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Trunk posture: reliability, accuracy, and risk estimates for low back pain from a video based assessment method

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Abstract

It has been recently reported that both dynamic movement characteristics, as well as the duration of postures adopted during work, are important in the development of low back pain (LBP). This paper presents a video-based posture assessment method capable of measuring trunk angles and angular velocities in industrial workplaces. The inter-observer reliability, system accuracy, and the relationship of the measured exposures to the reporting of low back pain are reported. The video analysis workstation consisted of a desktop computer equipped with digital video capture and playback technology, a VCR, and a computer game type joystick. The operator could then use a joystick to track trunk flexion and lateral bending during computer-controlled video playback. The joystick buttons were used for binary input of twisting. The inter-observer reliability for peak flexion and percentage of time spent in posture category variables were excellent (ICC > 0.8). Lower reliability levels were observed for peak and average velocity and movement related variables. The video analysis system time series data showed very high correlation to the criterion optoelectronic imaging system ($r = 0.92$). Root mean square errors averaged 5.8° for the amplitude probability distribution function data. Trunk flexion variables including peak level, peak velocity, average velocity indicators, and percent time in flexion category indicators all showed significant differences between cases and controls in the epidemiological study. A model consisting of the measures peak trunk flexion, percent time in lateral bend and average lateral bending velocity emerged after multivariable analysis for relationship to low back pain.

Relevance to industry

Risk of injury for the low back is multifactorial. The trunk position and movement velocity are emerging as important parameters. This analysis confirms the importance of these factors and demonstrates the utility of a video-based method to measure them in industrial settings.

Keywords: Low back pain; Posture; Kinematics; Epidemiology; Reliability; Accuracy

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1. Introduction

Effective prevention strategies for work related low back pain (LBP) demand a detailed understanding of the risk factors associated with low back pain. Awkward postures adopted during work are risk factors that have been identified as having consistently significant and epidemiologically powerful associations with LBP (Bernard, 1997; Garg, 1989). LBP, however, is known to be a multifactorial problem with both physical, psychophysical, and psychosocial components operating in the injury process (Kerr et al., 2001). To understand the relative importance of these factors, and to engage in active risk factor identification and quantification processes in the work place, reliable and accurate measurement tools are needed.

Many studies have used self-report methods to assess postures at work (Bernard, 1997). These approaches suffer from disadvantages of unreliability (Wiktorin et al., 1993; Burdorf and Laan, 1991). Additionally, the precise definition of what constitutes "awkward" in working postures is unclear for many body joints. Recent studies using detailed quantification of kinematic parameters have found strong risk-relationships (Punnett et al., 1991; Marras et al., 1995; Norman et al., 1998). These methods have helped to identify trunk kinematic variables in specific terms such as "percent of time flexed beyond 20°", "maximum trunk velocity", and "peak flexion level". If practitioners are to quantify these risk factors in the field they must have access to techniques which can be readily used in a variety of work situations. Data collection based on commercial video-recorder technology is portable, familiar to many people, does not encumber the worker in anyway, and is relatively inexpensive. Once a workplace recording is made, it must then be processed to extract the desired indicators. This paper describes and evaluates a method that allows quantification of trunk posture and velocity, in continuous scales, from field recorded video.

The purpose of this paper was to assess the reliability and accuracy of a computer-assisted video analysis technique for measuring trunk kinematics in the workplace. Additionally, this paper reports on the risk relationships of the kinematic parameters, determined using this system, in an epidemiological study of low back pain in the automotive industry.

2. Methods

2.1. Measurement system

The video analysis workstations consist of a desktop computer equipped with digital video capture and playback technology, a VCR, and a computer game type joystick, Fig. 1. Video was recorded in the field. Since flexion-extension was of primary interest, a side view was obtained whenever possible. The video section of interest, usually 3–10 min of work, was digitized and stored on a computer hard disk. During analysis, the digital video was played back in the top left quadrant of the screen while rear and side views of a stick figure, representing the figure in the video, were displayed on the bottom half of the screen. As the operator entered postural information corresponding to the displayed video frame the stick figure, at the bottom of the screen, adopted the entered posture. The system, therefore, provided continuous feedback to the operator with two orthogonal views of the stick figure mannequin to help the operator judge the correctness of complex body positions or postures outside of the plane of the camera. Constraints in the workplace often resulted in a variety of viewing angles on the video. In all the cases, the operator was required to use their best judgement in determining the correct posture or angle inputs to the system. Categorical postures such as sit, stand, walk, or squat were recorded using keyboard input. Continuous measures of trunk flexion/extension and lateral bending, operationally defined as the angle formed by the line between L4 and T9 with respect to the vertical, were recorded by the operator using a joystick to track the posture seen on the video. Trunk twisting was defined as being present, whenever the angle of a line between the hips relative to the line between the shoulders, was greater than 20°. Twisting was recorded using the

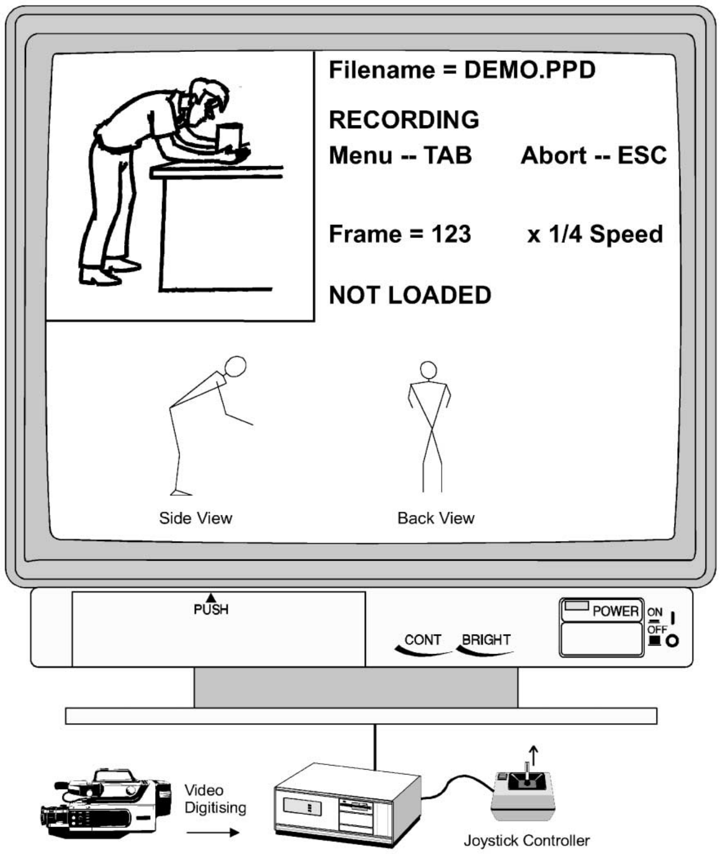

Fig. 1. Schematic diagram of the video-based posture analysis system in which the operator uses a computer game type joystick for continuous tracking of posture over a selected section of digitised video. Captured video is played back in the top left corner of the screen while stick figures (bottom of screen) provide continual visual feedback for the operator.

joystick 'fire' buttons, which allowed for binary recording of this variable.

The operator's task was to ensure that the joystick and keyboard controlled stick figures matched the posture adopted by a worker on the video throughout the video clip being analyzed. The computer sampled the mannequin posture once for each frame of digital video presented, resulting in a nominal 30 Hz signal recording regardless of the analysis speed chosen by the operator (usually about 1/5 speed). The computer handled all time-synchronizing functions allowing the operator to adjust playback speed and make changes or corrections at any point in the analysis. Data were then low pass filtered at 3 Hz using a dual pass Butterworth filter to remove high frequency artifact caused by the operator and input device characteristics. The time series data were then differentiated to generate a velocity profile. These traces were then converted into amplitude probability distribution functions (APDF) from which exposure variables were extracted in both time and amplitude domains (Jonsson, 1982). These included the percent time in neutral postures (-5° to 15° flexion), the percent time spent in forward flexion greater than 20°, and the percent time spent flexed greater than 45° (cf. Punnett et al., 1991). The peak flexion, lateral bend, and velocity levels were taken as represented by the top (1st) percentile level from the APDF.

2.2. Inter-observer reliability study

Seven (7) trained observers were used for the reliability portion of the study. All observers used in this study were the staff from the Ontario University's Back Pain Study physical loading assessment team and had been trained using a standard 10–15 h training protocol.

Ten (10) production jobs were selected from a larger pool of worksite video collected as part of the epidemiological study used in the risk-validity portion of this paper. All the jobs selected provided an unobstructed view of the worker throughout the work cycle, had a regular cycle time of approximately 1 min, and provided a realistic range of work activities seen in production workers in a large automobile assembly facility. A single cycle, deemed to be representative of the job, was chosen from the video and was digitised for further analysis. Each operator analysed the minute-long video samples, or clips, of each job, which were presented once, in random order. Intra-class correlation coefficients were used as an index of similarity of results between the observers (Shrout and Fleiss, 1979).

2.3. Accuracy study

Eight (8) trained observers were used for the accuracy assessment. The accuracy of determining trunk kinematics using the computer-assisted video method was assessed by comparing the operator's video analysis results to a criterion, or gold standard, measurement system. The video and the criterion 3D co-ordinate data, derived from an optoelectric imaging system (Optotrak, Northern Digital Inc., Waterloo), were collected simultaneously during the performance of a 1 min long simulated manual material handling task in a lab setting.

Infrared emitting diodes (IREDs) were attached to the skin at the C7 and L4 levels. A trial of quiet standing was collected to establish a baseline bias level that was removed from the data collected during the simulated task. The co-ordinate data from the optoelectric imaging system were processed, windowed and converted into degrees of trunk inclination and velocity, which were directly comparable to the video system data. This system had a stated accuracy of 0.3 mm in the x–y plane at the distance used for this study and was assumed as the criterion measure for comparison purposes (Northern Digital Inc., Waterloo, Canada). Accuracy was assessed by calculating the average difference and percent difference for selected variables of interest. Root mean square errors were calculated for the APDF values. Additionally, Pearson correlations between the observers' results and those from the reference system were calculated for both the time series and APDF data.

2.4. Risk relationship study

The study was performed in a large automobile assembly facility with a study base of over 10,000 hourly-paid workers. Incident cases were identified as they reported to the plant nursing station with low back pain. Cases were not required to have lost any work time due to their LBP. Controls were selected randomly from the employee roster at the same rate as cases. Both cases and controls were screened to have had no LBP reports in the previous 90 days. When a case was not available to be assessed, a worker doing the same job as the unavailable case was recruited and their data were used as a "proxy" to the missing case (cf. Punnett et al., 1991). In total, 129 controls and 105 cases (including 20 "proxies") were studied while they performed their regular work using a detailed battery of physical loading measurement instruments simultaneously. These methods included the computer-assisted posture assessment system described in this paper. Further details of the epidemiological investigation are available elsewhere (Kerr et al., 2001).

Participants included 'on-line' production workers, whose jobs had regular cycle times, as well as non-cyclic support and maintenance workers. Participants were monitored for 2–8 h, depending upon the complexity of observing the tasks of their job. The observer performed a breakdown of the job into tasks. This record was subsequently used to select representative sections of each task for each participant. This paper will report only on the results from the computer-assisted posture assessment method. Details of the other measurement strategies applied in the larger epidemiological study, different from the video-based method described here, are published elsewhere (Wells et al., 1997; Norman et al., 1998; Neumann et al., 1999, 2001).

Cases and controls were compared initially using a student's *t*-test. Variables showing significant differences were further examined in bivariable logistic regression analysis to generate odd ratios. Multivariable logistic regression analysis, using a backward selection procedure starting with all variables, was conducted to identify a set of postural variables, which have independent contributions to injury risk. Multicollinearity among the whole body posture categories (sit, stand, walk), which collectively summed to 100% of time, was identified as a problem in initial analysis. To avoid this problem only the "percent of time standing" category was retained for submission to the model as the most common risk factor present in this group (Magora, 1972; Xu et al., 1997).

3. Results

3.1. Inter-observer reliability study

Inter-observer reliabilities for key variables are presented in Table 1. The reliabilities of peak flexion and percentage of time spent in posture category variables were excellent (ICC$>$0.8). Somewhat lower reliability levels (ICC of 0.4–0.8) were found for peak and average velocity and movement related flexion variables. Slight or fair reliabilities (ICC$<$0.4) were found for the peak extension and lateral bending variables.

3.2. Accuracy study

The video analysis system data showed very high correlation to data from the optoelectric system ($r = 0.92$) when examined as time-series data. A representative example of a time-series trace is given graphically in Fig. 2. Root mean square errors were 12.85° when calculated from the time-series data and 5.79° when calculated from the APDF, which was used for the extraction of variables in the risk relationship study. Comparison of the operator mean scores to the optoelectric data is presented in Table 2. The lag of the video signal contributed to the moderate RMS errors but did not affect the APDF parameters that were used in the epidemiological study. Differences between the two systems were lowest for posture variables and highest for velocity variables. Digital video analysis tended to overestimate peak trunk velocity while average velocity showed less than 4% difference over the reference system.

3.3. Risk relationship study

The results of bivariable comparisons of all variables against case-control status are presented in Table 1. Trunk flexion variables including peak level, peak velocity, average velocity indicators, and percent of time in flexion category indicators all showed significant differences. Compound postures of flexion, twisting, and or lateral bending, which were infrequent in this population (less than 2% of time), showed no significant differences, and were not included in Table 1. Odds ratios indicating the strength of associations, for variables with significant case-control differences, are presented in Table 3. Odd ratios were calculated using an exposure difference equal to the inter-quartile spread observed in the randomly selected control subjects. Less conservative risk estimates were also calculated using an exposure difference equal to the spread between the 10th and 90th percentiles observed in the random controls. A multivariable model indicating a minimum variable set with statistical independence is presented in Table 4.

Table 1
Results of both the inter-observer reliability test and LBP risk relationship study[a]

Variable	Reliability	Case			Controls			t-test
	(ICC)	N	Mean	s.d.	N	Mean	s.d.	p-value
Peak extension 1%ile (deg)	0.04	80	−2.2	2.3	114	−3.0	3.6	0.05
Median flexion/extension (deg)	0.79	105	3.8	4.0	129	2.6	3.4	0.01*
Peak flexion 1%ile (deg)	0.80	105	51.2	22.3	129	39.2	23.4	0.00*
Peak lateral bend amplitude	0.24	105	28.9	12.6	129	29.1	12.4	0.90
% time extended (past −5°)	—	105	0.3	1.4	129	2.1	8.6	0.03*
% time in neutral (−5° to 15°)	0.90	105	84.5	12.7	129	87.6	13.5	0.08
% time flexed over 20°	0.87	105	11.6	11.2	129	7.5	10.6	0.00*
% time in severe flexion (>45°)	0.88	105	4.3	6.5	129	2.2	3.9	0.00*
Peak extension velocity 1%ile ($\deg s^{-1}$)	0.48	105	−42.5	16.8	129	−35.9	18.5	0.01*
Median trunk velocity ($\deg s^{-1}$)	0.09	105	0.7	0.4	129	0.7	0.4	0.71
Peak flexion velocity 1%ile ($\deg s^{-1}$)	0.43	105	41.3	15.2	129	34.2	17.3	0.00*
Peak lateral speed ($\deg s^{-1}$)	0.11	105	108.2	47.5	129	103.7	44.4	0.45
# back flexion movements ($\# \min^{-1}$)	0.61	105	2.9	2.1	129	2.3	2.3	0.04*
# back lateral bend movements ($\# \min^{-1}$) amplitude	0.16	105	1.1	1.6	129	1.2	1.6	0.64
# back twists ($\# \min^{-1}$)	0.27	105	1.4	2.3	129	1.0	1.6	0.11
% time in twist (>20°)	0.23	105	2.0	4.0	129	1.7	4.2	0.52
% time in lateral bend (>20°)	0.02	105	1.5	2.5	129	2.4	5.3	0.10
Average lateral velocity ($\deg \min^{-1}$)	0.17	105	269.9	109.2	129	238.1	118.9	0.04*
Average flex./ext. velocity ($\deg \min^{-1}$)	0.62	105	306.6	136.7	129	252.7	133.7	0.00*
Stand—% time	0.82	105	64.1	27.5	129	63.6	30.2	0.88
Sit down—% time	—	105	28.1	27.1	129	31.5	30.3	0.37
Walk—% time	0.82	105	6.9	8.4	129	4.5	6.5	0.02*
Squat—% time	—	105	0.3	1.2	129	0.2	0.6	0.42
Kneel—% time	—	105	0.5	3.1	129	0.2	1.4	0.42
Lie—% time	—	105	0.1	0.4	129	0.0	0.0	0.15

[a] Reliability is indicated by the intra-class correlation coefficient (ICC) or, if not available, with a '–'. The sample size, means, and standard deviations (s.d.) of cases and controls as well as t-test results from case-control comparisons are indicated for all variables. Significant differences ($p<0.05$) are indicated with a*. %ile = percentile.

4. Discussion

In selecting the video clips to be used for the inter-observer reliability evaluation, every effort was made to ensure that the trials used would be as similar as possible to the data collected in the epidemiological study. Comparison of the test data used here to the data from the Ontario Universities Back Pain Study, revealed that the test data set generally contained higher exposures in terms of increased flexion amplitudes, longer times spent flexed, and more flexion/extension movements than those seen in the main database. This use of more difficult tracking trials suggests that the reliability results are not inflated by the selection of unrealistically simple trial tasks.

The accuracy trial used a single test file for this study (see Fig. 2 and Table 2) which contained many movements with large amplitudes and fast movement speeds. In the accuracy test, the peak velocity was over twice as fast as those observed in the industrial site from the epidemiological data. Similarly, the average velocity in the accuracy test was over eight times higher than in the field observations. This suggests that the accuracy results presented in this paper are a conservative estimate of the results that might be expected in industrial worksites. The system presented here was put through a rigorous test of its performance characteristics with robust results. While caution may be required when assessing extension postures, or movement out of the plane of the video such as lateral bending or twisting, reliable and

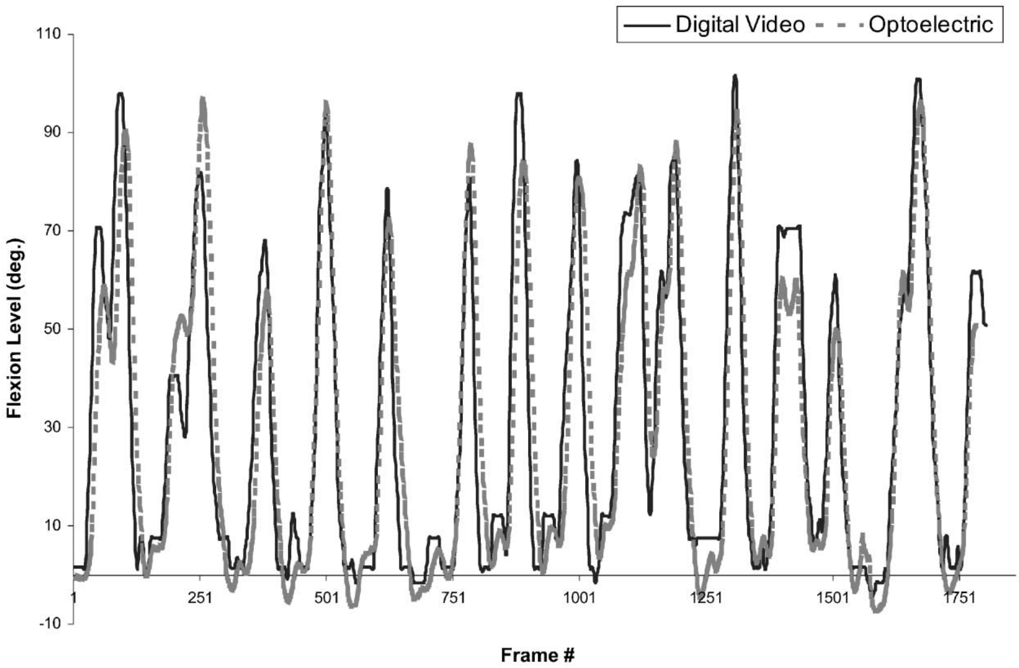

Fig. 2. A sample accuracy test result comparing digital video analysis system data over the simultaneously recorded data from the optoelectric imaging system in a trial lasting about 1 min and including many large flexion/extension movements.

Table 2
Results of the accuracy test for specific variables[a]

	Optoelectric system	Operators			Difference	% dif.
		Mean	s.d.	C of V		
Peak extension—1%ile (deg)	−6.6	−1.9	1.3	−0.70	4.7	71.4
Peak flexion—1%ile (deg)	94.6	97.8	5.7	0.06	7.1	9.4
% time in neutral (−5° to 15°)	45.1	49.7	2.2	0.04	4.6	10.3
% time flexed over 20°	48.9	47.3	2.4	0.05	−1.6	−3.3
% time in severe flexion (>45°)	33.3	33.7	4.6	0.14	0.4	1.3
Peak extension velocity 1%ile (deg s^{-1})	−112.1	−145.1	13.4	−0.09	−33.0	−29.4
Extension velocity—10%ile (deg s^{-1})	−76.5	−87.6	9.6	−0.11	−11.1	−14.4
Flexion velocity—10%ile (deg s^{-1})	77.0	83.8	5.6	0.07	6.8	8.8
Peak flexion velocity—1%ile (deg s^{-1})	110.7	150.2	21.7	0.14	39.5	35.6
# back flexion movements (min^{-1})	34.3	32.2	0.9	0.03	−2.1	−6.2
Average flex./ext. velocity (deg min^{-1})	2487.4	2581.2	242.2	0.09	93.8	3.8

[a] Optotrak system results are compared to the operator means, while operator variability is indicated by the standard deviation (s.d.) and coefficient of variation (C of V). Mean operator differences and percent difference (% dif.) from the referent system are also represented. %ile = percentile.

Table 3
Univariable odds ratios (OR), 95% Confidence Intervals (95% CI), and variance accounted for (R-square) for selected significant variables as calculated using an exposure difference (Unit) equivalent to the inter-quartile spread and to the difference between 10th and 90th percentiles of the random control subjects. %ile = percentile

Variable	R-square	10th–90th spread			Inter-quantile range		
		Unit	OR	95% CI	Unit	OR	95% CI
Median flexion/extension (deg)	0.04	5.6	1.8	1.1–2.9	0.3	1.0	1.0–1.1
Peak flexion—1%ile (deg)	0.08	63.6	4.2	2.0–8.9	39.0	2.4	1.5–3.8
% time extended (past −5°)	0.03	1.9	0.8	0.55–0.97	0.3	1.0	0.9–0.1
% time flexed > 20°	0.05	18.3	2.0	1.2–3.3	9.8	1.4	1.1–1.9
% time in severe flexion (> 45°)	0.05	6.7	1.8	1.2–2.8	2.7	1.3	1.1–1.5
Peak extension velocity—1%ile (deg s^{-1})	0.04	51.2	2.9	1.4–6.4	25.5	1.7	1.2–2.5
Peak flexion velocity—1%ile (deg s^{-1})	0.06	35.2	2.5	1.4–4.6	22.6	1.8	1.3–2.7
# back flexion movements (min^{-1})	0.03	5.5	2.0	1.0–3.9	2.9	1.4	1.0–2.1
Average flex./ext. velocity (deg min^{-1})	0.05	355.9	2.9	1.4–5.9	176.6	1.7	1.2–2.4
Average lateral velocity (deg min^{-1})	0.03	315.7	2.2	1.1–4.5	160.4	1.5	1.0–2.1
Walk—% time	0.03	13.3	1.8	1.1–3.1	5.4	1.3	1.0–1.6

Table 4
Results of the multivariable logistic regression of the trunk kinematic variables against case/control status using backwards elimination selection[a]

Variable name	10th–90th spread			Inter-quartile range		
	Unit	OR	95% CI	Unit	OR	95% CI
Peak flexion—1%ile (deg)	63.6	4.03	1.9–8.9	39.0	2.35	1.5–3.8
% time in lateral bend > 20°	5.8	0.50	0.2–0.9	2.2	0.77	0.6–0.96
Average lateral velocity (deg min^{-1})	315.7	2.54	1.1–5.9	160.4	1.61	1.1–2.5

[a] Odds ratios (OR) are calculated for exposure differences equivalent to the inter-quartile spread (IQS) and at the 10th–90th percentiles from the random control subjects. Model performance characteristics were as follows: Max. R-square adjusted = 0.127, Concordance = 66.9%, −2 Log Chi-Square = 292.7. %ile = percentile.

accurate assessments of trunk flexion parameters were possible from our field recorded video.

The postural risk factors identified in this analysis are consistent with other research identifying awkward postures as LBP risk factors (Garg, 1989; Bernard, 1997; Punnett et al., 1991). The results and data presented in this paper are comparable to, and consistent with, the previous work of Marras et al. (1995). Workers in the present study had higher average peak flexion levels, lower flexion movement speeds, and higher lateral bending speeds when compared to those reported by Marras et al. (1995). This is likely to be related to the different types of work studied; Marras studied manual material handling work while this study looked at hourly-paid workers in automobile assembly plants including maintenance workers and skilled trades.

While the average lateral bending velocity was an independent risk factor for LBP reporting, the percent of time spent in lateral bending postures showed an unexpected protective effect in multivariable analysis. Sensitivity analysis indicated that this variable added about 2% to the estimated injury variance accounted for in the multivariable model. This relationship has been observed with other instruments applied in this same epidemiological study (Neumann et al., 2001). Similarly, the percent of time spent in extension postures, defined as extension beyond 5°, showed some protective effect in bivariable comparisons. Mean exposure to extension postures in controls of 2.1% of time compared to the cases who averaged 0.3 % of time in these postures. Marras et al. (1995), reporting exposure differences between low, medium and high risk jobs, found that low risk jobs had slightly higher maximum left bending and maximum extension positions than did medium or high risk jobs. In the study by Marras et al., the exposure in all groups was also very low but statistically significant for the extension variable while lateral bending was marginally significant for low–medium risk job comparisons. In this study, the average percent of time spent laterally bent beyond 20° was small, under 2.5% of time, for both groups. It is biomechanically improbable that extreme amounts of lateral bending or trunk extension postures will prevent low back injury.

Neither sitting nor standing emerged as risk factors in this study. This result would be expected in situations where a risk factor such as standing is distributed evenly throughout the population, as was the case in the assembly workers. Walking, defined as taking more than two consecutive steps, emerged as a risk factor in bivariable comparisons even though the average time spent for walking is quite low, below 7% of time for both groups. This variable did not contribute to the multivariable model. There is not a large body of evidence in the literature supporting walking as a LBP risk factor so these results should be interpreted with caution. Anannontsak and Puapan (1996) have reported decreased LBP prevalence with standing and walking and Biering-Sorensen (1983) also reported walking as providing some LBP relief. It is possible that, in this study, the walking variable is acting as a marker for an exposure, such as carrying loads that was not recorded by this kinematic measurement method, although it was part of other methods used in this study.

In their recent review of epidemiological evidence surveying the association between postural factors and low back pain, the National Institute for Occupational Safety and Health (Bernard, 1997) concluded there was some, but not strong, evidence for posture being a LBP risk factor. Of 12 studies cited only one study failed to show an association in bivariable comparisons between posture and low back pain. Of six studies that examined it, five identified a dose-response relationship between posture and LBP. In three studies, postural risk factors, which were identified in bivariable comparisons, were not retained in multivariable modeling procedures. The exclusion of terms from a multivariable statistical model does not necessarily indicate a lack of relationship with outcome status, but rather that the variable retained in the final model accounted for slightly more of the injury variance than did the excluded, correlated terms. Other factors, such as practicality and clarity, need to be considered before dismissing potentially useful variables based on statistical grounds alone.

We found the risk relationship to be most obvious in postural indicators associated with higher biomechanical loading such as extreme flexion or fast movement. Norman et al. (1998) showed that, of the variables selected from all measurement methods, including the video method presented here, four groups of variables contributed independently to risk of reporting low back pain: peak spinal load, cumulative spinal load, hand load, and trunk kinematics. In particular, they showed that, in multivariable modeling with variables from all four factors, trunk velocity accounted for more additional injury variance than did peak trunk angle. When trunk kinematic variables were modeled multivariably here without peak spinal load, trunk angle remains in the logistic model instead of trunk flexion velocity. This is likely because peak trunk flexion captures injury variance from two factors: trunk kinematics (correlation $r \sim 0.68$ with trunk angular velocity), and peak spinal load (correlation $r \sim 0.33-0.48$ with peak spinal load; Norman et al., 1998).

The video analysis system described here has the advantage of allowing quantification of trunk kinematic parameters without encumbering the worker in any way. While there may be resistance to using video in some work places, and line of sight limitations in other locations, we were able to use the system successfully to assess a large number of workers in a broad range of types of work in an automotive manufacturing facility. Video analysis, if conducted at 1/4 speed, would take 20 min for a single pass through a 5 min section of video plus the time required to select and capture a representative video sample.

The case-control study design used in this project has a number of advantages over cohort designs including greatly reduced costs and less vulnerability to changes in physical exposure which occur regularly in this environment due to job or engineering changes. In the present study, substantial design efforts were made to assess post-injury reporting, and job performance bias that might have systematically altered cases' psychosocial and biomechanical exposure measurements via changes in either attitudes or body use after injury. No such serious biases were found to affect the final full multivariable model (Kerr et al., 2001). The 'proxies' used in this study were part of a larger group of 'Job Matched Controls' (JMCs) who performed the same work tasks as their case matches but had not reported LBP. When cases' physical loading data were compared to JMCs' agreement was generally good and no statistical differences were found (Kerr et al., 2001). This is consistent with Allread et al. (2000) who found that job design accounted for far more variability in trunk kinematics than did within or between worker differences. In our case, the JMCs had slightly lower exposures than the cases suggesting that the use of proxies would, by narrowing the difference between cases and controls, tend to attenuate the odd ratios found in this study (Norman et al., 1998). We agree with Punnett et al. (1991) who found that using proxies increased statistical power without unduly affecting their conclusions.

While steps were taken to limit the awareness of the field study teams to the worker's case-control status, formal blinding was not feasible. Although a physical exam was conducted, this study used the behaviour of reporting pain to the plant nursing staff, only some of whom subsequently filed a compensation claim. While genetic factors related to low back pain were not examined in this study, no major differences on personal characteristics were found which might counter the job-related risk factors identified in this paper (Kerr et al., 2001). Variability resulting from the selection of representative video clips and their analysis remain a potential source for error. These factors would likely to be a random error and affect both groups equally, thereby tending to reduce rather than exaggerate the likelihood of observing differences between the cases and controls. In spite of these limitations, significant differences and substantial odd ratios emerged on a number of trunk kinematic parameters. Trunk kinematics are one of a number of known risk factors for low back pain. These results indicate the utility of video-based methods for measuring these exposures both for etiologic research and for ergonomic practice in efforts to reduce musculoskeletal disorders in the workplace.

5. Conclusions

It is possible to obtain reliable and accurate quantification of trunk flexion/extension kinematic parameters from field recorded video. This type of low cost, adaptable system has the advantage of not encumbering the worker while providing a permanent record, which can be examined for other visible risk factors. Trunk flexion parameters, such as extreme flexion or velocity show strong and consistent associations with increased LBP risk. Trunk posture and other trunk kinematic parameters, especially those associated with high tissue loading, are risk factors for low back pain reporting in industrial workplaces.

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