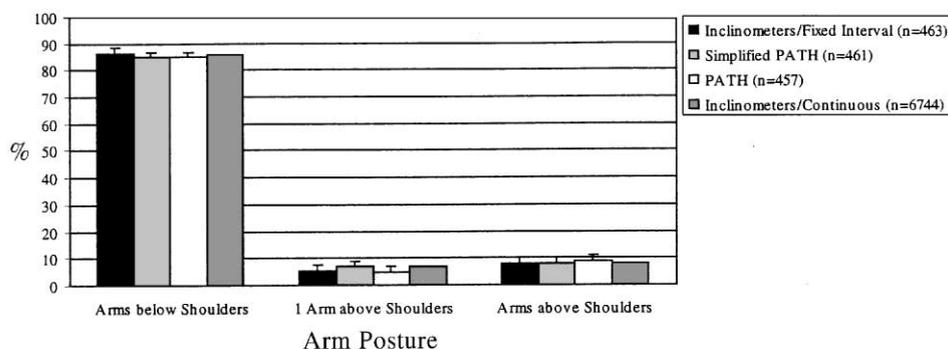

Fig. 1. The frequency of arm posture categories recorded with the electronic inclinometers (fixed-interval sampling), simplified PATH, PATH and electronic inclinometers (continuous sampling). The upper limit of the 95% confidence interval for each fixed-interval sampling method is shown.

Table 2
Inter-method reliability (proportion agreement and kappa coefficient) for body posture categories during the simulated construction tasks

| Body posture	Methods	Proportion agreement $P(a)$	Kappa (k)
Shoulders 3 categories	Inclinometers and simplified PATH ($n = 461$)	0.95	0.80
	Inclinometers and PATH ($n = 457$)	0.93	0.74
	Simplified PATH and PATH ($n = 455$)	0.93	0.75
Leg postures 6 categories	Inclinometers/video and simplified PATH ($n = 462$)	0.90	0.87
	Inclinometers/video and PATH ($n = 459$)	0.81	0.75
	Simplified PATH and PATH ($n = 458$)	0.84	0.76
Trunk postures 5 categories	Inclinometer/LMM and simplified PATH ($n = 463$)	0.74	0.60
	Inclinometer/LMM and PATH ($n = 456$)	0.68	0.51
	Simplified PATH and PATH ($n = 456$)	0.75	0.58
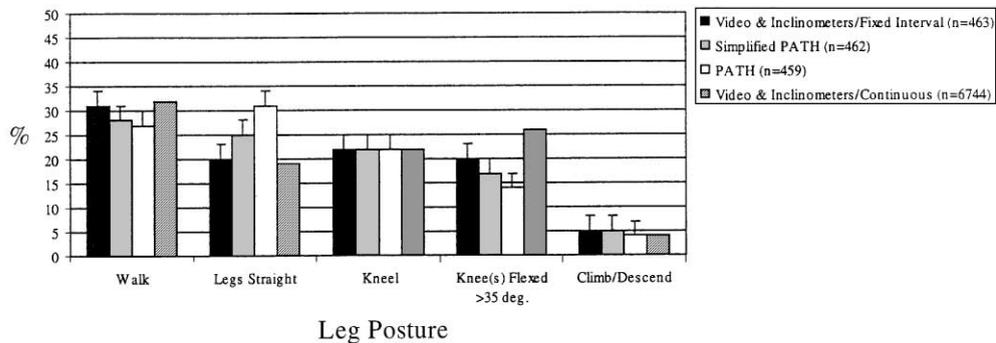
Fig. 2. The frequency of leg posture categories recorded with electronic inclinometers and video (fixed-interval sampling), simplified PATH, PATH and video and inclinometers (continuous sampling). The upper limit of the 95% confidence interval for each fixed-interval sampling method is shown.

the fixed-interval and continuous reference measures was quite similar for all exposure categories, except knee flexion at or exceeding 35°. For this category, the discrete reference measurements underestimated the continuous measurements by about 6% of the total observation period. (Fig. 2).

Inter-method agreement for the coding of leg postures was high among all fixed-interval measurement methods ($P(a) \geqslant 0.81$ and $k \geqslant 0.75$), with the highest agreement between the reference and simplified PATH methods (Table 2). The observations and reference values were in disagreement most frequently when knee flexion was recorded by the reference system. For this case, the "neutral" leg posture category was frequently recorded by observation.

3.3. Trunk postures

There were 463 reference and simplified-PATH measurements and 457 PATH observations for trunk postures. The frequency of trunk postures varied signifi-

cantly among the methods (chi square on 8 d.o.f. = 38.0, $p = 0.001$). When the frequency of exposure to each trunk posture category was compared among the methods, significant differences were found in the frequency of trunk lateral bending (chi square on 2 d.o.f. = 46.1, $p = 0.001$) and trunk twisting (chi square on 2 d.o.f. = 10.8, $p = 0.005$). The smallest differences were observed in the measured frequency of mild flexion, with differences among the methods within 2%. For the neutral and mildly flexed trunk postures, frequency estimates made with simplified PATH were slightly closer to the fixed reference measurements than the PATH frequency estimates; while for severe flexion, the opposite was true. The frequencies of trunk lateral bending or twisting, and flexion in combination with lateral bending or twisting, were underestimated with both work-sampling methods. Similar findings resulted when the observational data were compared to the continuous reference data (Fig. 3).

The agreement among methods was moderate ($P(a) \geqslant 0.68$ and $k \geqslant 0.51$), and comparisons to the reference measurements were more favorable for simplified
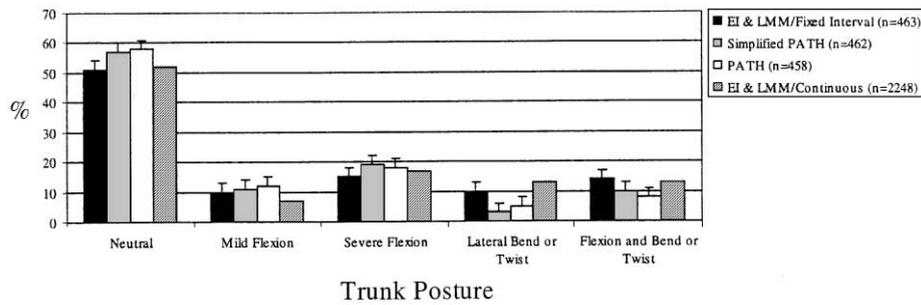
Fig. 3. The frequency of trunk posture categories obtained with the electronic inclinometer and lumbar motion monitor (fixed-interval sampling), simplified PATH, PATH, and electronic inclinometer and lumbar motion monitor (continuous sampling). The upper limit of the 95% confidence interval for each fixed-interval sampling method is shown.

PATH than for PATH (Table 2). The reference and observations contradicted one another most frequently when the reference measures recorded lateral bending or twisting postures. In these cases, approximately 70% of the simplified PATH and PATH observations were coded as neutral.

4. Discussion

4.1. Validity of fixed-interval observations

In approximately 225 min of work and six simulated construction tasks, the inter-method agreement among the fixed-interval reference and fixed-interval observational measurements of posture was generally high. The strongest agreement among the three methods was found in the categorization of shoulder postures. Analysis of the shoulder-posture frequency among methods demonstrated that the observational data closely approximated the reference measurements, with the largest discrepancies for the reference measurements of 1 arm at or above shoulder height. Misclassification of shoulder posture categories appeared random and was extremely rare.

While there were statistically significant differences in the frequency of leg-posture categories among the methods, the frequency of exposure to kneeling and climbing postures was quite similar and the overall agreement among the methods for assessing the leg postures was high. The most frequent misclassification involved the categorization of standing leg postures. The field observers were more likely to misclassify flexed knee postures as neutral (straight knee) than neutral postures as flexed. A similar phenomenon was found for walking postures. The misclassification of standing postures may have been due to limitations on the observers' ability to estimate the degree of flexion in both legs simultaneously, with a bias towards coding the knees as straight, or it may have been caused by a systematic error in the reference measurements. While much care and effort was devoted to the development of the electronic measure-

ment system, systematic error could exist if, for example, the electronic inclinometers shifted during the tasks.

Agreement among the methods was lowest for the assessment of trunk postures. Observation of the trunk required simultaneous quantitative evaluation of the included angles between the shoulders and hips in three planes. Additionally, changes between trunk posture categories occurred frequently and quickly during the dynamic activities in some tasks. Despite difficulties in evaluating trunk lateral bending and twisting, overall agreement among the methods was moderately high for the overall assessment of trunk postures. When the 5 trunk-posture categories were re-defined into 3 categories of trunk flexion ($< 20°$, > 20 and $\leqslant 45°$, and $\geqslant 45°$), the frequency differences among the methods narrowed and the agreement among the methods for assessing trunk flexion increased dramatically (see Fig. 4). No significant differences (chi square on 4 d.o.f. = 0.674, $p = 0.955$) were found in the frequency estimates and kappa coefficients exceeded 0.7 for categories of trunk flexion alone.

These results suggest that trunk flexion was observed more accurately than trunk lateral bending or twisting. This may be because trunk twisting, in particular, is difficult to visualize since it involves estimating the position of the shoulders relative to the hips in the transverse plane, while the observations are most likely made from a sagittal or coronal view. Heinsalmi (1986) also reported that observers had difficulty differentiating between neutral and twisted trunk postures.

In general, agreement with the reference measurements was slightly higher for simplified PATH than with the full PATH method. While each observer was assigned to perform either simplified PATH or PATH for the duration of the study, we believe that the results are probably less likely due to systematic inter-observer differences (e.g., expertise) than to the decreased cognitive demands of the simplified PATH method. The prior experience of each observer was similar and our training approach has previously demonstrated good inter-observer reliability for evaluating body postures with PATH (Buchholz et al.,
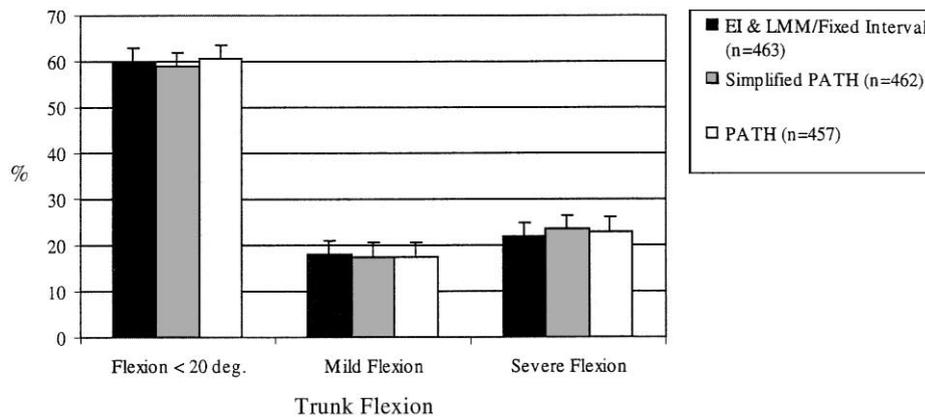
Fig. 4. The frequency of trunk flexion categories (regardless of trunk twisting and lateral deviation) recorded with the electronic inclinometers and lumbar motion monitor (fixed-interval sampling), simplified PATH and PATH. The upper limit of the 95% confidence interval for each method is shown.

1996). These findings suggest that the accuracy of posture observation may improve when the observer is required to code fewer exposures. In this case, more than one observer would be needed in order to record the same amount of information at each observation. For example, the TRAC method uses one observer to code body postures while the other codes tasks and activities (Van der Beek et al., 1992). Simultaneous characterization of postures and activities, however, may be more difficult to achieve with such an approach because even small differences in the timing of observations between coders may result in the missclassification of exposures for specific activities.

4.2. Comparisons with other studies

The results of this study demonstrated higher inter-method agreement than reported by others. For example, Leskinen et al. (1997) compared the Portable Ergonomic Observation (PEO) method with an optoelectronic three-dimensional postural analysis system during laboratory-simulated work tasks, and found that there was high agreement between the PEO method and optoelectronic system for clearly identifiable static postures but low agreement among the methods for dynamic work. PEO requires continuous vigilance (see Fransson-Hall et al., 1995), and is likely to be more difficult to perform than fixed-interval observations of similar exposure categories. Use of fixed-interval observations requires noting only the observed posture category rather than the change between categories, and also allows recovery periods between observations.

Burdorf et al. (1992) assessed the validity of fixed-interval observations with the same OWAS trunk posture category codes (Karhu et al., 1977, 1981) as used here. For the observations, the angle of trunk inclination was defined as the angle between a straight line connecting the pelvis and shoulders and the vertical, and an electronic inclinometer was attached to the spine at L2–L3. Large differences were found in trunk bending greater than 20° for individuals and observers consistently over-estimated the frequency of trunk flexion. One explanation for the higher frequency of observed moderate trunk postures offered by the authors was that the shoulders or the thoracic and cervical vertebrae contributed to the trunk inclination during moderate trunk flexion, rather than lumbar region of the back where the electronic inclinometer was attached.

De Looze et al. (1994) examined the validity of another fixed-interval observational technique, TRAC (Van der Beek et al., 1992), during a laboratory-simulated manual materials handling task. TRAC measurements were compared to those of a two-dimensional diode-based analysis system positioned to minimize distortion and a video analysis system. The authors found that inter-method agreement was high between reference and observational methods for distinguishing kneeling versus standing postures but was low for trunk, arm and other knee postures. Over one-half of the disagreements related to trunk posture occurred when the trunk was changing position, and even slight timing discrepancies between the methods could have decreased their agreement.

The validity of PATH for classifying trunk postures was previously investigated (Buchholz et al., 1996). PATH observations were made on laborers and carpenters who were video-recorded simultaneously, and the reference measurement method was Keyserling's simulated real-time analysis system. The percentage of time that the laborers and carpenters were observed in the trunk–posture categories differed markedly between the two methods (differences of 4–24% for the trade-specific data and 5–15% for the pooled data). However, differences of this magnitude could have been expected by chance alone, due to the small numbers of observations made on each trade. There may also have been errors in reference measurements, which required performing three-dimensional posture analysis from

videotape. This evaluation was performed during the development of the PATH method, and the observer had little training or experience in using the method in the field. The validity of PATH for evaluating arm and leg postures was not examined.

This study attempted to overcome many of the limitations mentioned above. The fairly large number of observations recorded with each of the methods allowed reasonably precise estimates of posture frequencies so that small differences in exposure frequency estimation could be detected. The reference and observational measurements had the same or similar operational definitions. The placement and calibration procedures used for the electronic system were designed specifically for a reliable assessment of posture categories consistent with the PATH method.

In order to enhance external validity, much effort was expended in the creation of an experimental environment that approximated a real construction site. Data were collected outside on a fully equipped mock-construction site, and the tasks were designed to be similar to those typically observed on construction sites. Subjects were also clothed in apparel similar to that worn by construction workers during the climatic conditions of the study. Observers were blinded to the exact task until the beginning of the data collection period, and therefore could not code the task before the beginning of the observation period. It should be noted, however, that the environmental and observational conditions were close to ideal in this study conditions (e.g., temperate weather conditions, experienced observers few viewing obstructions) and therefore the results may be more favorable than those expected for less experienced observers on a busy and crowded construction site.

The tasks in this study were designed specifically for the statistical tests of agreement. The measured strength of agreement assessed with statistics such as the proportion of agreement and kappa coefficient, depends on the prevalence of the exposure categories (Feinstein and Cicchetti, 1990). This is problematic, for example, when the prevalence of one exposure category is exceedingly high, which increases the probability of chance agreement. In this case, the proportion of agreement will indicate high inter-method reliability, while the kappa coeficient will indicate low inter-method reliability. This problem was reduced in this study because the construction tasks simulated in this study were designed specifically to encourage a variety of working postures, in order to reduce the effects of chance agreement between observers.

4.3. Study limitations

There are several limitations related to the use of the reference system. First, the electronic postural measurement system was found to be reasonably accurate in a laboratory study of static postures but was not tested under dynamic conditions. The electronic inclinometers were sensitive to body accelerations, and it is possible that their accuracy may have been compromised during some of the dynamic work activities, such as sweeping or shoveling. An evaluation of the video against the electronic inclinometer measurements, however, did not show this to be true. For example, the upper arms were recorded below the shoulders with the electronic inclinometers during sweeping activities, despite the constant motion of the upper arms during this work. The electronic inclinometer measurements of knee flexion were used only during standing postures and were disregarded during other leg posture conditions such as walking. An attempt was also made to increase the stability of the electronic inclinometer measurements at each observation by increasing the sampling frequency of the inclinometers and by taking the average of measurements made 0.25 seconds before and 0.25 seconds after the moment of observation. Measurements of trunk lateral bending or twisting were less likely to be compromised due to body motion, as the LMM is designed to measure lumbar postures in dynamic work situations (Marras et al., 1992, 1993, 1995).

The amount of active or dynamic work has been suggested to affect the reliability of observations for postural assessment (Burdorf et al., 1992; Leskinen et al., 1997). In this study, there were too few observations for each subject-task condition to evaluate the effects of subject and task characteristics on the reliability of the measurements. Most of the tasks in this study tended to be dynamic in nature, requiring the subject to change postures frequently.

The accuracy of the observations is very likely dependent on the expertise and experience of the observer. The results of this study probably reflect what could be expected of experienced observers. Both PATH and the simplified PATH observers had received 32 h of PATH training and had used PATH in a variety of work settings intermittently for more than one year previous to the study.

5. Conclusions

Fixed-interval observations made in real-time provided frequency estimates of shoulder, trunk and some leg posture categories closely approximated measurements obtained with electronic instruments or with video analysis. The largest discrepancies among the reference and observational methods were in the evaluation of knee flexion and trunk lateral bending and twisting. For the observational approaches used in this study, it appears that valid estimates of exposure frequency to arm postures at or above shoulder height, kneeling and climbing leg postures, and broad categories of trunk flexion can be obtained. The validity of observations is

likely affected by several factors and may not be generalizable from one research team or field setting to another. The effects of sampling frequency, subject characteristics, observer experience and nature of the tasks should be evaluated in the future.

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