DIAGNOSIS OF LOW BACK INJURY
USING STRENGTH MEASUREMENT

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ABSTRACT

A study was conducted to investigate the feasibility of using strength measurement as a diagnostic technique for assessing low back injuries involving symptomatic lumbar spine disease. The approach was to evaluate differences in the rates of strength build-up and in the variability of sustained lifting exertions performed by three groups of subjects. These groups included healthy subjects performing maximal exertions, healthy subjects performing submaximal exertions and symptomatic subjects with low back pain performing safe maximal exertions. The rate of strength build-up reliably distinguished between maximal and submaximal exertions while the ratio of within-trial variability to strength score differed significantly between the healthy and injured groups. Discriminant analysis was employed with partial success in distinguishing between the three groups using various derived measures of the force exertions.

INTRODUCTION

There is no more persistent, widespread and costly problem in the working world and throughout all human society than that of a disabling backache (Khalil et al., 1983). When the lost production days, impaired work capacity and pain related distractions, errors and accidents are added to the medical expenses and compensation payments, the costs due to low back pain syndrome are staggering. Goldberg et al. (1980) reported a loss during 1978 of approximately 14 billion dollars and 25 million work days in the United States alone. A major factor contributing to the high cost is the the number of employees who make false claims of back injury or who prolong low back pain symptoms to retain compensation payments.

Although back pain ranks among the most widely experienced ailments in western society, it is one of the least understood. The etiology of the condition is varied and does not appear to have any specific cause. As a result, reliable procedures for assessing the validity of low back injury claims do not exist. Physicians have used myelography, electromyography, lordosimetry and thermography to diagnose back injuries. However, these techniques are expensive and, although positive results confirm the validity of a patient's complaint, negative results cannot invalidate the low back pain claim. In many cases, determination of low back injury and the accompanying compensation payments are based solely on the employ-ee's complaint and response to treatment.

The use of static strength measurement as a diagnostic tool was explored by Daniel (1978) in a study involving both healthy and injured subjects. His approach assumed that healthy subjects faking injury would deliver submaximal exertions when requested to produce their maximum strength. Furthermore, he hypothesized that repeated submaximal exertions would exhibit higher variability than repeated maximal exertions. His results demonstrated statistically significant differences in the variability of submaximal vs. maximal efforts when using the coefficient of variation of the log-normal transformed data as the criterion measure.

Kroemer and Marras (1980) conducted a similar study to determine whether rate of strength build-up could objectively assess a subject's level of effort. They found that the force onset slopes for maximal exertions were steeper than those for submaximal exertions. However, using the coefficient of variation for the untransformed data as their criterion, they found *no difference in variability* between the levels of effort. This was in disagreement with Daniel's results but still provided promise for the use of strength measurement as a diagnostic tool for assessing level of effort.

The current study was conducted to examine several possible assessment mea-

sures derived from strength measurement data. The objective of the study was to determine if any of these measures could reliably discriminate between maximal and submaximal efforts and between healthy and injured individuals.

STRENGTH MEASURES

Static strength measurement is often conducted using the standardized procedure proposed by Caldwell et al. (1974). The regimen for producing a single maximal voluntary contraction (mvc) yields force output as a function of time for a sustained four-second period. The strength score is usually taken as the mean value recorded in the first three seconds of the exertion although several other measures have been used.

Owings et al. (1975) developed a procedure to time average the force values by sampling the data at the rate of 20 points per second and dividing the five-second exertion into intervals of 20 points in length. The strength score was then defined as the maximum one-second moving point average calculated for all possible intervals.

In this study, strength score for a given trial was computed in the above manner. In addition, the rate of strength build-up or slope was similarly computed using sampling at the rate of 5 points per second. Least squares linear regression was used to obtain slopes for all possible 5-point intervals during the first 2 seconds of the exertion. The maximum of these slopes was selected as the rate of strength build-up for the trial.

For a measure of within-trial variability, range was computed as the difference between the maximum and minimum force values recorded during the middle three seconds of the strength exertion. An additional measure was constructed by dividing the range by the strength score for each trial. This provided a more standardized measure of within-trial variability.

For each of the above measures which were computed on an individual trial basis, the mean, standard deviation and coefficient of variation across all trials were also computed to examine between-trial variability. An additional derived measure was the coefficient of variation for the strength scores after performing a log-normal transformation. The derived measures are summarized and coded in Table 1.

Table 1. Summary of Strength Measures

Measure	Definition
SCOREMN	mean strength for ten trials
SCORESD	strength standard deviation
SCORECV	strength coef. of variation
SCORECVLN	c.v. log-normal transform
SLOPEMN	mean slope for ten trials
SLOPESD	slope standard deviation
SLOPECV	slope coef. of variation
RANGEMN	mean range for ten trials
RANGESD	range standard deviation
RANGECV	range coef. of variation
RATIOMN	mean range/score ratio
RATIOSD	ratio standard deviation
RATIOCV	ratio coef. of variation

EXPERIMENTAL METHODOLOGY

Subjects

Three predominantly male groups of subjects were employed in the study, with sixteen subjects assigned to each group. The first group (HLTHMAX) consisted of healthy individuals age 19 to 61 ($\bar{x}$ = 28.5). This group was requested to exert their maximal lifting strength. The second group (HLTHSUB), consisting of healthy subjects age 20 to 51 ($\bar{x}$ = 33.4), were requested to exert fifty percent of their maximal voluntary contraction. Subjects for these two groups were randomly selected from the local population of students and residents in Norman, Oklahoma.

The third group (INJMAX) consisted of subjects suffering from low back pain and diagnosed by an orthopedic surgeon to be afflicted with low back injury. These subjects, age 23 to 63 ($\bar{x}$ = 39.4), were selected from the population of patients treated in low back pain clinics in the Oklahoma City area. They were requested to exert their safe maximal effort without incurring additional pain or discomfort.

Lifting Positions

The two lifting positions used in the study were variations of the leg lifting (SQUAT) and torso lifting (STOOP) positions described by Chaffin (1975). The knee angle in the SQUAT position was maintained at 90° for each trial. The hip angle in the STOOP position was fixed at 110° for all subjects. This is greater than the angle specified by Chaffin due to the inability of many injured subjects to bend forward more

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than this amount.

Equipment

The equipment used in the study consisted of lifting handles and a wooden platform, a strain gage Model SM-250 load cell by Interface, Inc., a Vishay/ Ellis-20 Digital Strain Indicator and a Model 220 Brush Chart recorder by Gould, Inc. The handles were constructed of aluminum according to the design and dimensions given by Chaffin (1975) as suitable for arm, torso, and leg lifting strength measurements. An adjustable length chain was used to connect the handle to the wooden platform on which the subject stood. A permanent record of each force exertion was produced with the strip chart recorder for further analysis.

Procedure

Ten trials were conducted for each subject in each position. Each trial consisted of a single force exertion following the instructions provided for that particular subject group. The height of the lifting handle was adjusted for each subject to maintain the angles specified previously for each position.

Subjects were asked to increase muscle tension to the requested level without a jerk and to maintain this level of exertion for five seconds as indicated by audio signals. Each trial was preceded by a verbal countdown to enable the subject to prepare for the exertion. Following each trial, the subject was given 2 minutes of rest. After ten trials in one position, a ten-minute rest break was provided before testing in the second position. The order of testing positions was randomly assigned for each subject.

RESULTS

A simplified representation of the data collapsed across all subjects, positions and trials is given in Figure 1. Mean values for the three groups are given in Table 2. A discussion of each strength measure follows.

Table 2. Strength Measures by Group

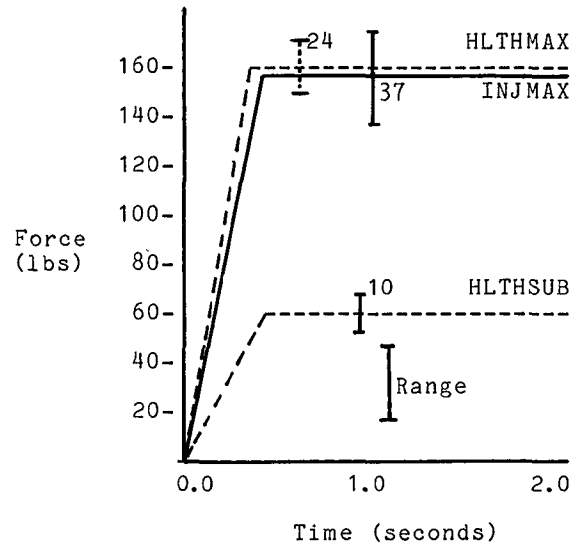|	HLTHMAX	HLTHSUB	INJMAX
Strength Score(lbs)	160	62	160
Slope(lbs/sec)	490	160	410
Range(lbs)	24	10	37
Ratio(range/score)	.15	.16	.23
Coef. Var(score)	2.6	4.8	4.5
Coef. Var(log-norm)	51	117	94

Figure 1. Mean Force Curve by Group

Strength Score

The average force produced by the healthy submaximal group was 38% of the force exerted by the other two groups, somewhat less than the requested 50% of maximum. Suprisingly the average strength scores for the HLTHMAX and INJMAX groups were almost identical in each lifting position. For all three groups, strength scores for the SQUAT position exceeded those for the STOOP position by an average factor of 1.22. Analysis of variance confirmed a highly significant difference for the HLTHSUB group and a significant difference between positions.

Rate of Strength Build-up (Slope)

The HLTHMAX group exhibited the highest slope (490 lbs/sec), which differed significantly from the slope of the HLTHSUB group (160 lbs/sec). The slope for the INJMAX group (410 lbs/sec) was comparable to that for the HLTHMAX group. Slopes for the STOOP position were significantly lower than those for the SQUAT position.

An observation was that subjects tend to build-up force over a fixed period of time regardless of the final sustained level. This explains the higher slopes associated with the higher strength scores. It also indicates that slope provides little additional information beyond that provided by the strength score itself.

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Range

The INJMAX group exhibited the smallest range (10 lbs) compared with the other two groups. As with slope, this is probably associated with the smaller forces produced by this group. However, there was also a significant difference between the range for the HLTHMAX group (24 lbs) and that for the INJMAX group (37 lbs). The range for the SQUAT position was higher than that for the STOOP position.

Standardized Range (Ratio)

By dividing the range by the strength score for each trial, allowance was made for differences in the level of effort between the groups. The value of this ratio was considerably larger for the INJMAX group (0.23) compared with the two healthy groups (0.15 and 0.16). This was the only measure which strictly distinguished the injured subjects from the healthy subjects regardless of their group assignment. It also minimized differences between the two lifting positions.

Coefficient of Variation

The HLTHMAX group had the lowest between-trial variability as measured by the coefficient of variation for the strength scores (2.55). Values for the HLTHSUB group (4.8) and INJMAX group (4.55) were very similar, confirming the inappropriateness of this measure for distinguishing between injured subjects and healthy subjects producing less than maximum strength. Analysis of variance indicated that none of the differences were statistically significant.

Coefficient of Variation - Log-Normal

The pattern of values for the coefficient of variation of the log-normal transformed scores followed that of the untransformed coefficient of variation. However, in this case, the mean c.v. for the HLTHMAX group (51) was significantly lower than those for the other groups (117 and 94). This confirmed similar results obtained by Daniel (1978), but does not provide a measure to distinguish the HLTHSUB and INJMAX groups.

Trials

None of the measures differed significantly over the ten trials regardless of position or group. This indicated minimal muscular fatigue over the testing period.

DISCRIMINANT ANALYSIS

Discriminant analysis was performed on the original data in an attempt to identify those strength measures which could be used to accurately classify subjects into their appropriate groups. Different sets of classification variables were examined. Using all thirteen measures listed in Table 1 produced the results given in Table 3 with an overall accuracy of 90.6% correct classifications.

Table 3. Thirteen Variable Model

From Group	To Group		
	HLTHMAX	HLTHSUB	INJMAX
HLTHMAX	90.6%	6.3%	3.1%
HLTHSUB	0.0%	100.0%	0.0%
INJMAX	15.6%	3.1%	81.3%

The subjects misclassified into the HLTHSUB category were female subjects whose strength scores were somewhat lower than the means for their respective groups. Based on an examination of the original data, it is suspected that the subjects from the INJMAX group who were classified as HLTHMAX had in fact made significant progress toward healthy status.

A reduced set of seven classification variables was obtained using stepwise discriminant analysis. The variables in this set were SCOREMN, SCORESD, SLOPEMN, RANGEMN, RATIOMN, RATIOSD and RATIOCV. Performance of the seven variable model is given in Table 4. This model resulted in a slightly better overall accuracy (91.6%) but misclassified a larger number of INJMAX subjects.

Table 4. Seven Variable Model

From Group	To Group		
	HLTHMAX	HLTHSUB	INJMAX
HLTHMAX	100.0%	0.0%	0.0%
HLTHSUB	0.0%	100.0%	0.0%
INJMAX	12.5%	12.5%	75.0%

Other sets of variables were examined without further improvement. An

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analysis involving only the male sub-
jects and using all variables except
SCORECVLN produced an overall accuracy
of 95.8%. This illustrates the
advantage of developing separate discri-
minant models for males and females.

CONCLUSIONS

In summary, it was determined that
several of the examined strength meas-
ures differed significantly between two
or more of the groups. Strength score
and rate of strength build-up easily
distinguished between maximal and sub-
maximal efforts, confirming the results
of Kroemer and Marras (1980).

The coefficient of variation of
the strength scores, used as a measure
of between-trial variability, did not
differ significantly between the groups.
However, the c.v. of the log-normal
transformed data was significantly lower
for the healthy maximal group, confirm-
ing Daniel's (1978) findings.

Within-trial variability as meas-
ured by range differed significantly for
all three groups. More importantly, the
standardized range obtained by dividing
range by the strength score distin-
guished the injured subjects from the
healthy subjects in the other two
groups.

A high level of predictability
(over 90%) was achieved with the dis-
criminant model. The analysis indicated
that several of the strength measures
contributed significantly to the dis-
criminant function. Validation of the
model using additional subjects is re-
quired to confirm its value as a diag-
nostic tool.

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