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Biomechanical evaluation of nursing tasks in a hospital setting

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A field study was conducted to investigate spinal kinematics and loading in the nursing profession using objective and subjective measurements of selected nursing tasks observed in a hospital setting. Spinal loading was estimated using trunk motion dynamics measured by the lumbar motion monitor (LMM) and lower back compressive and shear forces were estimated using the three-dimensional (3D) Static Strength Prediction Program. Subjective measures included the rate of perceived physical effort and the perceived risk of low back pain. A multiple logistic regression model, reported in the literature for predicting low back injury based on defined risk groups, was tested. The study results concluded that the major risk factors for low back injury in nurses were the weight of patients handled, trunk moment, and trunk axial rotation. The activities that required long time exposure to awkward postures were perceived by nurses as a high physical effort. This study also concluded that self-reported perceived exertion could be used as a tool to identify nursing activities with a high risk of low-back injury.

Keywords: Nursing; Spine; Kinematics; Compressive and shear force; Perceived risk of musculoskeletal injury

1. Introduction

Occupational low-back disorders have been a major concern for decades owing to their detrimental effects on quality of work life, mental and physical health of employees and associated social costs (Marras and Karwowski 2006). The biomechanical factors that affect low back pain include weight lifted, task asymmetry, lift rate, load position and

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reach distances (Kelsey and Golden 1988, Marras *et al*. 1993, 1995, NIOSH 1997, Burdorf and Sorock 1997, Ferguson and Marras 1997, Marras and Granata, 1997, Davis and Marras 2000). Effects associated with these factors are usually manifested in kinetic and kinematic characteristics of specific joints and electromyograms of related muscles. Published studies have also reported musculoskeletal disorders to be among the most important sources of occupational injury and disability in the nursing profession (Klein *et al*. 1984, Shelerud 1998, Daraiseh *et al*. 2003, Sherehiy *et al*. 2004, Karwowski *et al*. 2005, Bos *et al*. 2006). Engels *et al*. (1996) surveyed work-related risk factors for musculoskeletal complaints in nursing personnel. The results showed that more than one-third of the respondents regularly had back complaints (36%) but also had arm or neck (30%) and leg complaints (16%). Eighty-nine percent of all respondents considered nursing work to be physically strenuous. The physical variables that bothered the respondents most were lifting (65%), working in awkward postures (47%), and stooping (34%).

Patient transfers in hospitals, nursing homes and assisted living facilities have been reported to be the task with the largest contribution to low back injuries suffered by nurses. Stubbs and Buckle (1984) found that 36% of all episodes of low back pain in nurses were associated with patient handling tasks. Harber *et al*. (1987) found a correlation between specific 'manual handling' patient care tasks and increased injury rates. Stobbe *et al*. (1988) also identified this relationship in a comparison of two groups, defined as frequent and infrequent patient handlers. Jensen (1990) reported that the prevalence rate of low back pain in nursing staff who handled patients frequently was 3.7 times larger than those who handled patients less frequently.

Garg and Owen (1992) found that patient transfers were perceived to be the most stressful tasks that nurses' aides performed, while repositioning the patient in bed had the next highest perceived stress. In their study, Garg and Owen (1992) estimated static spinal compression forces during patient transfers to be 4751 N, which was considerably higher than 3400 N, the spinal tolerance recommended by the National Institute for Occupational Safety and Health (NIOSH). Marras *et al*. (1999) simulated patient transfer tasks in the laboratory and found that transferring a patient with either one or two patient handlers was a high risk task. The low back compression forces for transfer tasks in the lowering phase ranged from 4200 to 4700 N in two-person transfers, and 5400 to 6500 N in one-person transfer.

Postural analysis by observations has often being used to evaluate physical load on the lumbar spine in industrial work. Estryn-Behar *et al*. (1990) found that many low-back pain complaints resulted from performing strenuous tasks other than patient handling tasks. Harber *et al*. (1987) recorded nursing staff activities in order to determine the exposure to back stresses in terms of task performed. The results indicated that much of the handling work, such as moving furniture and carrying supplies, etc., did not involve direct patient care, and that many static actions contribute to back stress. Kant *et al*. (1992) watched the postures of operating room staff (surgeons, assistant anaesthetists, instrumentation nurses and circulating nurses) using the OWAS (Ovako Working Posture Analysis System). They found that most postures performed by the instrumentation nurses and surgeons were static, and 80% of them were awkward postures.

Wickstrom *et al*. (1996) developed a method for evaluation of the physical load on the lumbar spine in industrial work. The method is based on biomechanical analysis of video-recordings, and is suitable for identification of high spinal loads and their time duration. Compression of the L5-S1 intervertebral disc and strain on the lumbodorsal fascia was determined at 5 s intervals in each work task. The method showed the mechanical loads on some important tissues of lumbar spine and was helpful in identifying biomechanical risks of back disorders.

Engels *et al*. (1994) investigated physical work load and prevalence of musculoskeletal complaints of nurses in nursing homes. The results found that almost 60% of the observed time was spent on non-patient related activities. Twenty percent of the observed time was spent in 'poor' work postures as defined by the OWAS (Action Category 2 to 4). Activities contributing most to these poor work postures were patient care, and household and preliminary tasks. Engels *et al*. (1996) suggested that not only should patient related activities be taken into consideration for improving work postures, but other potentially strenuous aspects of nursing work such as household and preliminary tasks, ergonomic layout of the ward, and work pressure need to be addressed. However, focusing on patient-handling only would lead to an underestimation of the total working posture load of nurses.

However, it is quite evident from the preceding discussion that no biomechanical studies evaluated tasks performed by nurses at the hospital on a daily basis. Therefore, it is essential to quantify the physical workload of nurses performing typical working tasks, and to assess spinal loading exposure during such tasks. With this view, the objectives of the study were directed: (a) to evaluate the physical workload related to spinal loading in the nursing profession, (b) to assess the level of stress on the lower back of nurses related to various activities, (c) to evaluate the perceived effort of each activity performed and (d) to examine the relationship between perceived effort and spinal kinematics.

2. Methods

2.1. *Participants*

Twenty-one individuals, including 7 registered nurses (RNs) and 14 nursing assistants (NAs), volunteered to participate in this field study. Fifteen of twenty-one participants reported low back trouble (pain and/or discomfort) during the last year, while seven participants reported low back trouble during the previous 7 days. The participants worked in two different hosptial units, the heart and lung post-operative (HLP) unit and the general inpatient (GI) unit of a southern United States hospital in a mid-size metropolitan city. The participants consisted of 19 females and 2 males. The mean and standard deviation (SD) values of age, weight, and height for the female participants were 35 (11.3) years, 76.9 (14.7) kg, and 166 (7.7) cm, respectively. For the two male participants these mean values were 36.5 years, 76 kg, and 168.9 cm, respectively. While work experience of all subjects ranged from 2 months to 21 years, 80% of the participants had work experience of less than 3 years. On average, the subjects worked 36 h per week.

2.2. *Reports of low back problems and injury data*

Medical records for year 2000 were obtained from the risk management department of the hospital. According to these records, three back injuries were reported as 'sprain/strain' in HLP that participated in the study. One injury occurred while pulling a patient up in bed, one occurred when transferring a patient from chair to bed, and the other was reported as injury to the upper back owing to 'overexertion'. One additional injury was listed as 'sprain/strain to multiple upper extremities' owing to 'pulling patient up in bed'. In 2000, there were seven reported back injuries in the GI unit. Five injuries involved the lower back, and two injuries involved the upper back. These injuries were categorized as 'sprain/strain' and were related to moving patients. In addition, one injury was classified as an overexertion. Table 1 illustrates the combined injury data in the year 2000 for these two hospital units involved in the study.

Table 1. The number and activities associated with injuries in 2000.

Activity	Back injury	Number of injuries
Pulling patient up in bed	Sprain/Strain	2
Lifting patient from chair to bed	Sprain/Strain	2
Supporting patient to prevent a fall	Sprain/Strain	3
Not classified	Overexertion	2
Turning patient in bed	Sprain/Strain	1
Total		10

2.3. *Classification of nursing activities and major task categories*

Two hundred fifty-four (254) nursing activities were identified during twenty-eight (28) field observation sessions conducted in the hospital. These sessions had a total exposure duration of forty-two (42) hours. The data for fifty-four (54) of these activities either were incomplete or could not be grouped properly. The remaining two hundred (200) nursing activities were categorized into eighteen (18) specific task categories (Table 2). Table 2 also illustrates distribution of major tasks performed by RNs or NAs. Five of these task categories involved static work postures, seven were dynamic in nature, and the remaining six were identified as a mix of both static and dynamic tasks. The RNs performed thirteen (13) tasks, while NAs performed eleven (11) tasks. Five tasks, involving lifting of patients, were performed by both RNs and NAs.

2.4. *Kinematics of spine motion*

The risk of low back injury was evaluated using the Ohio State University Risk Model (OSU model) (Marras 1995). In this model, the probability of high-risk group membership (herein referred to as LBD risk value) is a function of five trunk motion factors. The LBD risk value is calculated as the average of five variables: moment, frequency of lift, maximum sagittal flexion, average twisting velocity, and maximum lateral velocity (see figure 1). The horizontal bars in figure 1 indicate the quantitative levels of the risk factors and the associated LBD probabilities observed for particular job. The vertical line shows the average risk associated with these factors.

2.5. *Apparatus*

The lumbar motion monitor (LMM) was applied, in order to collect trunk motion variables. The LMM enables three-dimensional (3D) assessment of the instantaneous angular position of the thoracolumbar spine (Marras 1995). The LMM system measures on-the-job low back motion in three dimensions: 1) forward flexion/extension, 2) lateral flexion, and 3) rotation. The LMM consists of an exoskeleton of the spine that has been equipped with relative angular position sensors. Data from each sensor are transmitted via the umbilical cable or a telemetry system to the computer, where angular position, velocity, and acceleration of the lumbar spine are calculated. Other variables, including trunk moment, frequency of lift, maximal sagittal flexion, average twisting velocity, and maximal lateral velocity were also calculated and entered into the LBD risk model. Risk values for the evaluated tasks were then calculated.

Table 2. Description of nursing task activities.

Task category	Description of the activity	Movement category*	Task performers	No. of observ.	Risk category
Assist patient to move	Help patient move to bathroom	Mixed	Both	9	Low
Bathe patient	1) Bathe patient on bed; roll patient side to side for access 2) Bathe patient in chair; kneeling down when washing feet	Dynamic	NAs	14	Low
Check blood glucose	Put lancet in spring loaded holder; prick finger with lancet; place blood drop on test strip; insert strip in glucometer; check reading	Static	RNs	20	Low
Check blood pressure	Wrap cuff snugly and uniformly around arm circumference; palpate brachial artery; check gauge reading	Static	RNs	13	Low
Dangling	Lift patient from lying to sitting on bed	Mixed	Both	7	Low
Draw blood	Draw blood	Static	RNs	3	Low
Make bed	Collect bed sheets and pillow cases; make bed (including organizing bed area for access)	Dynamic	NAs	20	Low
Medical wound care	Cleanse wound; apply new gauze dressing to cover wound	Dynamic	RNs	11	Low
Medicine injection	Inject medicine into patient's arm	Static	RNs	7	Low
Partial lift	Move patient up in bed using draw sheet under patient's back while patient bends knees to aid the movement	Dynamic	Both	4	High
Physical assessment	Check blood pressure, temperature, heart rate, and listen to lungs	Mixed	RNs	15	Low
Prepare medicine	Enter data in computerized medicine distribution machine; pick up medicine	Mixed	RNs	15	Low
Putting on stockings	Put on stockings (antiembolism knee-high elastic stockings)	Dynamic	Both	3	Low
Take temperature	Put probe of electronic thermometer into patient's mouth, hold its position for 1 minute, check reading	Static	NAs	24	Low
Total lift	Move patient up in bed using draw sheet under the patient's back without patient's aid	Dynamic	Both	6	High
Transport patient	Move patient from chair to bed, or bed to chair	Mixed	Both	8	High
Walk patient	Accompany patient while walking with or without equipment	Dynamic	NAs	7	Low
Weigh patient	Assist patient to stand up and walk to scale	Mixed	NAs	14	Low

Note: *Static means this activity involves performing static postures and maintaining postures for a period of time; dynamic means the activity involves performing continuous movement; mixed means the activity involves performing static postures and continuous movement.

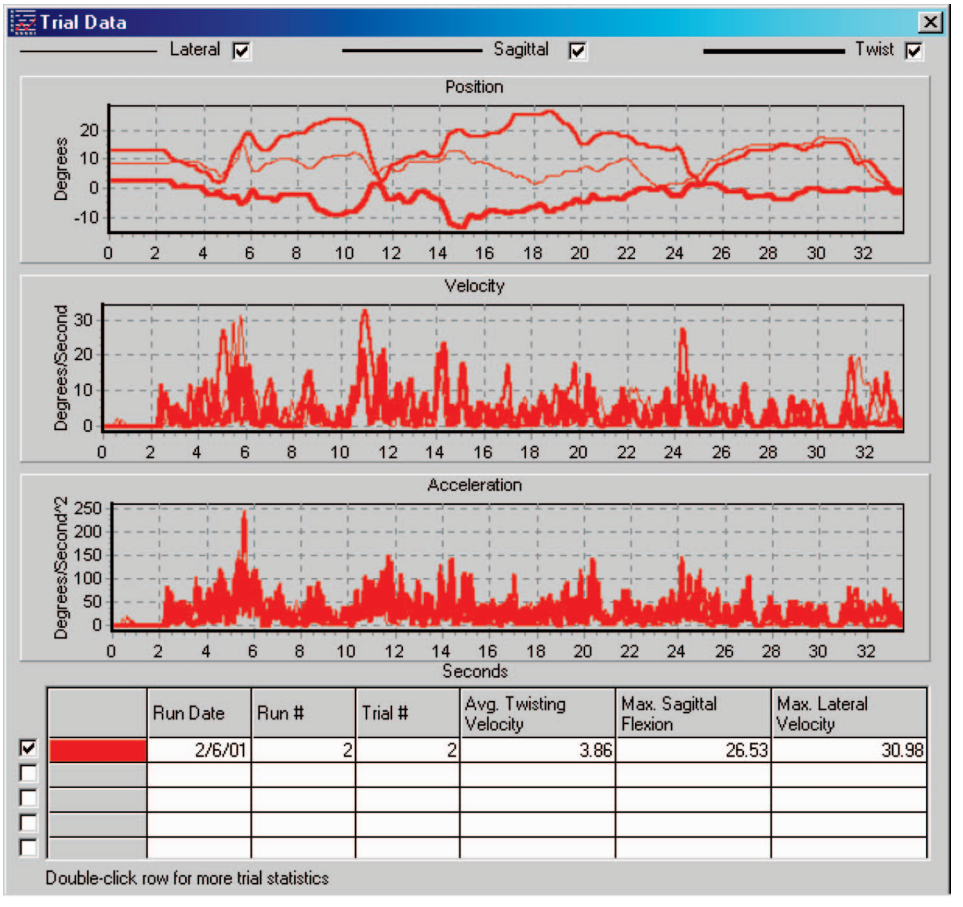

Figure 1. Example of the position (deg.), velocity (deg/sec) and acceleration (deg/sec^2) for an activity.

2.6. *Assessment of spinal forces*

In order to assess the spinal forces of the nursing activities, a 3D Static Strength Prediction Program (3DSSPP) developed at the Center for Ergonomics of the University of Michigan was utilized (see figure 2). This method assumes that inertial contributions to spinal moments are negligible. Thus, 3DSSPP is relevant for analysis of slow movement. The strength of this model is its ability to assess risks associated with one-time exertions and to estimate spine compression force.

To evaluate compression force on the low back, the nursing activity was broken into a sequence of static postures and each individual posture is then analysed. The inputs necessary for calculating spine compression force included:

(a) anthropometry: gender, height and weight;
(b) body segment angles:
  (i) limb angles: forearm, upper arm, upper leg, and lower leg at each side
  (ii) trunk angles: flexion, axial rotation, and lateral bending

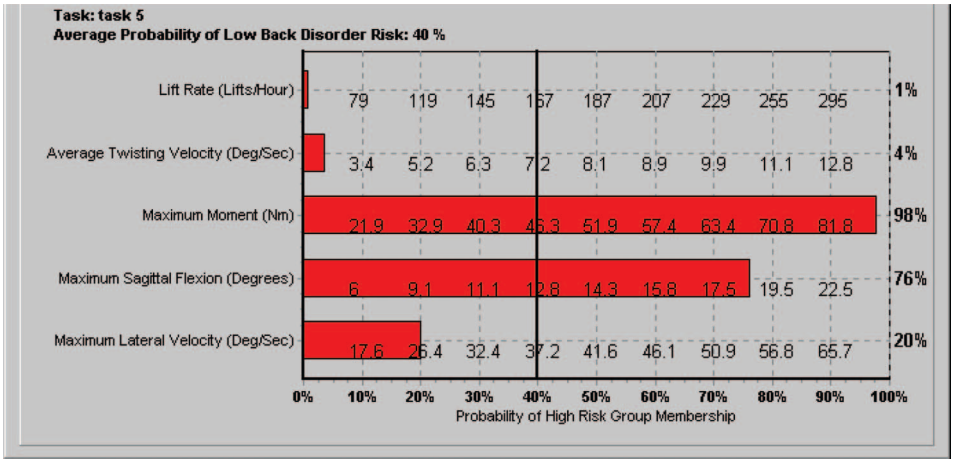

Figure 2. Example of calculation of the LBD risk value for 'dangling'.

(iii) hand position: orientation and location
(iv) hand load: applied load and angle and effort at each side.

In this study, trunk angles for each posture were obtained using LMMs. The other motion input data were estimated from videotaped simulation of activities.

2.7. *Postures selection and trunk angles estimation*

Since the spine compression force is a high risk factor for low back injury, in this study the spine compression forces for extreme postures were determined for each activity. The extreme posture in the course of any activity was selected from the LMM data file (figure 2). Limb angles and hand positions for calculating spine compression force were estimated by reviewing videotape of simulations of each activity.

For each activity, limb angles and hand positions were assumed to be the same for every repetition of the activity. For example, the limb angles and hand positions that were estimated for the 'partial lift' activity were used in the analysis each time this activity was performed. This approach assumes that all nurses would tend to perform each activity similarly, in accordance with their training. According to a postural angle sensitivity provided by 3DSSPP, a 10° difference in an estimated angle may produce a variation of about 12% in the percent capability model predictions (see figure 3).

The weight of patients being lifted was estimated on-site by the participating nurses. One hundred percent of patient weight was used when evaluating 'total lift' activities, while fifty percent of patient weight was estimated for 'partial lift' activities. The average weight lifted during 'total lift', 'partial lift', 'transport patient', and 'dangling' activities was 75, 42, 48, and 36 kg, respectively. It should be noted that he 'bathe patient' and 'make bed' activities involved strenuous pushing and pulling tasks.

2.8. *Background data: perceived physical exertion and risk of low back injury*

Background data on biomechanical task demands were collected for all 200 nursing activities. The Borg scale of 1962, with the scores ranging from 6 to 20 was

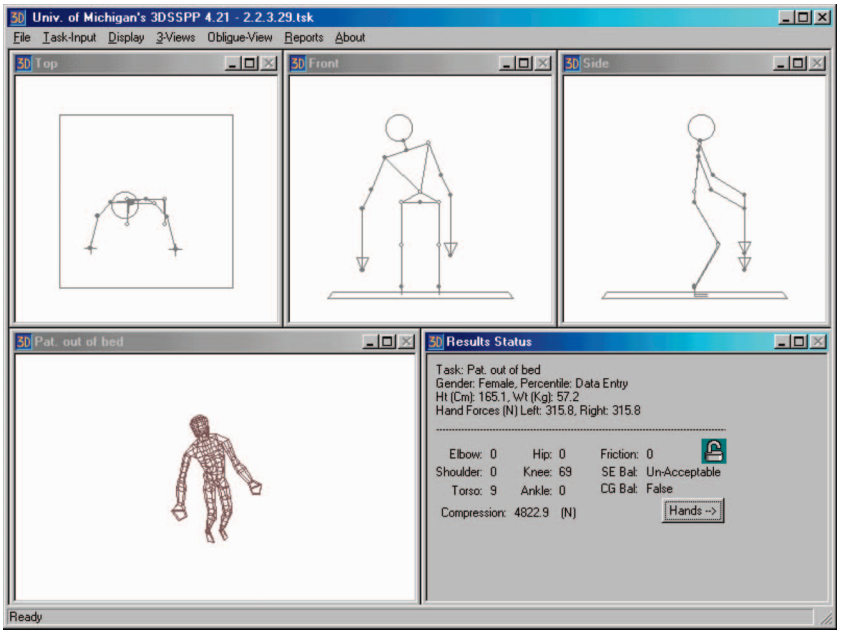

Figure 3. The selected posture for 'dangling' by subject 2.

used to rate the perceived physical exertion (RPE) for dynamic work activity (see figure 4(a). According to Borg (1962), the ratings (6–20) are related to the heart rates expected for corresponding levels of muscular exertion. In addition, perceived risk of low back injury for each nursing activity was assessed using the low back risk scale (LBRS) (see figure 4(b)). The LBRS utilized scores ranging from 0 (no risk) to 10 (extremely high risk / will almost certainly lead to an injury), following the idea of the Borg scale (1998).

2.9. *Procedures*

The LMM was used to measure back motion. The LMM waist and chest harness were applied to each participant and adjusted to the correct position. The exoskeleton was then secured on the harness. Each participant was asked to relax and maintain a stand-straight posture, in order to establish a 'zero' reference position. Each participant then returned to the workplace and performed tasks as usual.

During kinematic data collection, the recording would not be terminated until the activity was finished. Any related movements within the recording period were recorded as a part of the activity performed. If any unrelated movements were performed during the period, the recording was stopped and this file was discarded. For each lifting activity, the weight of the patient lifted was subjectively estimated and the distance between the lumbosacral joint and the center of the hands was measured. After each nursing activity, participants were asked to rate their RPE effort, and the perceived risk of LBRS. If the participant finished multiple activities continuously, then he/she gave the rating for each activity separately. Each session of data collection lasted 2 h: 30 min for preparation, and 1 h and 30 min for data collection.

6	-	no exertion at all
7	-	extremely light
8	-	
9	-	very light
10	-	
11	-	light
12	-	
13	-	somewhat hard
14	-	
15	-	hard
16	-	
17	-	very hard
18	-	
19	-	extremely hard
20	-	maximal exertion

(a)

0	-	No risk
0.5	-	Extremely low / negligible risk
1	-	Very low risk
2	-	Low risk
3	-	Moderate risk
4	-	Somewhat high risk
5	-	High risk
6	-	
7	-	Very high risk
8	-	
9	-	
10	-	Extremely high risk (will almost certainly lead to an injury)

(b)

Figure 4. (a) Borg scale for rating of perceived exertion (RPE), and (b) rating of perceived risk of low back injury (LBRS) owing to specific nursing activity.

3. Results

3.1. *Trunk motion and workplace factors*

Based on medical records of injuries that occurred in 2000, the activities associated with injury were placed in the high risk group. The activities with no injury records were assigned to the low risk group. Risk category assignments are shown in table 2.

Results from individual sample *t*-tests (see table 3), used to evaluate trunk motion variable differences between low and high risk groups, showed that the high risk group had significantly higher moment and weight handled values. Maximum right bend was also found to be significantly greater for the low risk group. The low risk group had significantly greater values for maximum sagittal velocity, maximum sagittal acceleration, maximum lateral velocity, maximum lateral acceleration, and maximum twisting

acceleration. The output from multiple logistic regression, used to investigate whether trunk moment and motion variables could be used to predict risk group classification for daily hospital activities, indicated that trunk moment with an odds ratio (95%CI) of 1.039 was the only significant variable (table 4).

Table 3. Descriptive and *t*-test (unequal means) statistics of the trunk motion factors in low and high risk group of nurses.

Factors	Units	Low risk group ($n = 171$) Mean	Low risk group ($n = 171$) Std Dev	High risk group ($n = 16$) Mean	High risk group ($n = 16$) Std Dev	*t*-statistics (unequal means)
Moment	Nm	8.20	32.58	161.50	72.71	8.36†
Weight handled	kg	2.63	10.47	54.93	27.73	8.39†
Maximum left bend	deg	−5.51	4.10	−6.79	3.45	1.39
Maximum right bend	deg	10.57	5.29	7.89	3.11	3.06†
Maximum lateral range	deg	16.09	7.65	14.68	5.87	0.89
Maximum extension	deg	−1.77	5.33	2.31	7.66	2.08
Maximum flexion	deg	30.47	14.04	30.53	12.27	0.02
Maximum sagittal range	deg	32.23	14.71	28.22	14.02	1.09
Maximum left twisting	deg	−10.71	5.51	−12.58	8.62	0.86
Maximum right twisting	deg	8.72	6.97	6.19	4.71	1.95
Maximum twisting range	deg	19.43	10.40	18.78	10.18	0.24
Average lateral velocity	deg	2.22	1.25	2.18	0.77	0.18
Maximum lateral velocity	deg	24.45	9.59	20.16	6.58	2.38*
Average sagittal velocity	deg	3.14	1.49	3.12	1.22	0.07
Maximum sagittal velocity	deg/sec.	37.00	16.72	27.02	12.00	3.06†
Average twisting velocity	deg/sec.	2.92	1.83	2.93	0.97	0.02
Maximum twisting velocity	deg/sec.	19.43	10.40	18.78	10.18	0.24
Maximum lateral acceleration	deg/sec.^{2}	163.25	66.12	131.84	47.75	2.42*
Maximum sagittal acceleration	deg/sec.^{2}	215.13	92.28	155.61	65.33	3.35†
Maximum twisting acceleration	deg/sec.^{2}	245.53	129.30	189.76	69.31	2.80†

Note: *$p < .05$ and †$p < .01$.

Table 4. Results of the logistic regression analysis for predicting risk of low back injury based on trunk motion variables.

Variables	Coefficients	Odds ratio	Standard error	95% Wald Confidence Limits	
Trunk moment	0.038*	1.039	0.010	1.019	1.059
Maximum lateral range	−0.054	0.947	0.161	0.691	1.299
Maximum flexion	0.012	1.012	0.080	0.866	1.184
Maximum sagittal range	0.013	1.014	0.100	0.833	1.233
Maximum twisting range	−0.016	0.984	0.098	0.812	1.192
Average lateral velocity	−0.919	0.399	1.601	0.017	9.202
Maximum lateral velocity	0.016	1.016	0.171	0.726	1.422
Average sagittal velocity	0.332	1.393	0.823	0.278	6.988
Maximum sagittal velocity	0.052	1.053	0.093	0.878	1.265
Maximum twisting velocity	−0.098	0.907	0.106	0.737	1.116
Maximum lateral acceleration	0.001	1.001	0.023	0.958	1.047
Maximum sagittal acceleration	−0.016	0.984	0.014	0.957	1.011
Maximum twisting acceleration	0.009	1.009	0.016	0.978	1.041

*$p < .0001$.

3.2. *Kinematic data analysis for activities*

Figure 5 shows the distribution of LBD risk value for all nursing tasks ($n = 200$). Seventy-five percent of the tasks had an LBD risk value below 40 while the remaining activities had an LBD risk value between 40 and 60. Table 5 shows the means of LBD risk value with values of risk factors for each nursing task category. Results showed that task categories involving lifting had generally higher LBD risk values than those with no lifting involvement. The maximum moment contributed most to those tasks with values over 40. Owing to the low lifting rates and moment values, most activities had low LBD risk values. According to Marras (*et al*. 1995), jobs with LBD risk values below 30, are more likely to be the in low-risk category. Very few jobs having a risk value over 50 were defined as 'low risk' and no low-risk job had a risk value over 70. Jobs with LBD values above 60 were virtually assured to have some risk of low back injury associated with them (Marras *et al*. 1995).

The LBD risk values for the 'partial lift' (41) and 'transport patient' (40.3) activities were in the category between 40 and 50 (see table 5). These activities had a 32% probability of being in the low risk group, and a 68% probability of being in the high risk group. The LBD risk values for the 'make bed' (32.7), 'bathe patient' (32.7), 'total lift' (37.8), and 'dangling' (34.1) activities were in the LBD risk category between 30 and 40. These activities had a 44.4% probability of being in the high risk group. The remaining activities with LBD risk values below 30 had over 70% probability of being in the low risk group.

3.3. *Spinal forces*

Figure 6 shows the distribution of spine compression forces for all activities ($n = 200$). Ninety-two percent had spine compression forces less than 3400 N. Six percent had spine compression forces between 3400 N and 6400 N. Two percent had spine compression forces above 6400 N. Table 6 shows means of spine compression forces, spine shear force,

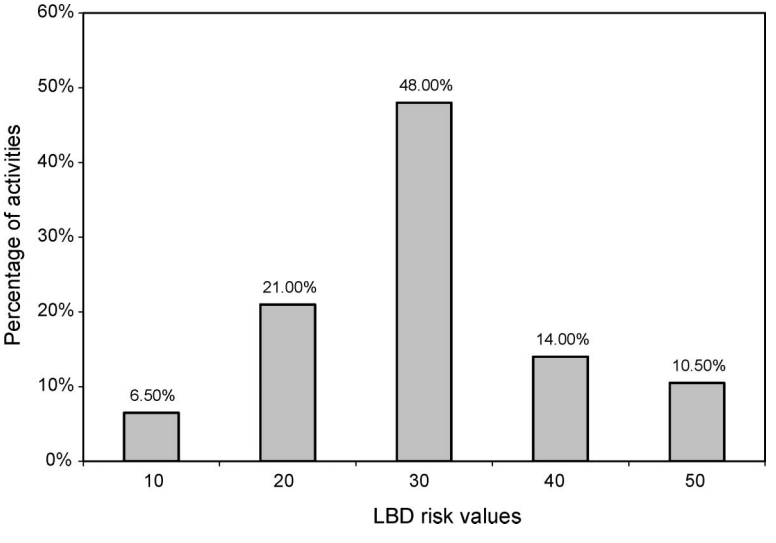

Figure 5. The distribution of LBD risk value for all activities.

Table 5. The low back disorders (LBD) risk factors values and their mean for each nursing task category.

		Risk factors				
Task Category	LBD Risk Value (%)	Lifting Rate (per hour)	Max. Moment (Nm)	Mean Twisting Velocity	Max. Sagittal Flexion	Max. Lateral Velocity
Assist patient to move	27.9	1.0	22.6	6.3	86.9	21.6
Bathe patient	32.7	1.0	1.0	20.7	98.0	43.1
Check blood glucose	22.6	1.0	1.0	10.1	79.6	16.7
Check blood pressure	21.0	1.0	1.0	1.3	86.8	14.2
Dangling	34.1	1.0	67.0	2.3	85.7	14.4
Draw blood	25.3	1.0	1.0	4.7	98.0	22.7
Make bed	32.7	1.0	1.0	24.2	95.2	36.9
Medical wound care	26.2	1.0	1.0	6.3	91.0	31.8
Medicine injection	18.3	1.0	1.0	1.0	74.9	4.4
Transport patient	40.3	1.0	87.4	7.9	88.0	15.3
Partial lift	41.0	1.0	91.5	3.0	95.8	14.8
Physical assessment	22.6	1.0	1.0	1.0	97.6	12.9
Prepare medicine	21.7	1.0	1.0	3.5	86.5	16.3
Put on stockings	28.7	1.0	1.0	7.7	98.0	34.3
Take temperature	16.4	1.0	1.0	1.0	70.7	7.7
Total lift	37.8	1.0	98.0	1.3	79.2	9.7
Walk patient	17.9	1.0	9.1	20.1	42.7	16.3
Weigh patient	24.4	1.0	21.8	5.4	68.6	24.4

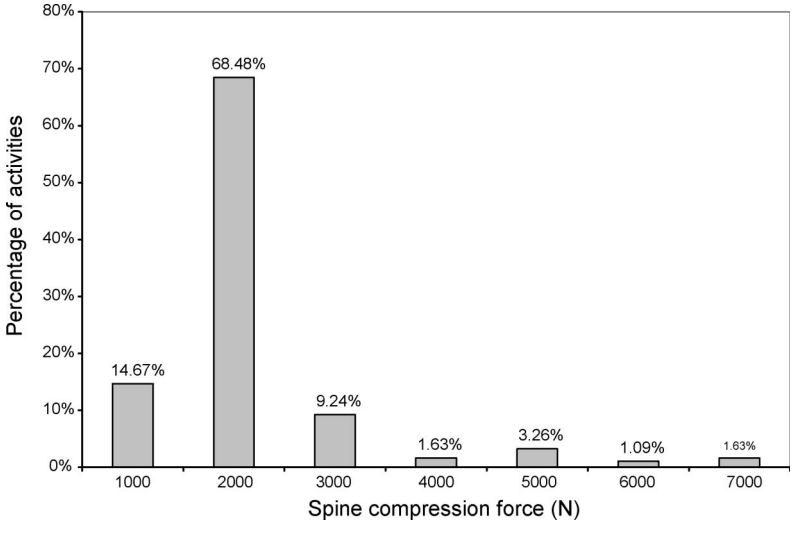

Figure 6. The distribution of spine compression values for all activities.

and ligament strain for each activity. The mean estimated spine compression force for those activities that involving no lifting was below 2000 N. Shear forces on the vertebral discs are due to upper body weight, posture, and horizontal hand forces. Ligament strain represents the value of strain in the lumbodorsal fascia, which is attached between the L5 and S1 vertebrae and plays a major role in resisting forward flexion.

3.4. *Correlation between subjective and objective measurements*

The correlation matrix shown in table 7 was determined for 187 nursing tasks to explore the relationship between perceived physical effort (RPE scores), perceived risk of low back injury (LBRS), LBD risk values (LBDRV), and estimated maximum spine compression forces (MSCF). The correlation between the ratings of perceived physical exertion (RPE) and the perceived risk of low back injury was 0.8193 ($p < 0.0001$); between the RPE and the spine compression force was 0.5434 ($p < 0.0001$); between the RPE and the LBD risk value was 0.4601 ($p < 0.0001$).

4. Discussion

4.1. *Analysis of kinematic data*

This study focused on quantification of spinal kinematics and spinal loading in nurses. The values of trunk motion indicated the presence of awkward postures in nursing. Such

Table 6. The mean, standard deviation, and range of spine compression force [N], spine shear force [N], and ligament strain for each nursing task category.

	Compression force		Shear force		Ligament strain	
Activity	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Total lift	13230 ± 4790	6000–18300	1210 ± 320	750–1570	11.0 ± 1.6	9–13
Partial lift	9150 ± 2920	6930–12460	850 ± 180	720–1050	12.0 ± 2.0	10–14
Transport patient	8900 ± 3290	3520–13780	980 ± 350	420–1580	11.8 ± 3.1	6–15
Dangling	6660 ± 3930	1730–12570	700 ± 350	230–1150	10.7 ± 2.6	6–14
Assist patient to move	2910 ± 2520	820–8880	440 ± 260	260–1050	9.2 ± 4.2	8–17
Bathe patient	2220 ± 1050	1470–4830	350 ± 250	140–1030	12.2 ± 2.7	8–17
Make bed	1860 ± 780	1180–4750	320 ± 160	240–960	11.4 ± 3.1	6–16
Draw blood	1730 ± 140	1640–1890	260 ± 40	230–310	14.0 ± 3.5	10–16
Weight patient	1730 ± 960	720–4220	320 ± 150	110–710	9.4 ± 5.1	2–17
Put on ted hose	1610 ± 480	1200–2130	250 ± 80	190–340	13.0 ± 1.7	11–14
Take blood pressure	1570 ± 300	890–1940	260 ± 40	200–310	10.3 ± 4.2	2–16
Prepare medicine	1520 ± 420	780–2070	250 ± 50	180–340	10.3 ± 3.7	4–15
Physical assessment	1520 ± 280	1180–2000	230 ± 30	180–280	12.3 ± 2.3	8–16
Medicine injection	1370 ± 220	1030–1670	240 ± 40	190–290	8.9 ± 3.0	6–13
Medical wound care	1370 ± 450	790–2140	230 ± 60	180–320	10.5 ± 3.2	6–15
Check blood glucose	1310 ± 420	810–2230	230 ± 60	180–330	9.0 ± 3.1	3–15
Take temperature	1300 ± 370	590–2170	260 ± 40	180–320	7.1 ± 2.9	1–13
Walk patient	1170 ± 610	620–2280	260 ± 60	190–340	5.7 ± 4.7	1–13

Table 7. Correlation matrix for four dependent study measures ($n = 187$).

	RPE	PRLBI	LBDRV
RPE	–	–	–
PRLBI	0.8193	–	–
LBDRV	0.4601	0.3692	–
MSCF	0.5434	0.3964	0.5730

Note: all are at the level of $p < 0.0001$.

postures may result from the restriction of the hospital environment, such as the patient's room, bathroom, and the computerized medicine center. The observed work pace of nurses was slow mainly because nurses were caring patients, not objects. Nurses were concerned with patients' comfort and safety, and helped them overcome the pain or the fear of falling during the transfer. Before or during any activity, the nurses very often communicated with patients to make sure patients understood the purpose of the activity. Therefore, the time to finish a simple activity was often longer than in other studies. The work place layout also restricted nurses' work pace. Frequently, nurses adjusted their postures to fit requirements of the tasks they performed. For example, nurses often performed activities in an awkward posture owing to confined space, equipment location, and non-adjustable furniture.

Examination of medical records indicated that pulling the patient up in bed ('partial lift' or 'total lift') and lifting the patient from chair to bed ('transport patient') resulted in injuries that occurred in 2000. This study compared the kinematic data between activities with year 2000 injuries, and activities with no injuries during the same time period. Results showed there were significant differences owing to some of the kinematic variables, trunk moment and weight handled. These results were consistent with the findings by Marras *et al.* (1995) who reported that only a few trunk motions and workplace factors could distinguish well between the risk and no-risk groups, and the most powerful single variable was the maximum trunk moment.

Our study showed that trunk moment was the only significant variable for predicting risk of daily hospital nursing activities. Interestingly, the high risk group in this study had lower velocity and acceleration in three planes than the low risk group did. These results could be due to nurses exercising caution when working with the patients during lifting tasks.

A comparison of kinematic data for activities in this study with normative values from OSU (Marras *et al.* 1995) revealed that many kinematic values for nursing activities exceeded high risk group normative values (see tables 8 and 9). For example, range of motion values for 'bathe patient' exceeded high risk normative values in all three planes. Peak twisting velocity and acceleration values for 'bathe patient' also exceeded high risk normative values. Owing to scheduling constraints, nursing assistants tended to perform this activity, which included undressing the patient, turning to pick up the warm towel, and rubbing and cleaning patient's body very quickly. The 'make bed' activity, which except for lateral range of motion exceeded the same high risk normative values as did 'bathe patient', involved a lot of quick motions, including bending and twisting postures to reach the other side of the bed. These activities may impose risk on the low backs of nurses owing to the quick motions. These results are compatible with other studies. Kelsey *et al.* (1984) found twisting without lifting was associated with disc prolapse (OR = 3). The highest risk was observed for simultaneous lifting and twisting with straight knees (OR = 6.1). Marras *et al.* (1995) found that rapid twisting motions could generate and increase shear or rotational forces that may impose risk on the low back (Marras *et al.* 1995).

4.2. *Characteristics of lifting tasks*

Most activities with high LBD risk values involved lifting tasks. Such high scores were mainly made up of two risk factors: maximum trunk moment and maximum trunk sagittal flexion. Nurses did not perform patient handling activities very fast because of their concern for patient comfort and safety (see table 10). Therefore, in most cases other

Table 8. Descriptive statistics of trunk motion factors for all task categories ($n = 200$).

		Nursing activities	
Variables	Units	Mean	Std. Dev.
Load weight	kg	7.27	19.53
Moment	Nm	22.19	59.47
Maximum left bend	Degrees	−5.97*	4.26
Maximum right bend	Degrees	10.37	5.15
Maximum lateral range	Degrees	16.34	7.59
Maximum extension	Degrees	−1.31	5.60
Maximum flexion	Degrees	30.85*	13.76
Maximum sagittal range	Degrees	32.16*	14.60
Maximum left twisting	Degrees	−11.14*	5.88
Maximum right twisting	Degrees	8.63	6.67
Maximum twisting range	Degrees	19.77	10.23
Average lateral velocity	Deg./sec.	2.25	1.19
Maximum lateral velocity	Deg./sec.	24.28	9.30
Average sagittal velocity	Deg./sec.	3.16	1.45
Maximum sagittal velocity	Deg./sec.	36.40	16.46
Average twisting velocity	Deg./sec.	3.02	1.79
Maximum twisting velocity	Deg./sec.	33.95	17.54
Maximum lateral acceleration	Deg./sec.^{2}	161.60	63.95
Maximum sagittal acceleration	Deg./sec.^{2}	213.00	92.81
Maximum twisting acceleration	Deg./sec.^{2}	244.36	125.02

Note: *value is larger than the compared value.

risk factors (maximum lateral velocity and average twisting velocity) contributed to the low scores for patient handling activity. Thus, in this study, the highest LBD risk values were between 40 and 50. Activities involving no lifting tasks, but with higher LBD risk values, were mostly due to high average trunk twisting velocity and maximum lateral velocity. For example, in the 'bathe patient' activity, nursing assistants twist and side bend more than during other activities. Therefore, the velocity related factors make this a risky activity. However, the LBD risk value is calculated by averaging all five factors. If any factor has no significant value, such as the low lifting rate, then the OSU risk model loses a certain degree of predictive power or may not reflect the real stress level well.

Table 11 shows a comparison between the current study and a laboratory based study conducted by Marras *et al*. (1999). The activities selected from the current study were similar to the patient transfer technique and reposition technique simulated in their study. However, the selected activities in this study were not performed exactly as those performed in the laboratory because of differences in patient weight, mobility, and location. In Marras's study, the patient weighed 50 kg, and lay or sat in the same bed or chair. In this study, the maximum weight of the patient was 103 kg and the bed and chair heights varied. The compression forces and shear forces were predicted by the EMG-assisted model in their study. Although patient handling conditions for these two studies differed, the results showed consistency with respect to compression and A–P shear forces. The low value of LBD risk value for all activities in this study mainly resulted from the low lifting rate.

The 3DSSPP analysis indicated that in most patient handling activities the spine compression force (with mean 13229 N) was greater than the NIOSH recommended value of 3400 N. This result was attributable to patient weight (maximum 103 kg), and was

Table 9. Trunk motion characteristics for each nursing task activity, and normative kinematic data at different risk levels from Marras *et al*. (1995).

	Range of motion (deg)			Average velocity (deg/s)			Peak velocity (deg/s)			Acceleration (deg/sec^2)		
Activity name	Sag.	Lat.	Twist	Sag.	Lat.	Twist	Sag.	Lat.	Twist	Sag.	Lat.	Twist
Assist patient to move	32.9	21.4	20.1	3.2	2.9	3.0	33.2	25.8	33.2	231	170	245
Bathe patient	43.1	28.2	33.3	3.6	3.0	4.3	50.8	34.5	53.5	290	224	369
Check blood glucose	30.0	14.1	17.4	2.9	2.0	3.4	32.6	22.6	36.9	200	150	284
Check blood pressure	35.4	14.2	16.8	3.0	1.9	2.1	35.2	21.5	26.5	186	146	205
Dangling	25.1	15.6	17.7	3.1	2.3	2.6	34.9	21.3	29.3	201	146	197
Draw blood	49.8	13.0	18.4	2.1	1.7	2.1	41.4	26.5	38.2	213	202	292
Make bed	40.4	22.0	30.5	5.4	3.9	5.9	49.6	33.8	50.5	307	226	363
Medical wound care	36.1	20.9	24.3	3.4	2.6	3.4	38.8	31.3	42.5	217	204	312
Medicine injection	23.9	11.4	10.1	2.2	1.5	1.8	29.8	14.3	20.2	168	92	160
Partial lift	23.8	13.5	16.0	2.7	2.4	3.0	22.6	22.0	23.8	143	135	173
Transport patient	35.0	17.8	23.7	3.7	2.4	3.2	32.6	22.4	33.5	184	148	223
Physical assessment	35.7	15.1	16.0	2.4	1.4	1.7	38.1	20.0	28.0	185	125	193
Prepare medicine	32.9	11.8	13.4	1.8	2.9	2.2	39.0	22.8	23.3	191	158	168
Put on ted hose	45.6	21.5	28.5	4.2	3.0	3.7	62.0	33.1	40.8	332	196	263
Take temperature	20.9	9.7	14.4	1.6	0.8	1.3	23.2	17.1	26.8	156	119	188
Total lift	17.9	11.7	12.9	2.5	1.7	2.3	20.1	16.5	20.5	117	108	144
Walk patient	20.4	13.0	23.2	4.1	4.3	4.9	25.9	22.8	31.7	189	158	200
Weigh patient	34.7	18.2	17.8	3.8	2.5	3.0	43.8	27.5	34.4	273	179	245
Normative low risk of LBDs (Marras *et al.* 1995)	23.8	21.6	17.1	6.6	7.2	5.4	38.7	35.5	38.0	226.0	229.3	269.5
Normative Medium risk of LBDs (Marras *et al*. 1995)	30.0	23.5	21.3	11.4	10.1	9.2	53.7	45.1	48.5	300.7	299.6	341.7
Normative high risk of LBDs (Marras *et al*. 1995)	34.0	23.4	21.3	12.4	10.2	8.8	59.0	44.6	49.7	340.3	294.8	320.9

Note: *mean value. The number in bold represents data that exceeded the normative value in the high risk group.

Table 10. Trunk motion characteristics for each task nursing category.

Activity name	Back Motion	Displacement (deg)			Velocity (deg/s)		Acceleration (deg/sec^2)
		MIN	MAX	ROM**	MEAN	PEAK	PEAK
Assist patient to move	Side Bending	−14.7	25.6	21.4	2.9	25.8	170
	Sagittal	−5.0	59.9	32.9	3.2	33.2	231
	Twisting	−17.4	20.4	20.1	3.0	33.2	245
Bathe patient	Side Bending	−18.6	21.15	28.2	3.0	34.5	224
	Sagittal	−9.1	51.9	43.1	3.6	50.8	290
	Twisting	−29.9	32.8	33.3	4.3	53.5	369
Check blood glucose	Side Bending	−13.2	15.1	14.1	2.0	22.6	150
	Sagittal	−9.9	49.6	30.0	2.9	32.6	200
	Twisting	−17.3	12.5	17.4	3.4	36.9	284
Check blood pressure	Side Bending	−9.6	15.1	14.2	1.9	21.5	146
	Sagittal	−10.6	56.2	35.4	3.0	35.2	186
	Twisting	−14.9	13.3	16.8	2.1	26.5	205
Dangling	Side Bending	−6.4	23.6	15.6	2.3	21.3	146
	Sagittal	−3.1	45.7	25.1	3.1	34.9	201
	Twisting	−19.0	19.1	17.7	2.6	29.3	197
Draw blood	Side Bending	−5.2	10.8	13.0	1.7	26.5	202
	Sagittal	−3.3	60.2	49.8	2.1	41.4	213
	Twisting	−13.2	9.9	18.4	2.1	38.2	292
Make bed	Side Bending	−14.9	26.5	22.0	3.9	33.8	226
	Sagittal	−17.0	60.9	40.4	5.4	49.6	307
	Twisting	−34.6	28.4	30.5	5.9	50.5	363
Medical wound care	Side Bending	−11.7	25.0	20.9	2.6	31.3	204
	Sagittal	−9.4	52.9	36.1	3.4	38.8	217
	Twisting	−17.7	25.5	24.3	3.4	42.5	312
Medicine injection	Side Bending	−14.0	15.5	11.4	1.5	14.3	92
	Sagittal	−3.2	39.3	23.9	2.2	29.8	168
	Twisting	−16.1	5.4	10.1	1.8	20.2	160
Partial lift	Side Bending	−9.6	12.4	13.5	2.4	22.0	135
	Sagittal	1.6	39.9	23.8	2.7	22.6	143
	Twisting	−19.9	9.2	16.0	3.0	23.8	173
Transport patient	Side Bending	−15.9	12.4	17.8	2.4	22.4	148
	Sagittal	−12.4	59.4	35.0	3.7	32.6	184
	Twisting	−35.0	13.5	23.7	3.2	33.5	223
Physical assessment	Side Bending	−10.7	20.1	15.1	1.4	20.0	125
	Sagittal	−3.3	62.0	35.7	2.4	38.1	185
	Twisting	−15.0	17.5	16.0	1.7	28.0	193
Prepare medicine	Side Bending	−9.1	11.7	11.8	1.8	22.8	158
	Sagittal	−8.3	53.1	32.9	2.9	39.0	191
	Twisting	−13.9	15.8	13.4	2.2	23.3	168
Put on ted hose	Side Bending	−11.6	15.3	21.5	3.0	33.1	196
	Sagittal	−6.8	48.6	45.6	4.2	62.0	332
	Twisting	−17.7	18.0	28.5	3.7	40.8	263
Take temperature	Side Bending	−9.8	15.6	9.7	0.8	17.1	119
	Sagittal	−6.6	38.2	20.9	1.6	23.2	156
	Twisting	−19.3	17.3	14.4	1.3	26.8	188
Total lift	Side Bending	−11.7	15.8	11.7	1.7	16.5	108
	Sagittal	0.5	30.8	17.9	2.5	20.1	117
	Twisting	−11.6	13.1	12.9	2.3	20.5	144

(*continued*)

Table 10. (*continued*).

Activity name	Back Motion	Displacement (deg) MIN	MAX	ROM**	Velocity (deg/s) MEAN	PEAK	Acceleration (deg/sec^2) PEAK
Walk patient	Side Bending	−12.0	21.0	13.0	4.3	22.8	158
	Sagittal	−13.6	40.1	20.4	4.1	25.9	189
	Twisting	−17.4	28.8	23.2	4.9	31.7	200
Weigh patient	Side Bending	−17.0	17.6	18.2	2.5	27.5	179
	Sagittal	−14.6	53.0	34.7	3.8	43.8	273
	Twisting	−19.2	17.6	17.8	3.0	34.4	245

Note: *mean value. The number in bold represents data that exceeded the normative value in the high risk group.

Table 11. The comparison with similar tasks between two studies.

Activity	LBD risk value (%)	A–P shear force (N)	Maximum compression force (N)	Patient weight (kg)
Marras *et al.* (1999)				
Two person transfer-hook				
Lifting-Left side	83.3 (23)	955.6 (436)	4948.2 (1598)	
Lifting-Right side	79.1 (24)	892.8 (495)	4455.8 (1539)	
Lower-Left side	81.1 (24)	1020.8 (503)	4713 (1640)	
Lower-Right side	77.1 (27)	935.6 (478)	4314.1 (1694)	
The current study				
Transport patient	40.3 (6.5)	979.6 (352)	8899 (3288)	48.2
Marras *et al.* (1999)				
One person transfer-hook	97.8 (7.0)	1202.3 (459)	9172 (2729)	
The current study				
Dangling	34.1 (9.3)	704.7 (353)	6659 (3953)	36.4
Marras *et al.* (1999)				
Draw Sheet				
Left	72.0 (25)	847.3 (296)	3902.5 (1273)	
Right	67.6 (27)	898 (287)	3819.7 (1400)	
The current study				
Partial lift	41.0 (3.7)	1209 (323)	9151 (2923)	42.1
Total lift	37.8 (7.5)	845 (178)	13229 (4787)	75.3

consistent with a study in which the standard patient weighed 50 kg (Marras *et al.* 1999). The review of epidemiologic studies of low back disorder by NIOSH (1997) found that heavy physical work, lifting and forceful movements, and bending and twisting (awkward postures) are the three most important risk factors for LBD. Heavy physical work refers to activities that generate large compressive forces at the spine (Marras *et al.* 1995).

According to the recommendation for action limit (AL) and maximum permissible limit (MPL) by NIOSH (1981), the maximum weight to lift for AL and MPL is 25.6 kg (65 lb.) and 59 kg (150 lb.), respectively. In this study, the average weight lifted for the 'dangling' activity was 36.4 kg. In the 'total lift' activity the average and maximum weight

lifted were 75.3 kg and 103 kg, respectively. These values exceed the maximum lift weight (25.6 kg) based on AL criterion. These heavy lifting tasks were hazardous even when they lasted less than a few seconds. These findings are consistent with Videman's study (Videman *et al.* 1984), which found that nursing aides had higher rates of back pain because of heavier workload, including patient handling and lifting.

4.3. *Perceived physical effort on the activities*

The RPE values showed the highest correlation with LBRS values, LBD risk values were highly correlated with maximum spine compression force values. Nurses perceived patient-handling as the most stressful activity. The estimated spine compression force in this study supports the high level of perceived physical stresses. The RPE scores in this study were moderately correlated with spine compression force. Therefore, ratings of perceived physical exertion could be a good indicator for evaluating the risk of low back injury. This was confirmed by two studies. Garg (1992) found a significant correlation (r) between RPE and the number of accident reports filed ($r = 0.4$), while Stuebbe (1994) found that biomechanical stress was highly correlated with injury rates ($r = 0.85$).

The perceived risk of low back injury was weakly associated with LBD risk value and spine compression force. The perception of low back injury is not as clear as the perception of physical effort. The perception of low back injury may require the participant to recall similar incidents, and compare the current condition with the recalled condition. If the participant was not previously exposed to injury information, it is difficult to rate perception of risk.

Four different estimates for low back injury risk showed consistently that patient handling activities had the highest risks compared with non-patient handling activities. The objective measurements, LBD risk value, and spine compression force indicated that the risk of patient handling activities resulted from the heavy weights of patients. The subjective measurements, RPE, and LBRS, indicated that activities needing more physical effort are perceived as having higher low back injury risk.

The rating of 15 ('very high') for the activity 'draw blood' indicated the perceived physical stress to RNs is high, which is inconsistent with other measurements indicating high stress. Some activities in this study required multiple trunk flexion along with axial rotation and lateral bending of the spine. Mean trunk flexion for most activities exceeded 30°. Some activities, such as 'draw blood', and 'medicine injection', required working in severe bending postures. In the 'draw blood' task, RNs had to bend over 60° and maintain such posture for 60 seconds. This activity could impose high risk on a low back, as reported by other studies. Punnett *et al.* (1991) identified that the time spent in awkward postures was strongly associated with risk of back disorder. Neumann *et al.* (1999) found that time spent in severe trunk flexion ($>45°$) was significantly associated with low back injury risk. Garg (1992) suggested that maintenance of awkward postures for extended periods could cause fatigue of back muscles. Any heavy lifting tasks performed immediately after working in an extreme bending posture could be hazardous owing to fatigued back muscles (Garg 1992). However, because injury records only indicate nursing activities being performed when injuries occurred, no causal relationship between unrecorded activities and injury can be inferred. Therefore, the cause of low back injury can not truly be revealed.

5. Conclusions

It could be concluded from the findings of this study that the major risk factor for low back injury in nurses was the weight of patients handled. While the study reveals that the trunk moment was the most significant risk factor for predicting low back injury, axial rotation of the trunk could also elevate low back injury risk among nurses. Activities that required long time exposure to awkward postures was perceived by nurses as high physical effort. This study also concluded that self-reported perceived exertion could be used as a tool to identify nursing tasks with high and low back injury risk among hospital nurses.

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