

Impairment Magnification During Dynamic Trunk Motions

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Study Design. An examination of a group of patients with low back disorder and a group of healthy (asymptomatic) individuals asked to produce trunk motions under sincere and insincere experimental conditions. Trunk motion components were examined to determine which combination of motion components could best distinguish between sincere and insincere efforts.

Objective. To determine whether examination of trunk motion components could be used to identify impairment magnification during unresisted repeated bending tasks.

Summary of Background Data. Trunk motion measures can be used to assess and "benchmark" the status of the low back. However, these measures typically are clinically useful only if the individual is producing an effort that does not magnify the impairment during the functional evaluation. This study addressed the issue of impairment magnification during the production of free dynamic trunk motion.

Methods. The trunk motion characteristics of 100 healthy individuals and 100 patients with chronic low back disorders were documented. All participants were asked to produce the trunk motions in two different types of conditions. In the one experimental condition, they were asked to produce sincere trunk motions. In the other experimental condition they were asked to pretend either that they were experiencing low back pain (the asymptomatic group) or that their pain was worse than it actually was (group with low back pain).

Results. A combination of trunk motion measures was able to distinguish well between the conditions. Sensitivity and specificity for the asymptomatic group were 92%, whereas they were 75% for the group with low back pain. Overall, sensitivity and specificity were 81.5% for all the participants combined.

Conclusions. These results indicate that motion measures can be used to help assess impairment magnification during functional trunk motion testing. These measures can provide a means by which to scrutinize the quality of quantitative measures indicating the extent of a low back disorder. These objective motion measures also can be used to complement other subjective observational methods for the assessment of impairment. [Key words: biomechanics, impairment magnification, injury quantification, low back pain, symptom magnification]

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Low back disorders (LBDs) continue to represent a major burden to the quality of life and to impose significant economic burdens on society.^{1,4,24} In an attempt to manage these problems, efforts have been made to develop quantitative measures for LBD. Such measures are needed for several reasons. First, they could provide a benchmark for determining the severity of the disorder, indicating when medical treatment is necessary. Second, these measures could provide an early and sensitive indicator of the success or failure of a potential treatment method. Third, they could provide an indicator of LBD relative to unimpaired status, thereby indirectly signifying return to work status. Fourth, quantitative assessments could be used to calculate the risk for a person performing a specific job by measuring the individual's functional capacity relative to quantitative demands of the job.

Quantitative methods attempt to document the functional capacity of the torso by observing its strength or dynamic motion profile. These methods, in one way or another, attempt to monitor or summarize the functioning of the trunk's musculoskeletal system status, which can be defined in terms of muscle recruitment patterns, muscle size and strength, joint stiffness, experience that can be affected by psychological and psychosocial factors (e.g., depression or fear of reinjury), and any other factors that may influence kinematic and kinetic performance. A clear understanding of the musculoskeletal system status is necessary if functional capacity is to be evaluated objectively.

A potential issue with these measurement systems is that the results are useful only if the patient cooperates and carries out the functional task without unnecessarily magnifying the impairment, thus performing at a level that reliably reflects the status of the trunk's musculoskeletal system. Patients may magnify impairment for several reasons including fear, mistaken beliefs, maladaptive coping strategies, and active attempts to seek treatment.¹¹ If a patient with LBD does not perform the task to the best of his or her ability during the functional test session, then the quantitative measure may erroneously document the musculoskeletal status of the trunk. Therefore, in assessing trunk status, it is important to judge whether the patient is magnifying the LBD impairment.

Assessing impairment magnification during a functional capacity test for the back has been a challenge. Assessments for other parts of the body often compare an individual's performance between limbs or different

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sites of the body. For example, Chengalur et al² compared grip force generation between dominant and non-dominant hands and were able to assess sincerity of effort in maximal grip strength with excellent sensitivity and specificity. However, this method is not feasible for trunk performance evaluation.

Many researchers have attempted to assess maximal *versus* submaximal exertions of the back by observing variations in back strength. Hazard et al⁵⁻⁷ observed variations in force curves produced by the muscles in the back during isokinetic exertions along with heart rate and reported that only heart rate was acceptably repeatable. Strength variance was found to vary greatly as a function of effort level and not necessarily sincerity.

Others¹⁸ observing nonisokinetic dynamic strength found that individuals with back pain and those without produced equally consistent levels of force. Robinson et al^{20,21} and Smith et al²³ found that consistency of isometric exertions was not a good indicator of submaximal exertions.

Still others⁹ have observed variability in isokinetic torque parameters during flexion and extension, finding that the ratio between flexion and extension strengths may indicate LBD. Luoto et al¹¹ also attempted to identify submaximal isokinetic strength generation by observing the coefficient of variation in torque generation. Such efforts resulted in reasonable sensitivity or specificity, but not both, in identifying sincere efforts.

A study by Reid et al¹⁹ represents one of the few studies that attempted to identify sincerity using a large population of subjects. A sufficiently large subject population is important if the data are to represent a normal distribution of participant performance. These researchers found that patients suspected of producing submaximal isokinetic exertions had lower trunk extension and flexion torque levels relative to their body weight.

Table 1 summarizes the ability of these measures to identify submaximal back exertions. In general, Table 1 indicates that few studies have included large samples of subjects in their evaluations, and few have reported reasonably high sensitivity and specificity. Hence, few methods exist to ensure the accuracy of quantitative LBD measures.

Recently, another method of quantifying a LBD has been suggested that does not rely on traditional measures of trunk strength. This method, developed by Marras et al,¹⁴⁻¹⁷ quantifies the extent of an LBD by comparing velocity and acceleration features of the trunk motion profiles relative to those produced by a person of a similar age and gender who has not experienced LBD. Statistics indicate excellent quantification of the extent of low back disorder for a group of patients experiencing various degrees of LBD.¹⁷ However, as with all quantitative trunk motion measures, the results of this assessment depend on the assumption that the patient is not magnifying his or her trunk impairment. Therefore, the goal of this study was to determine how well trunk motion efforts associated with magnification of impairment

can be detected using trunk motion velocity and acceleration parameters.

The underlying assumption associated with this study is that trunk motion profiles reflect the status of the trunk's musculoskeletal system. The musculoskeletal status is believed to represent the "central set" (also termed the "motor set") or recruitment and firing pattern of the trunk musculature. The central set, developed throughout life, is expected to remain relatively consistent unless LBD develops.⁸

When an LBD occurs, this recruitment and discharge pattern is altered, and a new central set is established as the limits of the disorder are discovered. Although the recruitment pattern has been changed as a result of the LBD, the pattern is believed to be consistent in its functioning and therefore repeatable. Specifically, it would be expected that higher-order derivatives of position such as velocity and acceleration would require more information processing on the part of the person to establish recruitment patterns. It was hypothesized that higher-order motion measures at certain points in the motion would be well established and repeatable because they represent this "mental model" of movement that a person is willing to accept. In magnifying the impairment, the patient would not rely on this mental model, so movements would be less repeatable. Hence, the current authors contend that it should be possible to assess the impairment magnification of an effort by observing a repeatable musculoskeletal recruitment pattern that should be reflected in trunk motion. Therefore, the objective of the current study was to determine how well sincere *versus* insincere efforts could be identified using trunk motion measures.

■ Methods

Approach. This study aimed to determine whether examination of trunk motion components could identify impairment magnification. For the purposes of this study, impairment magnification was controlled by asking study participants to produce "sincere" and "insincere" efforts during repeated trunk bending tasks. It was hypothesized that because participants would depend on an established central set, flexion and extension motion profiles would contain repeatable components when sincere efforts were generated. However, it was expected that motion profile components would not be repeatable if insincere efforts were produced. Therefore, this study investigated whether a combination of higher-order dynamic trunk motion variables exist that best discriminate between the sincere and insincere efforts in the low back.

Participants. Two groups of participants were recruited randomly for this study. The first group consisted of 100 participants with no history of LBP (asymptomatic subjects). These participants ranged in age from 18 years to 59 years. The second group consisted of 100 patients with LBD, ranging in age from 17 to 57 years. At the time of testing, these patients were visiting a secondary referral physician.

Table 1. Literature Review Summarizing the Ability to Identify Submaximal Back Exertions

Technique	Authors	Number of Subjects	Objective of Study	Methods	Statistical Methods and Major Findings	Sensitivity and Specificity
Lifting Simulation	Hazard et al ⁵	30 Normal	Distinguish effort level using force/distance curves.	Cybox Trunk Extension/Flexion and Liftask tests at two effort levels.	Need to combine variability in force/distance curves with visual assessment for acceptable classification.	Sensitivity 65–96.7% Specificity 51.7%–87.9%
	Hazard et al ⁴	44 Normal	Find indices to distinguish between effort groups.	Isometric, isokinetic, and isoinertial tests with Cybox Liftask at two effort levels.	Isometric tasks were not significantly different. Isokinetic and isoinertial indices provided moderate classification accuracy.	Sensitivity 73–78% Specificity 66–69%
Trunk strength	Reid et al ¹⁹	32 Normal 115 sincere LBD 40 suspect LBD	Determine effect of effort level on trunk strength deficits.	Cybox Trunk Extension/Flexion at maximal effort.	Suspect LBD subjects had lower trunk extension-flexion torque/body weight ratio than sincere LBD subjects.	Not reported
	Robinson et al ²⁰	20 Normal	Evaluate variability for isometric lumbar extension between effort groups.	Static lumbar extension at 100% and 50% effort levels.	High test-retest correlations in peak torque for both effort conditions. Therapist classification was unreliable.	Sensitivity 63% Specificity 53–58%
	Robinson et al ²¹	20 Normal	Determine effect of instructions on consistency of submaximal effort.	Isometric lumbar extension at maximal effort and feigning effort levels.	Sincere effort had greater variability than feigned. Test-retest peak torque cannot indicate sincerity of effort.	Not reported
	Simonsen ²²	270 LBD	Evaluate usefulness of CVs as an indicator of effort.	Static trunk strength measures.	CV may not be a reliable predictor of effort. May combination of measures.	Not reported
	Luoto et al ¹¹	12 Normal 10 Mild LBD 13 Severe LBD	Distinguish effort level through variability of trunk strength.	Lidoback dynamometer isokinetic flexion/extension for 100% and 50% efforts.	Using a single cutoff of CV for both patients and normals will misclassify those with severe LBD as low effort.	Sensitivity 37–83% Specificity 31–94%
Trunk dynamics	Smith et al ²³	44 LBD	Evaluate a protocol for detecting LBD feigning.	B-200 testing of peak torque, velocity, and range of motion.	Ratios of testing variables can act as flags for feigned effort if three or more variables are out of acceptable ranges.	Sensitivity 98% Specificity 82%

LBD = low back disorder; CV = coefficient of variation.

Age and gender breakdowns for the asymptomatic group and the group with LBD are displayed in Table 2. The average stature in the two groups combined was 179.9 ± 6.5 cm for the men and 165.5 ± 6.4 cm for the women. The average body

weight in the two groups was 84.2 ± 16.2 kg for the men and 66.6 ± 15.4 kg for the women. Significance tests indicated that there were no statistically significant anthropometric differences ($P < 0.05$) between the two groups within genders, ex-

Table 2. Age and Gender Breakdown of Asymptomatic Subjects and LBD Subjects

Age Group	Asymptomatic Subjects				LBD Subjects				Total	
	Men		Women		Men		Women			
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
Under 30	22	23.8 (2.9)	14	23.8 (3.4)	11	24.5 (3.1)	13	22.1 (3.4)	60	23.7 (3.3)
30-39	10	33.2 (2.6)	14	35.1 (2.7)	18	35.4 (2.8)	13	34.4 (2.9)	55	34.7 (2.9)
40-49	10	43.9 (1.9)	10	44.3 (3.1)	13	44.3 (3.2)	16	44.7 (2.7)	49	44.3 (2.8)
50-59	10	54.2 (2.9)	10	53.8 (3.5)	9	52.6 (2.1)	7	53.6 (2.4)	36	53.6 (2.9)
Total	52	35.3 (12.1)	48	37.6 (11.5)	51	38.4 (9.9)	49	37.4 (11.2)	200	37.1 (11.2)

cept for the weight of the men with LBD, who were 8 kg heavier on the average.

Experimental Design. The independent variable in this study was related to the presence or absence of impairment magnification. Impairment magnification was manipulated, in this study, by asking asymptomatic subjects to either produce true functional efforts or pretending they have a low back disorder, and by asking LBD participant to perform up to their ability or pretend their pain is worse than what it was. Thus, two conditions, sincere and insincere, categorized participants' performance to those reflecting their true functional status and those that were voluntarily manipulated. Dependent variables consisted of position, velocity, acceleration, and jerk derived from four repetitive trunk bending tasks. The four tasks consisted of: 1) controlled sagittal flexion and extension, 2) uncontrolled sagittal flexion and extension, 3) uncontrolled axial twisting about the waist, and 4) uncontrolled lateral bending. Controlled sagittal bending required that the subject flexed and extended the trunk while restricting the coupled twisting motion to within a $\pm 2^\circ$ "tolerance" within the transverse plane. During the uncontrolled conditions, the participant was asked to generate the trunk motion in a given plane, however, no tolerance was specified in the other planes of torso motion.

Every subject performed all four trunk bending tasks under both sincere and insincere conditions. The order of the tasks was randomized. The order in which the subjects performed the sincere or insincere effort was counterbalanced from subject to subject.

Apparatus. The lumbar motion monitor (LMM), developed in the Biodynamics Laboratory, was used to measure trunk motion in all three cardinal planes of the body. This device consists of an instrumented exoskeleton attached to a harness worn around the pelvis and thorax. The exoskeleton tracks the motion of the spine in three dimensions via a series of electrogoniometer signals tracked by computer and differentiated to yield velocity and acceleration profiles.

The LMM was calibrated on a three-dimensional reference frame for each of the three planes. A detailed description of the calibration may be found in Marras et al.¹³ The LMM measures instantaneous changes in the position of the thoracolumbar region of the spine relative to the pelvis. The signals from the LMM were monitored with an analogue-to-digital converter board (at a sampling rate of 60 Hz) interfaced with a

microcomputer and conditioned later to derive velocity, acceleration, and jerk profiles.

Controlled sagittal bending within a specific tolerance was accomplished by providing feedback to the participant. An oscilloscope provided a visual feedback display of the instantaneous voltage from the transverse channel of the LMM. Two "limit markers" indicated the voltage corresponding to $\pm 2^\circ$ from sagittally symmetric.

During the task, a comparator circuit determined whether the twisting motion exceeded the tolerance defined by the limit markers. If the participant exceeded the tolerance, an audible tone sounded and the trial was rerun. As long as the participant kept the twisting position of the LMM within the limit markers, the trial was acceptable. Previous studies¹⁶ indicated excellent test-retest reliability for this procedure.

Procedure. After the LMM was placed on the participants, they were encouraged to move around briefly and get used to the feel of the device. At the beginning of each test, participants were instructed to "cross your arms in front of your chest and stand with feet shoulder width apart." For the sagittal tasks, the participants continuously flexed and extended the torso, starting and ending in an upright posture. For the transverse task, they twisted continuously around the waist to the right and left. For the lateral task, the participants bent from side to side continuously.

To elicit a sincere effort from the participants for the controlled sagittal task (task 1), all participants were instructed to "move as fast as you can comfortably, staying between the markers." For the other three tasks (tasks 2-4), the phrase "staying between the markers" was omitted.

To obtain an insincere effort from the asymptomatic group, the participants were instructed to "move as fast as you can comfortably, staying between the markers while pretending you have a bad back." The patients with LBD were instructed to "move as fast as you can comfortably, staying between the markers while pretending your pain is worse." For the uncontrolled tasks (tasks 2-4), the phrase "staying between the markers" was omitted for the asymptomatic participants and the patients with LBD.

The participants were informed about the procedure and length of the data collection period according to an approved Institutional Review Board protocol. For the controlled sagittal task, participants were informed that if the twisting position exceeded the twisting range as shown by the oscilloscope, a warning tone would sound, and the trial would need to be

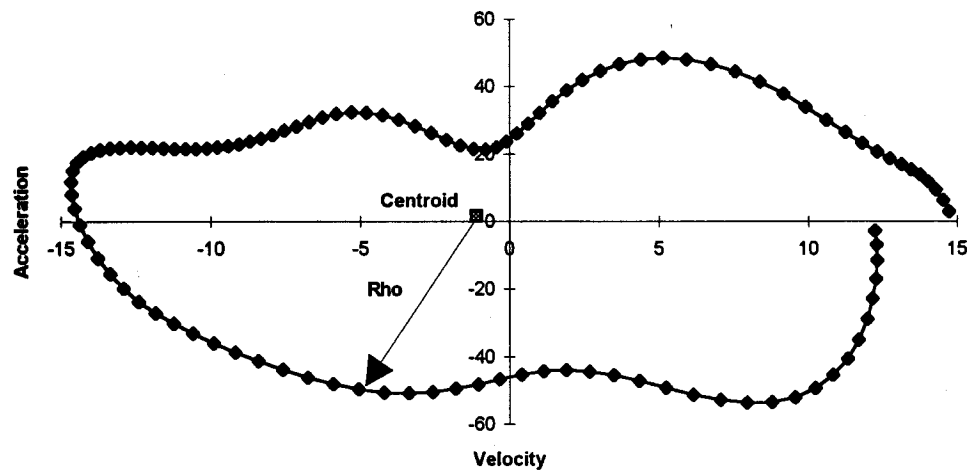


Figure 1. Phase plane of velocity and acceleration for uncontrolled sagittal bending.

repeated. Typically, 8 seconds of data were collected from the asymptomatic group and 14 seconds of data from the patients with LBD. All 200 participants recruited for participation in this study were able to complete the experimental conditions successfully.

Data Analysis. Custom software, developed in the biodynamics laboratory, converted the stored LMM voltage signals into triaxial angular positions as a function of time in the sagittal, lateral, and transverse planes of the body. The position signal was conditioned to determine velocity, acceleration, and jerk. The first and last cycle of each trial were discarded to remove any warmup or closure effects on the data.

For each trial, the maximum, minimum, range (maximum to minimum), average, standard deviation, and coefficient of variation were calculated for the position, velocity, acceleration, and jerk data. Only variables in the primary plane of motion were analyzed. In addition, phase plane diagrams were constructed for all six combinations of position, velocity, acceleration, and jerk. Phase planes allow the relation of two variables to be expressed as a function of each other. An example of a phase plane diagram is shown in Figure 1. For each of the phase planes, a set of rho values was constructed. Rho values represent the distance in phase plane space between each point in the phase plane and the centroid of the phase plane. The mean, standard deviation, maximum, range (maximum to minimum), and coefficient of variation for the rho values also were calculated.

Hence, 54 trunk motion profile measures were generated for each task. All four tasks yielded 216 possible measures, which were evaluated for their discriminatory ability. Each of the trunk motion measures was normalized with respect to the population variable mean value adjusted for age and gender under the sincere conditions. This normalization was performed for all the participants.

Discriminant function analyses were performed for each dependent measure separately to identify how well each individual motion parameter distinguished between the two groups of sincere and insincere effort. Multivariate discriminant analyses were performed on the basis of variable combinations (according to the study hypothesis) found to be sensitive in the univariate analyses. Three separate models were selected to discriminate between sincere and insincere efforts for the patients with LBD only, the asymptomatic participants only, and the patients

with LBD and the asymptomatic participants combined. Sensitivity, specificity, and cross-validation error rates were used for model evaluation.

■ Results

The univariate analyses confirmed the expectation that the higher-order derivatives of motion classified the experimental conditions better than the position variables. The mean classification error rate (standard deviation) for both patients with LBD and asymptomatic participants was 41% (4) for the position variables, whereas the mean (standard deviation) error rates for the velocity, acceleration, jerk, and phase plane variables were 29% (7), 27% (1.5), 32% (5), and 30% (5), respectively. In addition, the higher-order variables distinguished better between patients with LBD and asymptomatic participants. The difference between classifications within the patient and asymptomatic groups averaged about 2% for the position variables, whereas this difference averaged more than 11% for the higher-order variables. Therefore, the higher-order derivatives of movement, such as the velocity and acceleration measures, by themselves resulted in respectable classification.

Even better results were observed with multivariate models. Using the motion components available, three models were constructed that were intended to distinguish maximally between the sincere and insincere efforts. Behind the construction, the goal was to develop models that used motions from each of the three planes of motion and captured higher-order derivatives of position that would reflect a developed musculoskeletal pattern or central set. Using this logic as a guide, separate models were developed for the asymptomatic participants, the patients with LBD, and the two groups combined. The model components that best distinguished between the sincere and insincere efforts are shown in Table 3.

The ability of these models to distinguish correctly between sincere and insincere efforts among the partici-

Table 3. Model Components for the Sincerity Models

Model Type	Plane of Motion	Variable
LBD subjects	Lateral	Standard deviation of position
	Uncontrolled sagittal	Standard deviation of velocity
	Lateral	Coefficient of variation of acceleration
	Twisting	Coefficient of variation of rho for the velocity-acceleration phase plane
Asymptomatic subjects	Twisting	Coefficient of variation of rho for the acceleration-jerk phase plane
	Twisting	Coefficient of variation of position
	Twisting	Peak velocity during trunk extension
	Twisting	Peak velocity during twisting task
	Controlled sagittal	Coefficient of variation of acceleration
	Lateral	Coefficient of variation of rho for the position-acceleration phase plane
Combined	Uncontrolled sagittal	Coefficient of variation of position
	Lateral	Peak velocity during trunk flexion
	Lateral	Peak velocity during lateral bending task
	Uncontrolled sagittal	Coefficient of variation of rho of the velocity-acceleration phase plane
	Lateral	Coefficient of variation of acceleration
	Twisting	Range of rho for the position-jerk phase plane

LBD = low back disorder.

pants are shown for asymptomatic participants, patients with LBD, and the two groups combined in Table 4. Overall model error ranged from 8% to 25% among the models, with the best sincerity detection occurring among the asymptomatic participants. In all cases, excellent balance between sensitivity and specificity was achieved.

Discussion

The ultimate objective of this effort was to ensure the quality of the information used to assess the extent of an LBD via motion measures, and not necessarily to identify malingerers. As Main and Waddell¹² pointed out, the behavior of patients with LBD is complex and should be understood as responses affected by fear in the context of recovery from injury and the development of chronic incapacity. Behavior signs, in and of themselves, do not indicate credibility of faking,¹² and such judgments require consideration of multiple parameters. Many people believe that the effort required to identify malingering would be better spent in proper treatment of the patient.

In the current attempt to create impairment magnification conditions, it was necessary to use controlled "sincerity" conditions. It should be understood that this

study was not intended to assess "faking" or malingering, but was intended only to evaluate the quality of the data used in quantitative LBD evaluation. Impairment magnification was therefore the parameter of interest in this study. Some might argue that the impairment magnification in the patients with LBD might have reflected symptom magnification, but that the manipulation in the asymptomatic participants related without doubt to impairment magnification. However, it would be expected that symptoms (e.g., pain) would not be related closely to impairment (function).

The results of this study confirmed the hypothesis that a central set or mental model of how to recruit components of the musculoskeletal system would produce repeatable higher-order motion profiles. Higher-order derivatives of motion, such as velocity and acceleration, appear to be the key to this assessment. It has been shown that people have great difficulty in judging higher-order derivatives of a musculoskeletal exertion.¹⁰ Neurophysiologic studies⁷ have demonstrated that the musculoskeletal coordination pattern is fine-tuned through experience, and that everyday motion provides abundant opportunities for gaining experience. The generation of motion requires the processing (and differentiation) of great amounts of proprioceptive information.

Because the experimental task was to be performed quickly, the current authors believed that the participant had to rely on established lower-level neural control programs needed to form the central set. They hypothesized that this central set is well established for common tasks such as trunk bending. Therefore, the participants relied on these established motor recruitment programs and the motion components would be repeatable if the plane of motion were similar on each repetition (as in the unmagnified conditions). However, if they attempted to override this established central set (as during a magnification of impairment), they would need to reestablish the central set. When the task was performed quickly, the motion patterns would reflect this reprogramming as a lack of consistency.

Of particular significance was the finding that all models distinguishing impairment magnification well

Table 4. Cross-Validation Results for Discrimination of Sincerity of Effort Multivariate Models

Model Type		Model Sincere	Model Insincere	Total
LBD subjects	True Sincere	75.00%	25.00%	100%
	True Insincere	25.00%	75.00%	100%
	Error Rate	0.2500	0.2500	0.2500
Asymptomatic subjects	True Sincere	92.00%	8.00%	100%
	True Insincere	8.00%	92.00%	100%
	Error Rate	0.0800	0.0800	0.0800
Combined	True Sincere	81.50%	18.50%	100%
	True Insincere	18.50%	81.50%	100%
	Error Rate	0.1850	0.1850	0.1850

LBD = low back disorder.

contained components of the phase plane analyses. Further analyses of the results indicated that phase plane variability reduction was primarily because of a reduction in variability at certain positions throughout movement. These analyses indicated that it is not just motion that is repeatable in the central set, but motion at particular points in space. For example, an acceleration profile may be highly repeatable for sincere conditions, but only at the point where the subject changes direction. This finding is consistent with the idea that a recruitment pattern (central set) has been established.

It is also important to recognize that the characterization of motion pattern consistency is multivariate in nature. Individual motion parameters, in and of themselves, were not expected to contain rich information about the central set. However, models consisting of multivariate parameters that contained actions in all three cardinal planes were capable of discrimination between the conditions explored in this study. The authors believe that motion in the different cardinal planes requires different types of muscle recruitment patterns (concentric *vs.* eccentric; agonist *vs.* antagonist) and would be part of the central set that they are attempting to measure. Hence, differences in the interplay of motions (phase planes) would be elicited in a range of trunk exertions. This finding indicates that the central set is indirectly observable through motion profiles, but that it is complex in its representation.

The authors contend that this central set must be re-established after injury, but they believe that it would be better established the longer the injury stabilizes. Following this logic, they expect greater ability to identify magnified impairment efforts with asymptomatic participants (as demonstrated in this study) because such participants have established their motion patterns over a very long period of time. For the same reason, the authors also expect this technique to perform better in patients with LBD who have stabilized in their chronicity. However, they did not have access to the proper data to evaluate this expectation.

The overall performance of these models indicated that it was indeed possible to distinguish between the groups of interest using motion generation information. These results also indicated that the error rate for identifying sincere and insincere efforts in asymptomatic participants was much lower than in patients with LBD. This is probably because of a much better established central set for the asymptomatic participants than for the patients with LBD, who needed to reestablish their central set to adapt to their injury. However, even for these patients, the model was able to identify exacerbation of impairment 75% of the time. When the participant population was considered as a mixture of the two groups, the model performed better, with an 18.5% error rate.

The results of this study also produced an excellent balance between sensitivity and specificity. Although other models were found with better sensitivity or specificity, the emphasis of this research was to construct

multivariate models that optimally identified the sincere and insincere efforts. This was achieved successfully with the final models, as seen in the identical classification rates for both effort conditions. However, under applied conditions it would be possible to adjust the effective sensitivity or specificity to accept a greater risk of a particular error type.

The issue of sensitivity and specificity in this study needs to be placed in perspective. Ideally, a test is sought that has 100% specificity and sensitivity, which indicates that the test agrees completely with the gold standard. In the case of sincerity, the gold standard is a function of how well participants comply with the experimental procedure. In addition, the participants are not asked to vary their sincerity by any particular amount. Certain participants may have chosen a level of insincerity close to their sincere level of effort. In this case, it would be difficult to interpret accurately the meaning of the sensitivity and specificity measures.

If the participants in the current study had been asked to choose a greater level of insincerity (*e.g.*, pretend their back pain was far more severe than it actually was), their expected distinction between the sincere and insincere conditions would have been far better. However, the goal of this study was simply to explore whether any level of magnification could be identified. Relative to results from other low back diagnostic measures, the sensitivity and specificity reported here compare very favorably. For example, commonly used neurologic tests for lumbar disc herniation vary in sensitivity from single-digit percentages to 66%, and in specificity from 51% to 99%.³

The sensitivities and specificities reported in this article relate to the model coefficients providing the best balance between the measures. However, under practical circumstances, these coefficients and the model cutoff points might be adjusted to accept more of one error type in favor of minimizing another type of error. This adjustment obviously would affect the resultant sensitivity and specificity and, hence, model accuracy. The adjustment of the coefficients also would depend on the consequences of the quantitative measure. If the quantitative measure was being used as an indication of a serious intervention such as surgery, then one would opt for a greater specificity value. However, if the consequence of an incorrect interpretation had little negative consequence, then one might not demand the same level of specificity.

These findings can be compared with those from previous studies that tried to achieve these same goals. The summary of previous low back sincerity studies (Table 1) indicates that no previous study had used a subject sample of sufficient size to assess sensitivity or specificity adequately. Only Reid et al¹⁹ and Simonsen²² used sufficiently large subject populations, but neither group reported sensitivity or specificity. In addition, as compared with the previous studies, the current analyses resulted in one of the best balances between sensitivity and specificity.

The ability of the current study to identify unmagnified impairment in trunk motion was better than that of previous studies attempting to identify sincere levels of strength. The authors believe that this is related to the idea that motion reflects the central set well whereas strength exertions require a "learning" process. It would be expected that under loaded conditions, as during strength testing, greater variability in recruitment and rate coding would occur from trial to trial because the participant essentially would need to "learn" to negotiate the resistance, which is not a practiced event. Therefore, equal amounts of variability would be expected for both asymptomatic participants and patients with LBD.⁶ Hence, the current authors believe that motion testing has an advantage over strength testing because it better reflects the established (programmed) central set or musculoskeletal recruitment patterns.

Several potential limitations of this study should be discussed. First, no means exist by which the hypotheses regarding the role of the central set in these findings can be confirmed directly. The findings and explanations provided in this report are consistent with this hypothesis that the more established the central set (as seen in the asymptomatic participants), the more consistent the motions, and when the participants produced less sincere motions, variability increased. However, this study did not confirm or reject the causal mechanisms discussed.

Second, it may be possible that with extensive practice, one can more easily mask the existing central set. The participants in this study were not provided with extensive practice. They simply were allowed to become comfortable with the task. Greater amounts of practice may have allowed them to mask insincere efforts to a greater degree.

Finally, all patients in this study had experienced their LBD long enough to be referred to a secondary treatment facility. Therefore, the results may be most applicable to patients with LBD who may be classified as chronic. It is not known how well the system would perform for acute or subacute LBD episodes. However, it can be speculated that the same logic would apply, at least in the pain-free planes of motion.

Collectively, the information supplied in this study provides a promising approach for assessing the quality of motion measures relating to the extent of LBD. The motions evaluated should yield comparable results regardless of the instrumentation or methods by which the motion is measured, as long as the sensitivity of the motion measure is comparable with that used in this study.

■ Key Points

- Trunk motion can be used to assess the quality of functional low back testing measures.

- Trunk motion repeatability reflects an established recruitment pattern among torso muscles.
- Trunk motion repeatability can identify impairment magnification and symptom magnification during functional testing.

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