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Modeling of functional trunk muscle performance: Interfacing ergonomics and spine rehabilitation in response to the ADA

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Abstract—The combination of increasing costs of musculoskeletal injuries and the implementation of the Americans with Disabilities Act (ADA) has created the need for a more objective functional understanding of dynamic trunk performance. In this study, trunk extensor and flexor strengths were measured as a function of angular position and velocity for 20 subjects performing maximum isometric and isokinetic exertions. Results indicate that trunk strength is significantly influenced by trunk angular position, trunk angular velocity, gender, and direction, as well as by the interaction between trunk angular position and velocity. Three-dimensional surfaces of trunk strength in response to trunk angular position and velocity were constructed for each subject per direction. Such data presentation is more accurate and gives better insight about the strength profile of an individual than does the traditional use of a single strength value. The joint strength capacity profiles may be combined with joint torque requirements from a manual material handling task, such as a lifting task, to compute the dynamic utilization ratio for the trunk muscles. This ratio can be used as a unified measure of both task demand and functional capacity to guide job assignment, return to work, and prognosis during the rehabilitation processes. Furthermore, the strength regressions developed in this study would provide dynamic strength limits that can be used as functional constraints in the computer simulation of physical activities, such as lifting. In light of the ADA, this would be of great value in predicting the consequences of task modifications and/or workstation alterations without subjecting an injured worker or an individual with a disability to unnecessary testing.

Key words: *dynamic utilization ratio, ergonomics, performance models, rehabilitation, task analysis, trunk strength.*

INTRODUCTION

Occupationally related low back disorders continue to be of paramount concern in industrialized countries due to the extensive economic and productivity loss associated with them. It is estimated that 9.2 million people are currently impaired and 2.4 million are currently disabled by low back pain (LBP) in the United States. As many as 85 percent of adults experience back pain that interferes with their work or daily activities, and up to 25 percent of people between the ages of 30 and 50 report

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LBP symptoms (1). The economic consequences (including lost wages) of LBP have been reported to range from $16 billion to over $50 billion each year (1). Fortunately, the majority of low back problems are self-limiting; it has been estimated that up to 90 percent of persons with LBP recover within 6 weeks, irrespective of the type of treatment they receive (2). On the other hand, the small portion of those who become chronic are responsible for 80 percent of the total costs of low back claims (1). Therefore, quantification of spinal function, particularly trunk strength, is of increasing interest in the management of persons with LBP to prevent chronic disability (3,4).

The need for more objective functional understanding of trunk performance is further enhanced by the implementation of The Americans with Disabilities Act (ADA). The ADA became law in 1990 as the first comprehensive federal law to ensure access to public accommodations and services, as well as equal opportunity in employment, for the estimated 43 million Americans with disabilities (5). Title I of the ADA went into effect on July 26, 1992 for companies with 25 or more employees and on July 26, 1994 for companies with 15 to 24 employees. The provisions of Title I cover all aspects of employment and prohibit discrimination against individuals with disabilities who are qualified to perform the "essential functions" of a job, with or without "reasonable accommodations." Essential functions are those that are an integral and necessary part of the business and not just marginal tasks. Reasonable accommodations are any modification or adjustment to the job or to the work environment that enables a qualified individual with a disability to enjoy equal employment opportunity, benefits, and privileges (6). All medical examinations used to determine job qualifications must be job-related and consistent with business necessity. Since Title I of the ADA went into effect, more than 20 percent of the 31,242 charges filed with the Equal Employment Opportunity Commission (EEOC) under the ADA have been related to back disorders (5). Therefore, in light of the ADA, descriptive and predictive modeling of trunk performance is of utmost importance, since it would provide a benchmark against which the performance of a person with LBP can be measured, so that rehabilitation strategies could be planned, and so that assistive devices could be developed or evaluated.

Until recently, the majority of techniques for the ergonomic assessment of trunk strength have been static in nature (7,8). The underlying assumption for the use of static models to evaluate trunk loading during manual material handling is that these activities are quasistatic in nature. However, observation of many industrial tasks, such as lifting, indicates that such activities are highly dynamic and far from being well controlled or smooth (9). Recent literature has emphasized the significance of studying dynamic parameters, such as trunk angular velocity and acceleration during trunk motion (9–15). Despite the considerable amount of research done on isolated single-joint and coordinated multijoint strength assessment, the majority of trunk performance descriptive models are still reported in the form of torque as a function of joint angle (16–18). Such models have been related to tension-length relationships well documented by physiological studies of muscle mechanics (19–21). In reality, trunk strength is a function of both the joint angle and the velocity. Descriptive models of strength should take this interaction into consideration to represent the three-dimensional (3-D) functional capacity profiles (22,23).

The purpose of this study was to develop 3-D surface responses of trunk strength as a function of trunk angular position and velocity, and apply it to the interface between ergonomics and rehabilitation. The strength profiles can be combined with task-demand parameters in order to provide appropriate task assignment based on the capabilities of an individual. Such data representation can be of further use in the formulation of biomechanical simulation models of lifting. The accuracy of predictions of the upper limit of trunk performance in simulation models is highly dependent on the validity of the imposed constraints. The strength regressions developed in this study would provide dynamic strength limits that can be used as functional constraints in the simulation of physical activities, such as lifting (18,24,25).

METHODS

Subjects

Nonimpaired males and females participated in this study. The mean (SD) age, mass, and stature were 26.2 (3.8) years, 85.1 (14.0) kg, and 178.6 (10.7) cm for the males (N=10), and 24.2 (3.2) years, 58.6 (10.7) kg, and 165.2 (9.6) cm for the females (N=10), respectively. None of the subjects reported a history of LBP or disorders in the previous 6 months. The subjects were briefed on the goals and procedures of the study prior to signing an informed consent form.

Apparatus

The isometric and dynamic trunk strength of the subjects were tested in an asymmetric reference frame (ARF) interfaced with a KIN-COM dynamometer (Chattecx Corp., Chattanooga, TN) that controlled the trunk position and velocity (**Figure 1**). The subjects were tested in the standing posture to better simulate industrial lifting and lowering tasks. A more detailed description of the device is provided elsewhere (13). The KIN-COM consists of a servomotor-controlled rotary arm with an attached load cell. In order to couple the subject to the load cell, a specially designed attachment was comfortably fastened around his or her shoulders. The subjects were also strapped around the pelvis so that only trunk flexion and extension motion were permitted (**Figure 1**).

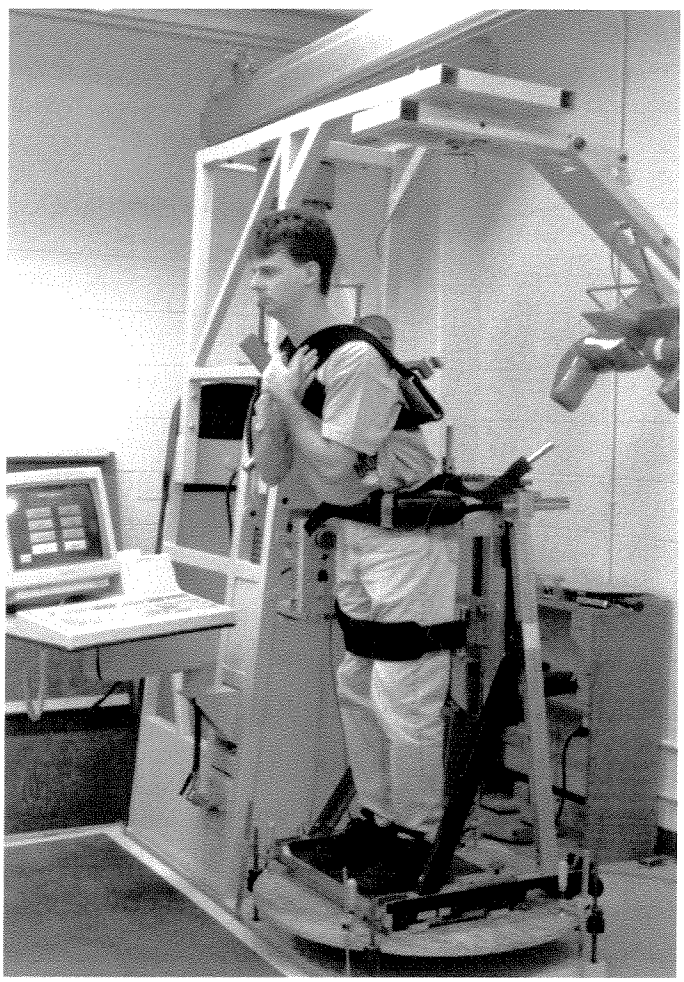

Figure 1.
A subject placed in the asymmetric reference frame (ARF) in preparation for an isometric exertion.

The load cell measured the reaction forces between the trunk and the rotary arm in the direction of motion, which, when multiplied by the linear distance between the arm axis and the load cell, gave a measure of the torque about the L5/S1. In addition to the torque, trunk angular position and velocity were collected at a frequency rate of 100 Hz via an analog to digital (A/D) converter interfaced with a 486 microcomputer.

Experimental Design

The independent variables in this study were trunk angular position and velocity, direction of trunk exertion (flexion/extension), and gender. Trunk position was defined at 5 levels (0, 10, 20, 30, and 40°), with the 0° angle corresponding to the upright standing posture. Six levels were defined for the trunk angular velocity (10, 20, 40, 60, 80, and 100°/s). The measured trunk strength (torque, Nm) was the only defined dependent variable.

Experimental Protocol

Three modes of strength testing were used: isometric, isokinetic, and isotonic (4,26). In the isometric mode, the KIN-COM arm remained stationary during the exertions. Trunk maximal isometric flexor and extensor strength were measured at the five defined levels of trunk position (0, 10, 20, 30, and 40°), and the subjects were instructed to perform a maximal exertion at each of these angles for 5 s. A period of at least 60 s of rest was given between the exertions. The strength data were sampled twice at each isometric position and averaged across the two trials. It has been shown that two exertions provide highly reliable strength assessment without prolonging the test, thereby avoiding muscular fatigue (11,27,28). In the isokinetic mode, maximal trunk concentric flexor and extensor strength was measured at the six defined levels of angular velocity (10, 20, 40, 60, 80, and 100°/s) through a range of motion of 40°, utilizing the isokinetic mode of the KIN-COM. Two sets of three flexion/extension repetitions were collected at each velocity. The subjects rested for at least 60 s between sets and 2 min between velocities. The KIN-COM dynamometer imposed a limit of a 100°/s on the maximum velocity for safety purposes. The preliminary analysis of the male population data revealed that the results of the isotonic test were inconclusive due to technical limitations of the dynamometer.

The trials were randomized for the isometric, isokinetic, and the isotonic modes of exertion to minimize

unintended fatigue and order effects. The angular velocity and resistance values were selected from values in the literature (9,14,15,29–32), as well as from results of coordinated lifts performed in a previous study (26,33,34).

Analysis

For the isometric data, the trunk torque at each angle was averaged over the stable portion of the 5-s exertion and across the two trials (28). For the isokinetic data, each torque value was assigned to a cell within a bivariate cross-tabulation that was a function of angular position and velocity. The distributions were constructed with a bandwidth of $\pm 3°$ for the angular position and ± 10 percent for the angular velocities with respect to reference levels of the independent variables. A single torque value was then calculated, from the average of the data within each cell. The measured torques were corrected for the moment due to the postural load using the anthropometric data of the subjects (35).

Using the average torque values determined from the bivariate distributions, a regression analysis was performed on the measured data, resulting in equations of the trunk strength as a function of angular position and velocity in flexion and extension. These equations were plotted to produce dynamic 3-D strength surfaces for each of the subjects per direction. Within-subjects analysis of variance (ANOVA, repeated measures design) was used to test for the effects of angular position, angular velocity, and direction, while between-subjects ANOVA was used to test for the effect of gender on trunk strength. Furthermore, the various interactive effects were evaluated using the ANOVA procedure. Upon identifying the significant effects, a post-hoc Tukey test was used to determine the corresponding levels of significance ($p \leq 0.05$).

RESULTS

Descriptive Results

Descriptive results of the study are summarized in **Tables 1–4** for the trunk isometric flexion and extension strength as a function of trunk angular position and for the trunk isokinetic strength as a function of trunk angular position and velocity.

3-D Strength Surfaces

The 3-D strength surfaces for trunk flexion and extension as a function of trunk angular position and velocity were constructed for each of the 20 subjects (**Figure 2**). The relatively high intersubject variability resulted in relatively low predictive regression models for the strength surface responses, based on the whole population data (R^2 ranged from 0.42 to 0.61). Hence, the results of the regression analysis are tabulated for each subject per direction of exertion. Such representation may be used as a "performance capacity envelope" to comprehensively characterize the dynamic trunk strength performance of the individual. The regression analyses resulted in an R^2 mean (SD) value of 0.67 (0.11).

Isokinetic Strength

Table 5 summarizes the results of the between and within subjects ANOVA tests for trunk isokinetic strength. The results indicate that the trunk isokinetic strength responded significantly to changes in position, velocity, direction, and gender. The interaction effect of the velocity by angle is significant, while that of the position by direction approaches significance (**Table 5**). This confirms the necessity of the surface representation of trunk strength as a function of both the angular position and velocity, since the interaction of these two main effects is significant. The Tukey post-hoc tests revealed that the trunk extension strength at 20 and 30° of trunk flexion was significantly greater than the strength at 0, 10, and 40° ($p<0.05$). In terms of the effect of velocity, the extension strength was found to be significantly greater at 0, 20, and 40°/s as compared to 60, 80, and 100°/s. Furthermore, the trunk extension strength was higher than the flexion strength and was systematically higher for males than for females.

Isometric Strength

Table 6 summarizes the results of the between and within subjects ANOVA tests for the trunk isometric strength data. The results indicate that the trunk strength responded significantly to changes in trunk position, direction, and gender, as well as to the interaction effect of position and gender. A Tukey post-hoc test illustrated that the isometric trunk strength at 20, 30, and 40° of trunk flexion was significantly higher than that at 0 and 10° for males, while the strength at 20 and 30° was significantly greater than the strength at 0, 10, and 40° for females. In addition, the trunk extension strength was found to be significantly greater than the flexion strength. The strength values were also significantly greater for males.

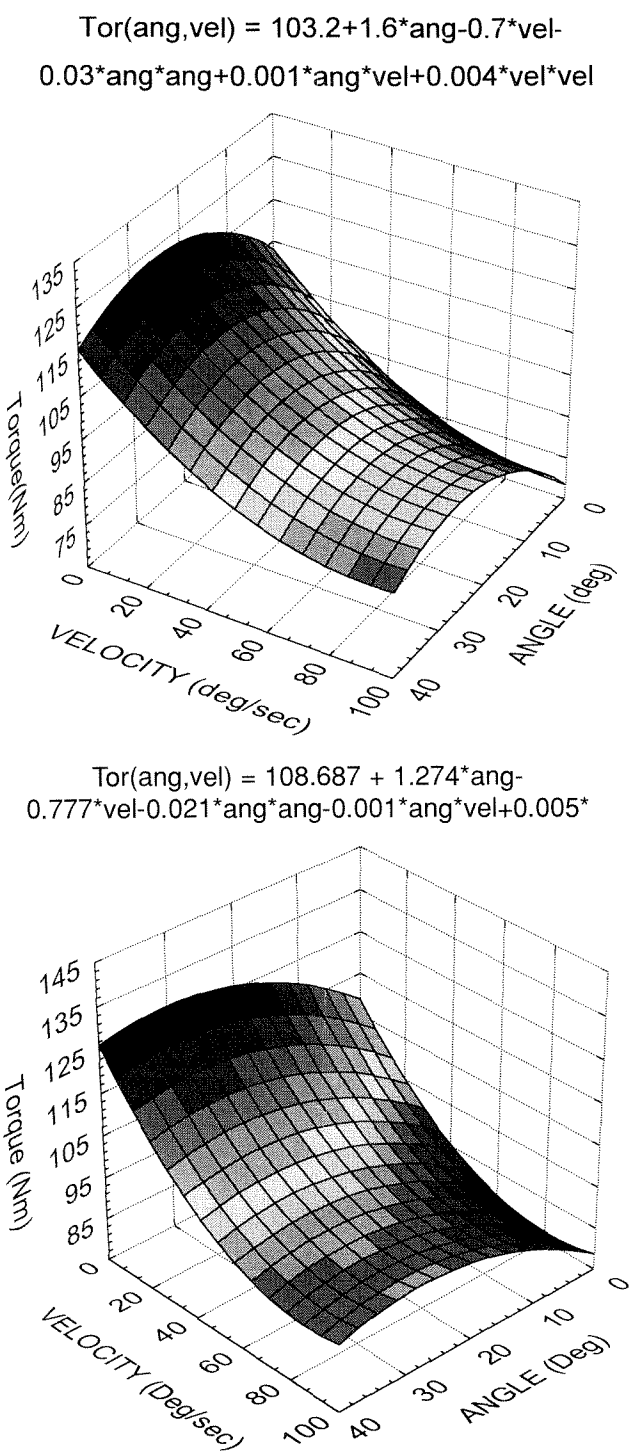

Figure 2.
Two 3-D surface plots of trunk extension as a function of trunk angular position and velocity. Top: subject #4, female: age=28, height=163 cm, weight=46 kg. The regression model yielded the R^2 of 0.61 ($p<0.05$). Bottom: subject #6, female: age=22, height=165 cm, weight=55 kg. The regression model yielded the R^2 of 0.48 ($p<0.05$).

DISCUSSION

Despite the evidence that manual material handling tasks, such as lifting, are highly dynamic in nature (9,36,37), regressions of trunk strength solely as a function of position have been traditionally used in various applications (17,18). This is probably due to the wide availability of such data representation (16,38). Our results show that trunk strength is significantly influenced by dynamic parameters, such as trunk velocity, and that the interaction between trunk angular position and velocity is highly significant. This confirms earlier results of Parnianpour and Marras et al. (12,39,40) and extends them over a wider range of these dynamic variables. When compared with trunk strength values reported in previous literature, our values were close to those found by Mayer et al. (14,15) and Hazard et al. (41), but were higher than the values reported by Newton and Waddell (29) and Newton et al. (30). The differences may be attributed to the use of different isokinetic dynamometers and the population demographics. Studies investigating the intercorrelation among isometric, isokinetic, and isoinertial muscle performance during multijoint coordinated exertions and isolated single joint trunk exertion have shown that the isokinetic trunk peak torque at different velocities had low correlation with peak force during isometric arm and leg exertions (31).

The 3-D surface responses of the trunk strength as a function of angular position and velocity were constructed for all the subjects per direction. Such data presentation is more accurate and gives better insight about the strength profile of an individual than does the traditional use of a single value of strength. The latter does not consider the tension-length-velocity relationship for contractile machinery and the dynamic change of moment arm of muscles as a function of trunk position. Performance envelopes have been previously used to dynamically assess muscle performance by developing 3-D surface responses of muscle contraction as a function of muscle length and velocity of contraction (22,23).

The maximum possible velocity of 100°/s of the dynamometer diminished the nonisokinetic portions of the isotonic exertions, thereby eliminating their usefulness. The females, therefore, were only tested in the isometric and isokinetic modes. The isotonic mode simulated by the dynamometer can best be called isoresistive: the dynamometer provides the resistance set by the experimenter. When the generated muscle torque

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Table 1.
Maximum isometric and isokinetic trunk extension torque (Nm) as a function of trunk angular position and velocity in standing for males.

	Isometric	Isokinetic: Angular Velocity (Degrees/sec)					
Angle	**0°**	**10°**	**20°**	**40°**	**60°**	**80°**	**100°**
0°	114.5(30.9)	153.1(35.5)	140.1(21.1)	118.9(30.3)	97.3(48.8)	110.5(68.4)	109.7(38)
10°	156.8(28)	118.4(41.4)	140.9(18.2)	149.3(21.1)	138.7(31.9)	132.4(43.9)	119(41.6)
20°	189.5(25.7)	129.4(43.6)	152.1(19.2)	158.2(18.2)	152.7(25.4)	156.7(55.1)	146.9(50)
30°	222.8(28.6)	134.6(51.8)	143.6(18.5)	153(24.2)	141.8(23.6)	151.9(51.5)	144(47.3)
40°	189.8(25.6)	158.3(47.5)	172(46.2)	175.1(46)	128(52.4)	136.2(35.9)	137.3(41)

N = 10; all values given as mean(SD).

Table 2.
Maximum isometric and isokinetic trunk extension torque (Nm) as a function of trunk angular position and velocity in standing for females.

	Isometric	Isokinetic: Angular Velocity (Degrees/sec)					
Angle	**0°**	**10°**	**20°**	**40°**	**60°**	**80°**	**100°**
0°	118.3(46.8)	116.2(23.1)	111.2(21.9)	104.5(25.3)	96(27.2)	103.7(22.8)	96.3(21.5)
10°	126.7(40.8)	127(24.1)	114.1(21.2)	106.6(26.2)	98.7(23)	105.7(25.4)	104.8(18.6)
20°	145.4(39.1)	133.6(25.5)	124.2(24.4)	110.4(26.3)	104.3(22)	113.6(26.8)	110.6(23)
30°	172.4(54)	132.4(23.5)	127.4(22.5)	112.4(26.7)	113(21.7)	122.7(21.7)	109(17)
40°	153.9(30.2)	115.9(26.4)	108.9(21)	98(32.4)	105(20.9)	105.5(23.6)	96(17.5)

N = 10; all values given as mean(SD).

Table 3.
Maximum isometric and isokinetic trunk flexion torque (Nm) as a function of trunk angular position and velocity in standing for males.

	Isometric	Isokinetic: Angular Velocity (Degrees/sec)					
Angle	**0°**	**10°**	**20°**	**40°**	**60°**	**80°**	**100°**
0°	80.2(21.2)	151.8(31.4)	130.7(61.9)	135.3(39.8)	117.9(56.7)	117.4(57.3)	186(27.4)
10°	112.6(19.8)	120.8(40.9)	131.7(66.6)	155.5(44.4)	137.4(62.5)	128.1(57.2)	117(25.8)
20°	128.8(20.9)	130(42.3)	153.3(36.5)	153.5(38.4)	138(54.2))	132.5(37.6)	124.8(47)
30°	133.5(21.9)	135.5(45.1)	146.9(54.8)	151.4(40.9)	133.3(49.4)	121.6(55.8)	98.5(52.8)
40°	96.8(20.8)	135.2(45.1)	141.1(61.1)	142.9(45.7)	116.7(45.9)	99.7(50.1)	105(57.1)

N = 10; all values given as mean(SD).

Table 4.
Maximum isometric and isokinetic trunk flexion torque (Nm) as a function of trunk angular position and velocity in standing for females.

	Isometric	Isokinetic: Angular Velocity (Degrees/sec)					
Angle	**0°**	**10°**	**20°**	**40°**	**60°**	**80°**	**100°**
0°	76.5(20.8)	81.4(28.1)	83.2(28.1)	84.7(30.3)	85.9(31.2)	84.5(25.8)	81.6(25)
10°	103.1(20.6)	91.7(29.7)	83.9(26.3)	87.8(34.2)	86.5(28.9)	86(25.3)	83.3(25.8)
20°	112.1(18.6)	100.6(30.8)	93.7(30.9)	94.1(33.6)	92.1(31.8)	93.9(27.4)	88.4(27.9)
30°	118.8(22.3)	112.4(28.3)	100.7(29.4)	100(31.8)	97.4(25.7)	99(28)	143.6(47.3)
40°	98.2(21.6)	92.3(32)	84.6(31.6)	87.3(28.6)	86.2(27.5)	85.5(31.7)	79.2(28.6)

N = 10; all values given as mean(SD).

Table 5.
The results of ANOVA on isokinetic strength for the main effects of angle, velocity, direction, gender and the significant interactions.

Source	F Value	P Value
Angle	8.12	0.0001**
Velocity	2.58	0.0311*
Direction	6.74	0.0178*
Gender	7.94	0.0114*
Angle * Velocity	6.25	0.0011**
Angle * Direction	2.40	0.0500*

* = $p < 0.05$; ** = $p < 0.001$; NS = not significant.

Table 6.
The results of ANOVA on isometric strength for the main effects of angle, direction, gender and the significant interactions.

Source	F Value	P Value
Angle	12.51	0.0001**
Direction	10.61	0.0041*
Gender	22.37	0.0002**
Angle * Gender	4.31	0.0035*

* = $p < 0.05$; ** = $p < 0.001$; NS = not significant.

exceeds the resistance, the initial isometric condition changes to isoresistive condition, while the joint velocity is allowed to vary. The device imposes a limit of 100°/s for back testing, which caused the subjects to switch to the isokinetic mode very early in the range of motion (26). Future studies should consider modifying the existing dynamometer in order to accommodate a higher maximum threshold velocity limit. It was our original intent to see whether the dynamic strength at a given angular position and velocity would be affected by different modes (isokinetic vs. isotonic) of dynamic testing (26). This hypothesis is significant, since the trunk seldom moves isokinetically while performing the functions of daily living. Such studies are needed to further validate isokinetic assessment and allow us to generalize the present results.

Lifting Utilization Ratio

The inquiry regarding whether a subject can perform a specific task considering his/her functional capacity at specific joint levels remains unresolved. Quantitative assessment of job demands can be combined with the performance capacity profiles resulting from this study to determine the utilization ratio (task demands relative to strength capacity) of an individual. The utilization ratio provides a joint-specific unified scalar quantity representing the task demand normalized by the maximum capacity of an individual (42). It would indicate whether a subject is capable of performing the task and how much of his/her maximum capacity is taxed by a given physical activity such as lifting.

To illustrate this concept, the strength surface responses that were obtained from this study were combined with task demand parameters of a lifting task performed by a typical female subject. The task demand parameters were determined in a previous study that examined the effects of load, mode, and speed of lift on power generation, absorption, and transfer during a multi-link coordinated lifting task (31,43). **Figure 3** depicts the relevant kinematic and kinetic profiles for a female subject lifting a load of 13.5 kg using a preferred lifting technique at a rate of one lift/s. This load corresponds to 34

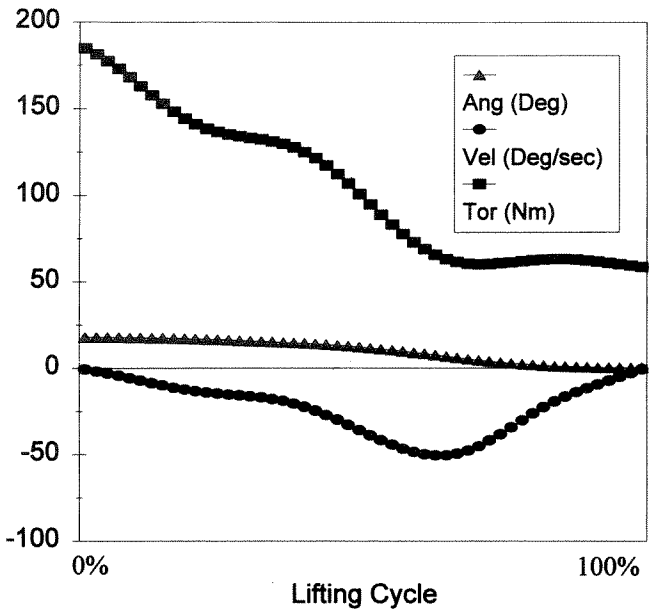

Figure 3.
Trunk angular position and velocity, net trunk muscle torque generated by subject #4, during the lifting phase of a load of 13.5 kg, using a preferred technique at a rate of 1 lift/s.

percent of the maximum isoinertial lifting capacity of the subject. The following three utilization ratios were computed for the lifting cycle (**Figures 3** and **4**): 1) the ratio of the L5/S1 torque to the trunk strength as a function of both angular position and velocity (UR1); 2) the ratio of the L5/S1 torque to the trunk strength as a function of trunk angular position (UR2); and 3) the ratio of the L5/S1 torque to the isometric strength in the upright position (UR3). For each of the above computations, the numerator, which is obtained by an inverse dynamic model (34), represents the task demand and remains the same. The denominator, however, changes, based upon our experimental results and the alternative strength models.

In computing the three utilization ratios, the primary assumptions were:

1. UR1 is computed considering both the angular position and velocity dependence of strength, and therefore using the results of the regression analysis: $T(\theta, \dot{\theta})$
2. UR2 is computed considering the posture dependence of isometric strength: $T(\theta, \dot{\theta}) = T(\theta, 0)$
3. UR3 is computed based on the assumption that the maximum isometric trunk strength can be estimated by a single value measured at the upright standing posture.

The last method has been explicitly and/or implicitly used in major epidemiological studies when the task demand is compared with maximum strength (44). One of the reasons for the poor results of many such investigations for prediction of future low back injury based on isometric strength is shown here. To increase the predictive power, it has been suggested that the measured strength must simulate the essential functions of the task as closely as possible (45,46). The first two methods diverge in their predictions when the velocity approaches its maximum value. The maximum extensor strength of the subject showed a strong dependency on trunk position and velocity (**Figures 2** and **4**). The influence of posture on the strength and utilization ratio is shown by the divergence of the last two methods. In the more flexed position, the trunk strength is higher than it is in the upright position, leading to the most significant divergence at the beginning of the lift cycle.

The results of these data indicate that accurate estimation of the utilization ratio requires both the multiple measurements of the external moment and strength in the range of joint positions being experienced during the performance of the lifting task. Moreover, the dynamic characteristics of the task should be considered. It is clear that the higher magnitudes of the dynamic components

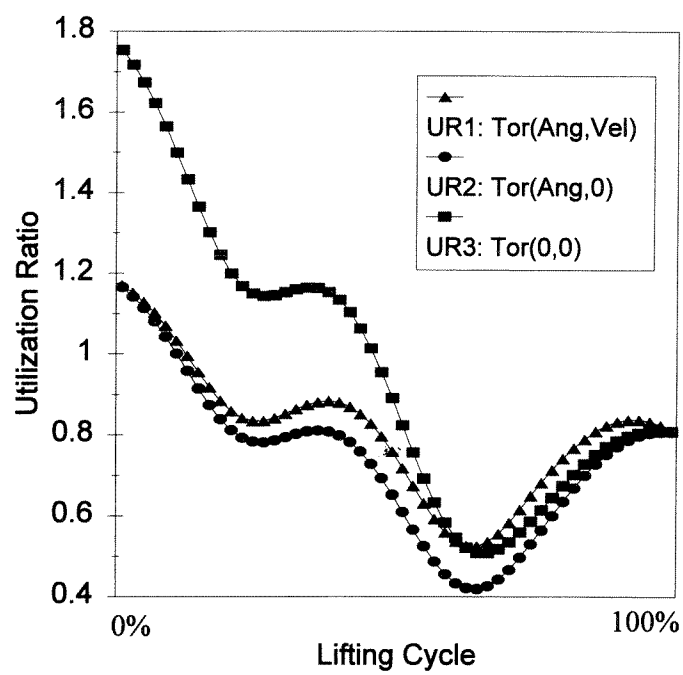

Figure 4.
The results of three alternative methods for computing the utilization ratio for the lifting task performed by subject #4.

increase the task demand and reduce the maximum functional capacity, thereby increasing the utilization ratio. The dynamic utilization ratio is computed considering the strength dependence on both the angular position and velocity. At the fast rate of one lift/s, the numerator of the utilization ratio (task demand) is increased due to the increased acceleration. On the other hand, the denominator (maximum strength capacity) is decreased, since the tension is inversely proportional to a muscle's speed of shortening, according to Hill's tension-velocity relationship (19). Hence, the utilization ratio approaches unity even for lifts that are only a fraction of the maximum lifting capacity.

It is interesting to note that a utilization ratio of greater than one is predicted at the beginning of the lifting cycle, which indicates that we have underestimated the maximum strength, at least in the first 10 percent of the lifting cycle (**Figure 4**). The cause of this discrepancy is not known; however, we can postulate a few mechanisms. Due to the repetitive nature of the lifting task, the extensor muscles are eccentrically activated during the deceleration phase of lowering before the trunk is accelerated into extension. It has been suggested that energy stored in the series elastic element could be released to potentiate subsequent concentric activation of the muscle after an eccentric action (47–49). Secondly, the strength regression is based on isokinetic modes of testing and their application to free dynamic lifting tasks, a subject that needs much more detailed validation. Our initial attempt of using the isoresistive mode for strength measurement was not successful in this study due to the speed limitation of the device. Thirdly, the R^2 of the strength model developed for this subject was 0.61, and therefore 0.39 of the variation of data remained unexplained. Also, lifting is a multijoint, coordinated activity, which could greatly affect the function of the multiarticular muscles; the strength measurement was used with the pelvis and legs stabilized, which is very different from what actually happens during free dynamic lifts (4). Lastly, Gordon et al. (50) have shown mathematically how the action of each muscle may affect the acceleration of the joint and the link that it does not even span. The effects of dynamic inertial coupling on the utilization ratios require further investigation. Any of the aforementioned mechanisms could have led to underestimation of the maximum extensor strength. However, this is only the first attempt to provide motivation for establishing dynamically based utilization ratio, and much more detailed studies are needed to further delineate or validate this concept.

Use of Model in Simulation of Manual Lifting Tasks

Functional assessment of body motion and the evaluation of the kinetics and kinematics involved require the knowledge of the distribution of forces and torques for the various segments, joints, and soft tissues of the human body. Unfortunately, there is no direct method for measuring active muscle forces noninvasively, which makes biomechanical modeling a necessary tool that complements experimental studies. Biomechanical simulation takes the process a step further by providing indirect means of performing the kinematic and kinetic analysis without the need for extensive experimental data collection (18,24). In addition to providing a time- and cost-effective tool, biomechanical simulation provides a means by which one can answer "what if" types of questions. This is of great value in predicting the consequences of task modifications and/or workstation alterations without subjecting an injured worker or an individual with a disability to unnecessary testing.

Optimization techniques are being used to find the feasibility of a task performance, given the existing impairments and limitations on functional capacity, such as range of motion, strength, and speed (24). The results of these simulations can also be used as a biofeedback tool for training injured workers during rehabilitation and after their return to work. The functional capacity surfaces developed in this study will be useful as functional constraints on the dynamic joint strength limits. It is hoped that this would minimize the amount of experimental testing required, since the strength surfaces could be input into the optimization model in order to predict the performance of the individual on multiple tasks. According to Hsiang and Ayoub (18), the ideal joint strength limits should be predicted under dynamic conditions based on both the joint position and angular velocity instead of the traditional static regressions available. We are presently involved in simulation of lifting tasks similar to the one studied by (18,34) for further validation and illustration of these concepts.

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