Acceptable Maximum Effort (AME)
A Psychophysical Measure of Strength in Back Pain Patients

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A new quantitative method for measuring functional abilities of chronic low-back pain patients is introduced. The method is based upon a psychophysical model referred to as acceptable maximum effort (AME). AME is the highest level of voluntary effort that a person can achieve without inducing unacceptable pain. In the current study, the AME method was applied to strength measurement. By use of a static strength measurement procedure, arm, leg, shoulder, back, and composite strengths were assessed upon admission to and discharge from a 4-week, nonsurgical comprehensive pain treatment program. The reliability of the AME method for each strength measure was assessed. In addition, the method was used to evaluate pre- to post-treatment changes in strength. Results indicate the AME method to be highly reliable and useful in determining treatment outcome. Reliability coefficients for all strength measures were above .90. The results are discussed in terms of their implications for standardized functional ability measurement in the area of chronic pain. [Key words: low-back pain, treatment outcome, functional ability, measurement, psychophysical method]

BACK PAIN REMAINS ONE of the most debilitating and prevalent medical problems in the United States. The devastating consequences of chronic back pain on its sufferers as well as on industry and the health care system have been well documented.[2,13,16] In response to the highly debilitating nature and prevalence of back pain, a myriad of medical treatment approaches have been advocated by different care providers. Unfortunately, the evaluation of the efficacy of these approaches has been typically performed on qualitative, subjective bases. For the most part, outcome evaluations have relied on the clinical judgment of a single physician delivering the particular treatment or upon patient self-report. Self-report evaluations, whether on the part of a physician or patient, lack the scientific rigor and reliability of appropriately developed quantitative measures. The operational definition of success used for self-report measures is, typically, ambiguous and, as such, renders meaningful interpretation of results difficult.

Two common forms of physician or patient self-report-based measures have been used in evaluative studies and include rating scales completed by physicians and patients concerning their perception of overall treatment outcome and patient report of analgesic pain medication intake, pain level, or activity level.[1,6,14,15,23] In a concise review of the literature, Trief[24] pointed out many of the more common shortcomings of self-report measures used to evaluate pain treatment. In particular, self-report measures allow a number of extraneous variables to enter into the evaluation process and potentially confound the relationship between treatment and reported outcome. The more salient of these confounding variables associated with the use of self-report measures are social desirability needs on the part of some patients, demand characteristics of the measure, patient affect toward treating physician or setting, and perceived secondary gains on the part of both patients (eg, continuance of disability benefits) and physicians (eg, publish results). These potential confounding variables are entered into the measurement process wittingly or unwittingly and bring into the question the reliability and validity of self-report measures regardless of the outcome index (eg, pain relief, medication usage, amount of physical activity). The dubious reliability of these measures does not permit completely valid evaluations of a single treatment approach nor assessments of the relative effectiveness of different care approaches. The recognized problems with self-report measures have led many investigators[4,8,9,11,12] to call for the establishment and use of more standardized and reliable quantitative measures of functional abilities among chronic pain victims.

One method that has been used to obtain more objective data on functional activity is clinical measurement of strength and flexibility, performed by physical or occupational therapists. Unfortunately, these clinical measures, while yielding numerical data, often involve some degree of subjective input on the part of the therapist and, especially, with strength assessment (eg, 0 to 5-gradient scale for strength), lack the needed specificity adequately to compare the outcome of one patient with another.

In view of the deficiencies in measuring outcome of treatment for chronic pain, the Comprehensive Pain and Rehabilitation Center (CPRC) of the University of Miami School of Medicine has for the last 4 years established and tested an ergonomic approach to evaluating patient response to treatment. A description of the CPRC may be found elsewhere.[8,17-20] The focus of the evaluation approach used in the CPRC is upon measurement of functional capacities. Assessing functional capacity establishes a human performance profile that can be used to determine the effectiveness of treatment and physical readiness to return to work and other activities of daily living.

Muscular strength has been the primary focus of ergonomic measurement of human functional capacities. Methods used to evaluate strength fall into one of two categories: 1) dynamic strength testing methods and 2) static strength testing methods. Some dynamic methods are generally considered to produce values that are more realistic in predicting functional capacities.[22] However, static strength testing methods have been shown to produce less biomechanical stress on the musculoskeletal structures than dynamic regimens and prove to be quite safe.[4,7,10] In static testing, an individual is capable of exercising better body control than in dynamic testing. Static testing also affords a better capability of focusing on the output of a defined muscle group or set of muscle groups. These

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factors provide the bases for concluding that static strength testing measures are quite desirable for use with individuals suffering back injury or long-standing, low-back pain.

For the most part, the ergonomic measurement approach with chronic pain persons has been viewed by investigators as a mere extension of assessment approaches used with healthy, unimpaired individuals.[7] Instructions in these studies call for the exertion of maximal effort, a level of function which often may be physically detrimental to a chronic back pain sufferer. For the chronic pain population, these maximal output instructions do not take into account the functional qualities of muscular performance which are shaped and limited by the person's perception of pain. Moreover, the procedure for evaluating maximal output may, in fact, place individuals with injury or chronic pain at increased risk of further injury.[5] Maximal function testing requires back pain individuals to exert themselves beyond their acceptable pain level, a level of effort which they would not likely go beyond in any other setting. Furthermore, maximal function testing is not a readily acceptable procedure to individuals with back pain. In our experience, many patients complain when they are asked simply to perform to their maximal effort. These complaints center on risk of re-injury and exacerbation of the painful condition.

In light of the potential risks to the patient, as well as the patient's reticence about maximal ability testing, a decision was made to employ an ergonomic test battery to quantify functional abilities that relies on a psychophysical static testing model. Such a model requires that the critical interaction between actual physical capability and one's perception of his or her capability be taken into account. For the chronic pain population, a measure that assesses the person's physical ability in relation to his or her perception of what is tolerable should, in the long run, yield results more indicative than a maximal ability measure of what the person's likely output would be in more general settings, such as the job site or home. Moreover, the quantifiable nature of the ergonomic measures minimizes subjectivity and affords the necessary sensitivity to detect small, yet clinically, significant differences in function among patients. It should still be recognized that despite their subjective quality, physician and patient reports must be considered as essential complementary components in the overall evaluation of treatment outcome. More quantitative measures can augment these subjective assessments, particularly with respect to actual functional ability. The purpose of the current study was 1) to assess the reliability (ie, test–retest reliability) of a newly developed psychophysical model for use in evaluating functional ability among chronic low-back pain individuals and 2) to demonstrate the model's feasibility in quantifying pre- to post-treatment changes in functional capabilities of chronic pain patients.

MATERIALS AND METHODS

The Concept of Acceptable Maximal Effort (AME). The psychophysical model used in this study relied on the concept of acceptable maximal effort (AME). For evaluating function in persons with chronic pain, AME refers to highest level of voluntary effort that the person can achieve without incurring (ie, perceiving) unacceptable pain.[9,11] It defines the highest functional level that can be attained within the bounds of acceptable pain.

The continuous decision making process involved in achieving AME is depicted by the flow diagram in Figure 1. The patient enters the task situation with a given level of pain. Before exertion of initial effort, the patient decides whether the exertion of any effort would immediately lead to unacceptable pain. If the expectancy is "yes, exertion of effort would indeed cause unacceptable pain," then the patient would be expected not to perform the task. However, if the expectancy is "no," the patient would begin to exert effort. After increasing effort, the patient then makes a decision on whether he or she has achieved maximal physical effort possible (ie, for static strength in a healthy population this would be maximal voluntary contraction). If it is perceived that maximal effort possible has been reached, the patient terminates effort. However, if it is perceived that maximal effort has not been achieved, then the patient returns to the decision of whether the next immediate level of effort will produce unacceptable pain. If that decision is "yes", the patient will then terminate effort at the present level; this level would be the patient's AME. If the decision is "no", then the patient increases the effort and proceeds through the decision-making process again until AME is reached.

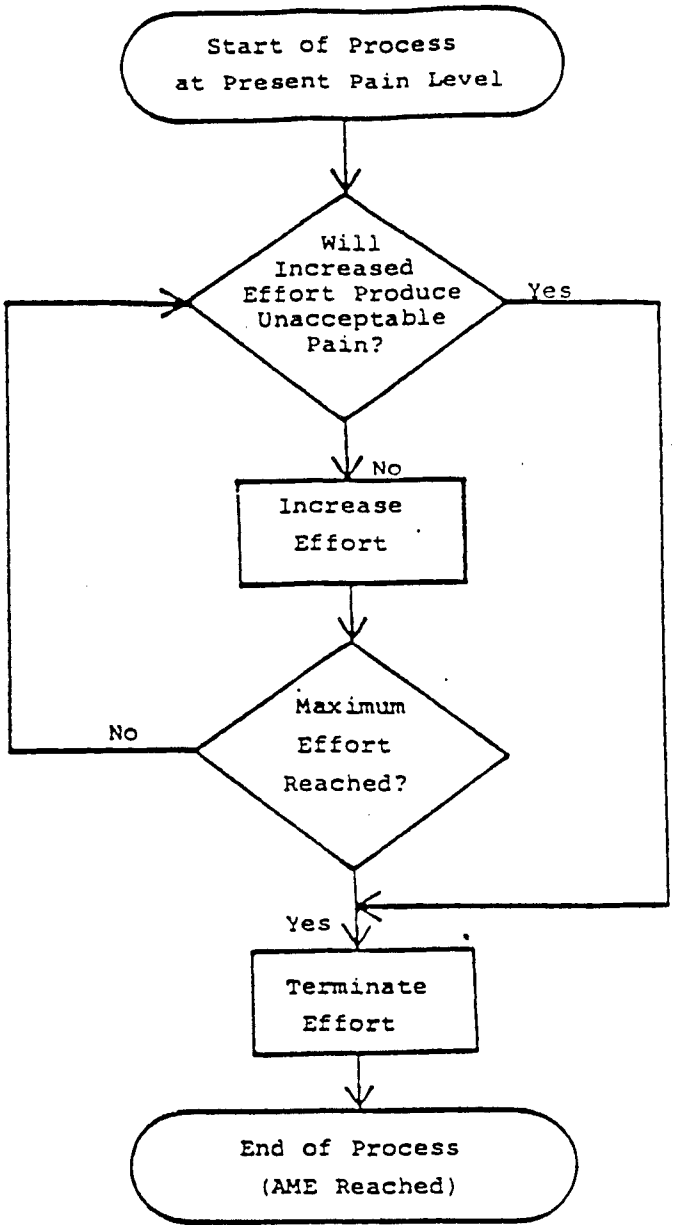

Fig 1. Dynamics of the AME decision-making process for chronic pain patients.

In accordance with the AME concept, instructions to the patients for completing evaluation tasks requiring muscular exertion request continuation of effort (eg, building of strength) to the point at which any further increase in effort would immediately evoke unacceptable pain. In so doing, the patient achieves an outcome

which is shaped by his or her inherent physical capabilities as well as by perceptual factors related to pain status.

Procedures. The human performance profile derived from the test battery used by the Ergonomics and Bioengineering Division of the CPRC is divided into four ability areas: muscular strength, flexibility, kinesiologic factors (eg, walking pace, posture) and psychomotor skills (eg, reaction time, hand steadiness). Even though all these measures are pertinent to the evaluation of functional abilities, discussion of each of them individually, or their interrelationships, is beyond the scope of this report. The AME concept has been incorporated into the measures of strength, flexibility, and certain kinesiologic variables. To address the issues of the reliability and functional changes across time, data on the use of the AME concept in the measurement of strength were collected and analyzed in this study.

Subjects were evaluated three different times during their stay in the CPRC. Assessments were performed within 24 hours of admission to the program, at the end of the first 2 weeks of the program, and at the end of week 4 of the program (ie, at the time of discharge). Each evaluation session included all measures comprising the human performance profile and lasted approximately 30 minutes. The ordering of measures in all three evaluation sessions was the same.

Muscular strength was assessed by using a static strength paradigm. For this assessment, five testing positions were used. The testing positions were adopted from those used by Chaffin.[3] The positions were chosen on the basis of their high degree of applicability to on-the-job lifting positions required of most workers' compensation patients treated at CPRC. The five testing positions allowed assessments of arm lifting strength, leg lifting strength, torso lifting strength, shoulder lifting strength, and composite lifting strength. These testing positions are depicted by stick diagrams together with a photograph of the composite testing position in Figure 2. It should be noted that these testing positions do not necessarily isolate a given muscle but rather permit assessments of functional strength in these positions.

Except for instructions to the patient concerning AME, the methodology used to obtain strength values followed the procedures recommended in the Ergonomics Guide for the Assessment of Human Static Strength established by the American Industrial Hygiene Association.[3] As part of the instructions to the patient, the evaluator demonstrated how to perform lifting tasks in each position immediately before testing the patient. In each position, the patient applied force to a lifting handle linked to a force transducer. The width of the handle approximated a person's body width at the shoulders. To record force data, a digital read-out from the electronic force measure device was obtained. Before each test, the patient was requested to build strength slowly, without any "jerky motions," until a point was reached which was perceived to be the upper limit of pain acceptance (ie, AME). The subject was asked to hold this acceptable maximal static force level for 4 seconds and then slowly release the tension. Feedback of force was not provided to the patient during the time of exertion.

To establish the reliability of the AME measurement method, the consistency of two successive assessments of muscular strength for each of the five testing positions described above was examined. For this examination, the subject was required to perform each of the five strength-assessment maneuvers twice during the initial (pre-treatment) evaluation session. Before each lifting attempt, the subject was reminded of the initial instructions describing the AME concept. The subject was allowed to rest for 30–60 seconds between each lifting attempt. Consistency between the successive measures was determined by correlational analysis.

Changes in functional ability were evaluated for a group of patients who completed the CPRC treatment program. For the purposes of these evaluations, only pre-treatment (program admission) and post-treatment (program discharge) data from the strength

Fig 2. Schematic diagram (top) of the five strength testing positions and photograph of the composite testing position.

measures for the five testing positions were used in the statistical analyses.

Subjects. Subjects for the current study were drawn from the patient population of the CPRC treated over the last 3 years. The CPRC delivers care on both an inpatient and outpatient basis. Typically, patients who are accepted into the program receive 4 consecutive weeks of treatment; inpatient care is provided for the first weeks and daily outpatient care is provided for the following weeks. Treatment is provided 5 days a week during the 4 weeks. Patients are accepted into the CPRC program for management of pain for which surgical intervention is not indicated at the time of the pretreatment evaluation[15]; however, prior to entry into the CPRC, many patients have undergone surgery for their pain condition.

For the current study, three specific criteria were used to select subjects from the CPRC patient population. These included 1] low-back pain resulting from myofascial syndrome or herniated disc, 2] patient receipt of workers' compensation, and 3] medical clearance for isometric strength testing by the CPRC physician staff. Diagnosis of the disorders leading to low-back pain was established independently by a neurosurgeon and a physical medicine

physician, both of whom were members of full-time, attending CPRC physician staff.

Two overlapping samples of patients were used to evaluate separately the reliability of the AME measurement method and assess pre- to post-treatment changes in functional ability. For the determination of reliability, 189 patients met the subject selection criteria and were used in the analyses comparing two successive AME measurements of strength. The mean age of this sample was 41.2 ± 10.9 years. In the analyses examining changes in functional ability as a result of the CPRC treatment program, data on 122 subjects were available for the pre- to post-treatment comparisons.

RESULTS

Reliability of the AME Measurement Method

Test–retest reliability of the AME measurement method was evaluated for strength measures by correlational analyses. As described in the Materials and Methods section, data for the correlational analyses were obtained by having subjects perform each strength test twice within the initial testing session. (It should be noted that in the early development of the AME strength test battery, not all test positions were consistently used. In order to use all available data for the reliability assessment, unequal numbers of subjects were, therefore, included in the different correlational analyses.) Prior to statistical analysis, an examination of the strength values across subjects for each testing position indicated that the values were not normally distributed; each distribution was substantially skewed in the positive direction. As such, a nonparametric statistical technique, the Spearman rank correlation analysis, was used to determine test–retest reliability.[21] Results from the correlational analyses for each test position are presented in Table 1. All correlational coefficients were found significant with each rho (r) value above .90. The correlational coefficients indicate an extremely strong, positive relationship between the first and second AME measures for each of the five testing positions.

Changes in Functional Ability

The direction and magnitude of differences between initial and final assessments for each of the AME strength measures were statistically examined by means of the Wilcoxon matched pairs signed ranks test for large samples.[21] Separate analyses on strength measures were performed for males and females. A summary of the results from each Wilcoxon test is presented in Table 2. As can be seen in this table, a significant difference between baseline and final outcome was found for each measurement for males and for females.

The means and standard deviations for initial and final assessments on all measurements are presented in Table 3. A review of the values in Table 3 shows that all differences between baseline and final outcome for males and for females were in the direction of improved function.

Table 1. Spearman's Rank Correlation Coefficient (Rs) for the Five AME Strength Testing Positions

Testing Position	*N*	*RS*	*t value*
Arm	189	.93	35.7*
Shoulder	144	.95	36.9*
Composite	104	.98	44.4*
Leg	82	.97	35.2*
Back	71	.97	32.5*

*$P < .0005$.

Table 2. Results of Wilcoxin Match Pairs Signed Ranks Test Comparing Pre- to Post-treatment AME Strength Values

	Z value	
Testing position	*Males (N=77)*	*Females (N=45)*
Arm	8.33*	6.26*
Shoulder	7.91*	6.15*
Composite	8.53*	6.58*
Leg	8.85*	6.21*
Back	8.13*	6.23*

*$P < .01$.

DISCUSSION

The purpose of the current study was to describe and demonstrate the utility of a conceptually new quantitative method for assessing functional ability of individuals with low-back injury or chronic back pain. Previously reported methods for such assessment were overly subjective in nature, lacked sufficient sensitivity to detect small yet clinically meaningful differences among patients, or were unsuitable for chronic pain patients because of an emphasis upon exertion of maximal effort beyond pain tolerance. The quantitative method described and evaluated in this study was based on a psychophysical model that attempts to account both for physical capabilities of the individual and for perceptual factors related to pain.

Results from the current study provide a preliminary indication that the AME measure of muscular strength is stable in terms of test–retest reliability. During the period of time that treatment is provided, day-to-day fluctuations in both physical and pain perception related factors would be expected. These fluctuations would in turn lead to commensurate changes in values on the AME measure. As such, test–retest reliability needs to be performed with a relatively short time lapse between assessments, as was the case in this study. Despite the high correlational coefficients found for each strength test position, further work on the reliability of the AME measurement method is warranted. In our analyses, different sample sizes were used. Whether a more complete data set would have affected our results remains unknown. In addition, it should be noted that reliability was assessed only on AME values obtained before treatment. In view of possible changes in intersubject variability and changes in performance levels, it could be argued that the high correlational coefficients found for the pretreatment measurements may not hold for post-treatment measurements. To shed some light on post-treatment AME reliability, a supplemental series of Spearman rank correlational analyses was performed on

Table 3. Means (X) and Standard Deviation (SD) for Pre- and Post-treatment AME Strength Values by Testing Position

	Males (N=77)		*Females (N=45)*	
Testing position	*Pre*	*Post*	*Pre*	*Post*
Arm	(X) 51.3	83.8	26.6	44.7
	(SD) 32.2	36.3	17.1	21.3
Shoulder	(X) 52.6	89.0	23.1	41.1
	(SD) 39.3	37.6	17.8	19.7
Composite	(X) 97.6	211.6	42.9	100.4
	(SD) 89.7	113.7	45.2	65.2
Leg	(X) 122.4	249.7	54.9	129.7
	(SD) 92.4	116.3	52.2	78.1
Back	(X) 61.4	148.3	35.1	82.3
	(SD) 64.2	79.2	37.7	51.2

repeated post-treatment AME measurements obtained from another group of low-back pain, workers' compensation patients treated at the CPRC. For these analyses, sample sizes ranged from 26 subjects for leg lifting strength to 60 subjects for arm lifting strength. All measurement procedures followed with these subjects were the same as those presented in the Materials and Methods section. The correlational coefficients for all five testing positions were above .95 and, as such, indicate very strong test–retest reliability for the post-treatment AME measures.

Quantitative measurement, using scales like force, as was used in our method, affords the necessary sensitivity to detect meaningful differences in functional ability among patients or across time within a single patient or group of patients. Although the results of the present study indicate significant improvement in function as a result of the treatment provided at the Comprehensive Pain and Rehabilitation Center of the University of Miami, they are even more illustrative of the utility of the AME method for determining changes in functional aspects of chronic low-back pain patients, whether the changes are in the positive or negative direction. The main objective of the current study was to establish the reliability of the AME strength measures and the feasibility of using them for assessing changes in function as a result of treatment. The results of the study, particularly those pertaining to reliability, provide the foundation for further research to determine the degree to which the AME measures can predict successful return to work. Such studies are currently under way in our center.

It should be considered here whether the use of a psychophysical model for determining functional ability would in some cases lend credence to an individual's demonstrated level of function which may be below his or her "true" functional capability. Although they provide a method for improved quantification of functional abilities, the AME measures need to be used in conjunction with other clinical measures of function performed by physicians and other health professionals. In our experience, multidisciplinary assessment can help determine a patient's "true" level of functional capability.

Quantitative methods such as the one described in this study can provide clinicians and researchers, alike, a vehicle by which evaluation of functional abilities of pain patients becomes standardized. Currently, it is nearly impossible to compare results from different studies on treatment outcome in patients with chronic pain in view of the widely divergent methods used to measure progress. Quantitative methods for assessing functional ability based on ergonomic principles have been used successfully in industry to standardize evaluations of workers' physical abilities relative to the demands of the work environment. While greater attention must be given to pain-related perceptual factors than is used in industry evaluations, such a quantitative approach needs to be adopted for the assessment of functional ability of chronic pain patients.

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