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Spine Kinematics Predict Symptom and Lost Time Recurrence: How Much Recovery is Enough?

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Abstract *Purpose* The purpose of the study was to determine thresholds for low back kinematic measures for the amount of functional recovery necessary to reduce the risk of recurrent pain symptoms or lost time. *Methods* Low back kinematic ability measures were collected at baseline when the workers returned to work for full duty. The range of motion, velocity, and acceleration were collected using the lumbar motion monitor. *Results* Follow-up data was collected on 196 of the 206 workers. Workers with sagittal extension velocity of <40 deg./s at baseline were twice as likely to report recurrent low back pain symptoms. Workers with sagittal flexion velocity <34 deg./s were 3 times more likely to report lost time. *Conclusions* Kinematic functional performance measures may be used as recovery criteria in low back pain patients to minimize recurrence risk.

Keywords Low back pain · Trunk kinematics · Functional performance

Introduction

The economic impact of low back pain is exceedingly high in the United States and elsewhere around the world [1–4]. Low back pain is recurrent in nature [5–14] and these recurrent low back pain cases have been found to be more costly than the first episode cases [15]. It is hypothesized that a greater understanding of low back pain recovery may provide insight to prevent high cost recurrent low back pain cases.

Kamper et al. [16] in a review article found a wide variety of recovery measures have been used over the past decade including pain measures, disability questionnaires, return to work, and functional performance measures. Kemper et al. [16] indicated that several of these recovery measures were continuous in nature unfortunately the researchers failed to explicitly define recovery criteria. The lack of a clearly defined recovery criterion may lead to ambiguity in our understanding of low back pain recovery resulting in increased risk of recurrent low back pain episodes that are higher cost than initial episodes.

Marras et al. [8] predicted the risk of recurrent low back injury (pain, medical visits, lost time and confirmed lost time) using multidimensional models including quantitative functional performance, psychosocial, workplace demands and impairment of activities of daily living. In the previous research classification and regression tree (CART) [17] software was used for variable selection and it also provided cut-points or thresholds for each continuous measure in the multivariate model. For quantitative functional performance measures, it was thought that these thresholds reduce the ambiguity in the level of performance needed in order to be considered recovered furthermore these threshold may provide a quantitative criteria for medical provider decision making for recovery or needs for further treatment. Marras et al. [8] only reported these thresholds for measures that entered the final multivariate models. It was thought that reporting univariate threshold values for dynamics functional performance measures may provide insight into low back pain recovery process. Thus, this study has three specific goals. First, to quantify low back pain recovery using dynamic kinematic functional performance measures including range motion, velocity

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and acceleration. The second goal was to define a cut-off point that clearly defined a performance criterion for recovery for each individual kinematic measure. The third goal of the study was to evaluate the odds of recurrent injury given the kinematic performance criterion of recovery for each individual measure.

Methods

Approach

The concept behind this study was to quantify continuous kinematic measures of recovery and then dichotomize the measure to determine how much functional recovery was necessary (at the time return to work) in order to prevent recurrent low back pain symptoms and lost time.

Setting

Forty-one (41) industrial facilities participated in the study. A wide variety of auto manufacturing, material processing, metal stamping, printing, food processing, construction, health care, appliance manufacturing and distribution centers participated in the study. Company medical records were examined to identify workers with reported low back pain episodes that may be recruited for the study. The worker was approached by a company representative and told about the study. If the worker agreed, an appointment was scheduled for the research team to visit the facility.

Participants

Two hundred and six (206) workers with low back pain participated in the study. All the workers had been cleared to return to full duty work at the time of the baseline evaluation. Subject average age was 41.8 with standard deviation 10.3. Seventy-three percent of the population was male. The mean Million Visual Analog Questionnaire score was 50.7 with standard deviation 27.1. This population was previously described in greater detail elsewhere [8].

Experimental Design

This was a prospective study designed with a 1-year follow-up time. Trunk kinematic measures of functional performance including range of motion, flexion velocity, extension velocity, flexion acceleration and extension acceleration were collected at baseline and used as candidate predictors of outcome. The outcome measures were self-reported low back pain and lost time from work.

Baseline Measures

Trunk kinematic measures were quantified using the lumbar motion monitor (LMM)^{TM}. The measures included controlled sagittal range of motion, flexion velocity, extension velocity, flexion acceleration and extension acceleration. The measures collected while controlling twisting posture at zero degrees as well an uncontrolled task. This functional performance protocol has been described previously [8, 18, 19]. To ensure good quality data a sincerity of effort score was calculated [20, 21].

Procedure

The eligible worker was brought to the testing area and met with the research team privately. The study was explained to the worker and an institutional review board consent form was signed prior to any testing.

The LMM was placed on the workers. The display screen was explained to the worker and the worker performed a few motions to become accustomed to the device and task. The first task consisted of controlled sagittal motion exertions. The worker was instructed to "bend forward and back to upright as fast as you can comfortably while staying in the control zone". The control zone required the subject to stay within $\pm 2^{\circ}$ of twist. The control zone was displayed on a computer screen and the workers were instructed to keep their head up and watch the screen. Data was collected for 8 s. The workers were instructed to move continuously for the entire 8 s. Next, the subjects twisted as far as possible to the left and right. The control zone was moved to other locations and up to 4 more control tasks were repeated. The workers then performed the uncontrolled sagittal plane task. Again the workers were instructed to move as fast as they could comfortably. The LMM has been validated in the literature [22] and this functional assessment has been described previously [8, 18, 19, 23–25].

Outcome Measures

Participants were contacted via telephone 1-year after the baseline evaluation. Phone interview included a self-report of pain symptoms and lost time from work during the past year.

Statistical Analysis

Range of motion, velocity and acceleration were calculated for each trial using custom software. The means and percentile data were calculated for the entire dataset as well as by recurrent injury outcome measure. Classification and regression tree (CART) analysis was performed on each

kinematic measure for each outcome measure [17, 26]. CART is a nonparametric regression method. Salford Systems CART software version 5.0 was used for analysis. The software uses a least squares regression and the gini classification tree method for splitting the data was used. The software experiments with each possible cut-point and evaluates goodness of cut-point and selects the best cut-point. The classification tree will often make multiple cut-points on the same variables. The first threshold from the CART tree results was used to dichotomize each kinematic measure. PROC LOGISTIC (SAS) was used to estimate odds of recurrent injury for each outcome measure [27].

Results

One hundred and ninety-six (196) of the 206 workers (95 %) reported follow-up data collected at 1-year. Table 1 provides descriptive means (standard deviations) and multiple percentiles 95, 90, 75, 25, 10 and 5 % of the entire data set. The recurrence rates vary greatly between the low back pain definition and the lost time definition. One hundred and fourteen workers had recurrent low back pain symptoms out of 196 (58 %) participants and 29 out of 196 had lost time recurrence (15 %).

Table 2 lists the CART threshold value, relative risk and odds ratios of low back pain recurrence given each kinematic measure observed at baseline. Range of motion was not statistically significant for both controlled and uncontrolled sagittal bending. The velocity thresholds were all approximately 40 deg./s. In the controlled sagittal velocity measures the threshold resulted in an odds ratio of approximately 2 indicating those with baseline velocity measures <40 deg./s were twice as likely to have recurrent symptoms (Table 2). The uncontrolled sagittal velocity produced an odds ratio of 3.7 indicating that those participants who did not reach 44 deg./s at baseline were nearly 4 times more likely to have a recurrence (Table 2). The acceleration thresholds were more disperse with values of 64.8 deg./s^2 for controlled extension acceleration, 97.4 deg./s^2 for controlled flexion acceleration, and 143 deg./s^2 for uncontrolled sagittal acceleration. The controlled sagittal extension acceleration measures had the highest odds ratio at 5.15 indicating that if baseline extension acceleration was

Table 1 Means (standard deviations), 95, 90, 75, 25, 10 and 5 % percentiles for all subjects

Kinematic measures	Mean (SD)	95 % Quantile	90 % Quantile	75 % Quantile	25 % Quantile	10 % Quantile	5 % Quantile
Uncontrolled sagittal range of motion	34.8 (12.7)	54.2	49.0	41.7	26.3	21.5	18.4
Uncontrolled sagittal velocity	54.3 (20.5)	90.2	82.2	65.8	41.3	27.4	20.6
Uncontrolled sagittal acceleration	212.4 (127.1)	429.6	348.0	265.4	133.1	86.4	70.9
Control sagittal range of motion at zero	30.3 (11.5)	52.5	45.1	37.6	21.8	15.9	13.9
Control sagittal flexion velocity at zero	42.4 (19.5)	77.7	69.7	57.2	26.0	18.0	13.8
Control sagittal extension velocity at zero	46.4 (20.7)	82.5	74.9	61.8	29.4	19.7	14.7
Control sagittal flexion acceleration at zero	162.4 (104.7)	364.3	292.0	214.9	89.4	63.4	52.3
Control sagittal extension acceleration at zero	177.5 (110.7)	355.5	315.5	233.9	95.1	69.3	54.4

Table 2 CART thresholds, relative risk and odds ratio results for recurrent low back pain at 1 year follow-up

Kinematic measures	CART threshold	Relative risk	Estimate	Wald score	Odds ratio	95 % confidence interval
Uncontrolled sagittal range of motion	29.3	1.17	0.40	1.67	1.45	0.82–2.71
Uncontrolled sagittal velocity	44.5	1.59	1.31	13.5	3.72*	1.84–7.50
Uncontrolled sagittal acceleration	143.5	1.57	1.26	13.0	3.53*	1.78–7.01
Control sagittal range of motion at zero	15.1	1.42	1.13	2.91	3.09	0.84–11.35
Control sagittal flexion velocity at zero	38.0	1.37	0.78	6.76	2.18*	1.21–3.94
Control sagittal extension velocity at zero	40.0	1.32	0.71	5.29	2.03*	1.11–3.70
Control sagittal flexion acceleration at zero	97.4	1.38	0.84	6.55	2.31*	1.22–4.41
Control sagittal extension acceleration at zero	64.8	1.55	2.34	4.99	5.14*	1.13–23.45

* Statically significant odds ratio

less that 64.8 deg./s^2 then workers were 5 times more likely to have recurrent pain symptoms.

Table 3 lists the means and standard deviation for the recurrent low back pain cases and non cases as well as the percentage of each population that was below the threshold value listed in Table 2 for that kinematic measure. The threshold values for recurrent low back pain tend to be below the mean values of the cases but are quite diverse among the kinematic measure. For example the CART threshold value for controlled sagittal extension velocity was 40 deg./s the mean for the low back pain cases was 44.5 deg./s and the mean for the entire data set in Table 1 was 46.4 deg./s The CART threshold value for controlled sagittal extension acceleration was 64.8 deg./s^2 and the mean value for the recurrent low back pain cases was 167.8 deg./s^2. Table 1 shows that the 10 % would be above the threshold and 5 % would be below the threshold. Thus, depending on the kinematic measure (velocity or acceleration) the threshold value was at a different point in the distribution.

Table 4 lists the CART threshold values, relative risk and logistic regression results for the lost time outcome measure. All the kinematic measures were statistically significant for predicting lost time recurrence. The uncontrolled velocity threshold was nearly twice that of the controlled velocity thresholds 65 versus 34 deg./s. The controlled velocity measures both had odds ratios of approximately 3 whereas the uncontrolled odds ratio was 11, indicating that if baseline uncontrolled velocity was <65.8 deg./s then workers were 11 times more likely to have a recurrent lost time episode. The controlled sagittal extension acceleration threshold of 102 deg./s^2 is nearly double that of the sagittal flexion acceleration criterion. The uncontrolled sagittal acceleration is more than twice the controlled sagittal extension acceleration threshold at 223 deg./s^2. The odds ratio indicates that workers whose acceleration did not meet these thresholds were at least 3 times as likely to have a recurrent lost time episode due to low back pain compared to workers who exceed the threshold. The sagittal flexion acceleration odds ratio was highest with those workers whose baseline sagittal flexion acceleration was <52 deg./s^2 and were 5 times more likely to have an injury than those who were exceeding that level.

Table 5 reports the mean values and the percentage of cases and non cases below the CART threshold values listed in Table 4. For the uncontrolled measures the recurrent lost time threshold values are above the mean value for the cases. The uncontrolled sagittal velocity

Table 3 Means (standard deviations) and percentage below threshold for recurrent low back pain cases and non cases at 1 year follow-up

Kinematic measures	Cases N = 114		Non cases N = 82	
	Mean (SD)	% Below threshold	Mean (SD)	% Below threshold
Uncontrolled sagittal range of motion	35.0 (14.2)	39	34.5 (10.3)	30
Uncontrolled sagittal velocity	51.0 (21.4)	41	58.8 (18.2)	16
Uncontrolled sagittal acceleration	191.8 (111.6)	42	241.0 (141.7)	17
Control sagittal range of motion at zero	30.0 (11.8)	10	30.7 (11.2)	3
Control sagittal flexion velocity at zero	40.9 (20.6)	52	44.4 (17.8)	29
Control sagittal extension velocity at zero	44.5 (21.2)	46	49.1 (19.7)	29
Control sagittal flexion acceleration at zero	155.4 (102.4)	39	172.2 (107.9)	22
Control sagittal extension acceleration at zero	167.8 (105.2)	11	191.2 (117.3)	2

Table 4 CART threshold, relative risk and odds ratio results for recurrent lost time at 1 year follow-up

Kinematic measures	CART threshold	Relative risk	Estimate	Wald score	Odds ratio	95 % confidence interval
Uncontrolled sagittal range of motion	28.6	2.79	1.22	8.80	3.41*	1.52–7.67
Uncontrolled sagittal velocity	65.8	9.59	2.45	5.65	11.63*	1.54–87.85
Uncontrolled sagittal acceleration	223.5	3.04	1.67	6.02	3.54*	1.29–9.76
Control sagittal range of motion at zero	33.4	2.38	0.99	4.20	2.70*	1.04–6.98
Control sagittal flexion velocity at zero	34.0	2.82	1.23	8.72	3.42*	1.51–7.75
Control sagittal extension velocity at zero	34.0	2.53	1.12	7.38	3.05*	1.36–6.82
Control sagittal flexion acceleration at zero	52.0	3.31	1.64	5.46	5.18*	1.30–20.62
Control sagittal extension acceleration at zero	102.0	2.68	1.19	8.33	3.29*	1.47–7.40

* Statically significant odds ratio

Table 5 Means (standard deviations) and percentage below threshold for recurrent lost time cases and non cases at 1 year follow-up

Kinematic measures	Cases N = 29		Non cases N = 167	
	Mean (SD)	% Below threshold	Mean (SD)	% Below threshold
Uncontrolled sagittal range of motion	32.2 (16.8)	59	35.3 (11.8)	29
Uncontrolled sagittal velocity	42.9 (17.4)	96	56.2 (20.4)	71
Uncontrolled sagittal acceleration	166.7 (88.2)	83	220.4 (131.3)	57
Control sagittal range of motion at zero	25.9 (11.4)	79	31.1 (11.4)	59
Control sagittal flexion velocity at zero	34.7 (20.7)	62	43.7 (19.0)	32
Control sagittal extension velocity at zero	37.8 (21.1)	55	47.9 (20.3)	29
Control sagittal flexion acceleration at zero	134.7 (92.6)	14	167.2 (106.3)	3
Control sagittal extension acceleration at zero	141.8 (94.8)	52	183.8 (112.4)	24

threshold value is nearly the same as the 75 % of the entire data set in Table 1. For the controlled sagittal flexion velocity at zero the threshold value is nearly the same as the mean value of the cases with the threshold value at 34.0 deg./s and the mean value for the cases at 34.7 deg./s. Interestingly the controlled acceleration threshold values are below the mean values for the cases and the controlled sagittal flexion acceleration threshold is nearly the same as the 5 % of the entire data set in Table 1. Thus, again with the lost time outcome measure the threshold values are from various points in the distribution depending on the kinematic measure.

The CART software has six methods for splitting classification tress. These methods include gini, symmetric gini, entropy, class probability, towing and ordered towing. All these methods were tried and the first split value which is reported as the threshold values in Tables 2 and 4 remained the same for all these methods. Therefore, it is thought that the threshold values reported are robust.

Discussion

The definitions of low back pain recovery have not been clearly defined [16]. The CART thresholds provide an objective quantitative value to define how much recovery is enough to prevent recurrent low back pain symptoms as well as lost time. The thresholds allow continuous measures of recovery to be dichotomized into impaired and recovered criteria. The univariate kinematic measures allow us to not only examine recovery based on range of motion but also dynamic measures of velocity and acceleration. Marras et al. [17] showed that range of motion recovered first followed by velocity and culminating with acceleration recovery. Since individuals are injured during dynamic activities velocity and acceleration may provide a better indication of recovery.

Low back pain is recurrent in nature [5–14]. The development of kinematic functional performance recovery measures may allow practitioners to use both the continuous measure as well as a dichotomous measure simultaneously. Since low back pain patients have a high recurrence rate multiple evaluations over the course of time may allow the care giver to quantify the extent of functional decrement with each relapse as well as quantify the extent of recovery with different treatments. Not only would the caregiver know whether or not the patient's performance exceeded the threshold but also by how much it exceeded the threshold. Furthermore, kinematic measures may provide quantitative information for which treatment had the most functional improvement for each patient, which may lead to more personalized health care.

The sixth edition of the AMA Guide to Evaluation of Permanent impairment states that range of motion is no longer used as a basis for defining impairment because the evidence does not support the reliability of the measures [28]. In the current study the range of motion predicted lost time recurrence however the range of motion was not statistically significant for predicting recurrent low back pain symptoms. This may provide further evidence for the inconsistency of range of motion as in indicator of functional status. Furthermore, since dynamic measures of velocity and acceleration were significant predictors of both pain symptoms recurrence and lost time recurrence these dynamic measures may provide a reliable measure of recovery.

The controlled sagittal flexion and extension velocity cut-points can be compared to previous published [23] normal database values for these tasks. The healthy database has flexion and extension velocities over 100 deg./s for males between ages 20 and 50. At age 60 the average flexion and extension velocity was still approximately 80 deg./s. The threshold for controlled flexion and extension velocity for low back pain recurrence was 38 and 40 deg./s. This is well below the normal velocity for males

of any age [23]. Furthermore, 73 % of the participants in the current study were males therefore it seemed appropriate to make that comparison. The average age of the study population was 41.8 years. The average for females in their 40 s was 70.8 and 76.6 deg./s for flexion and extension velocity, respectively. In either case the threshold for the recurrent low back pain was well below the average performance of healthy individuals in the database performing the exact same tasks. Furthermore, the threshold for recurrent lost time was even lower (34 deg./s). This may suggest that individuals with recurrences have some functional performance decrements well below the average healthy population. Individual or genetic risk factors have been suggested to have a causal role in risk of low back injury [29] thus the additional decrement in the recurrent cases may provide further evidence for these individual risk factors.

The velocity and acceleration thresholds from the uncontrolled sagittal task were compared to job demand velocity levels found in high and low risk jobs [30]. The maximum sagittal velocity found in high risk jobs was 55 deg./s and approximately 39 deg./s in low risk jobs. The threshold for uncontrolled sagittal velocity was 44.5 and 65.8 deg./s for low back pain and lost time recurrence, respectively. Thus, the physical demands of high risk jobs 55 deg./s exceed the threshold velocity for recurrent low back pain symptoms. Thus, some individuals may have performance levels well below job demands that create a mismatch and result in recurrent low back pain or lost time. It may be hypothesized that a combination of functional performance and job demand together place an individual at risk of recurrence.

Marras et al. [8] used recurrent low back pain, medical visits, lost time and confirmed lost time. The current analysis was performed using only recurrent low back pain symptoms and recurrent lost time. The recurrent medical visit outcome measure was dropped because Kamper et al. [16] did not report any literature citations using this outcome measure. The confirmed lost time measure had 20 recurrent cases and lost time had 29 recurrent cases the cut-point results were nearly identical between the two lost time definitions therefore confirmed lost time was dropped to focus on the two most commonly reported outcome measures.

Limitations

The thresholds provided an indication of recovery however the threshold values need to be validated in future studies. Furthermore, the population in this study was from a manufacturing environment therefore workers from other work environments such distribution centers, patient care assistance and nurses just to name a few may have different threshold values based on exposure in the workplace. Therefore, a follow-up study would be necessary and would need to include a wide variety of workers from various working environments.

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