Journal of Rehabilitation Research and Development
Vol. 40, No. 4, July/August 2003
Pages 337–348

Lower-limb extensor power and lifting characteristics in disabled elders

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Abstract—Few reports address lifting in disabled elders. Resistance training may facilitate function by improving coordination and muscular recruitment in common lifting tasks. Subjects were considered "functionally limited" if they reported a limitation in at least 1 of 9 possible functional areas listed on the Short-Form Health Survey physical function scale (SF-36), excluding the vigorous activity item. Eighty-nine functionally limited elders (60.3 to 89.8 years old) consented to participate in an intervention trial consisting of a 6-month in-home video-facilitated resistance exercise program using elastic bands. Biomechanical variables (leg extensor power, work, squared jerk), temporal outcomes (lift time and time to peak leg powers), and leg extensor strength were analyzed with the use of analysis of variance (ANOVA) between the (1) experimental group versus control group and the (2) subgroup of the weakest third of subjects (pretest leg extensor strength as percent of body weight [BW]). The experimental group had significant improvements in strength in knee extension (16.7%) and hip extension (20.5%). Resistance-trained weak subjects significantly increased hip extension strength compared to controls. A trend toward improved performance in lifting—decreased total lift time—was noted in the resistance-trained subjects. Significant correlations were found between total leg extension power, total leg extension strength, total work, and lift time. Resistance-trained disabled elders demonstrated strength benefits and several trends consistent with improved coordination and more efficient lifting. Leg-muscle power was related to better functional performance in lifting.

Key words: biomechanics, disabled elders, functionally limited elders, lifting, power, strength.

INTRODUCTION

Functional limitations are prevalent in the elderly [1–2]. The cause of sarcopenia, or decline in muscle mass with aging, remains unclear, and its role in disability is undetermined [3–4]. Schultz has suggested that most activities of daily living (ADLs) require only modest amounts of strength [5]. Muscle power may decrease even more quickly than muscle strength in the elderly [5]. Both Schultz and Bassey et al. contend that power may be a better measure of physical performance capacity, since it incorporates speed [5,6]. Several investigators have reported a relationship between leg power and functional performance such as chair rise and gait [6–9]. Other evidence suggests that strength may be related to functional performance in activities, such as gait, and that

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Abbreviations: ADL = activity of daily living, ANOVA = analysis of variance, BW = body weight, HHD = hand-held dynamometer, MANOVA = multivariate analyses of variance, SD = standard deviation, TRACK© = Telemetered Rapid Automatic Computerized Kinematic.

This material was based on work supported by grants from the National Institute of Health, R01-AG12561 and P50-AG11669, and the Arthritis Foundation.

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task-specific strength threshold values may exist [6–9]. Gill et al. noted that community-dwelling elders who were in the lowest half of timed functional performance in their cohort were at increased risk for future disability [10].

Strength and the Elderly

Strength training has been shown to be beneficial in both healthy and frail elders [4,11–16]. Although strength improvement has been linked to increases in walking velocity [7, 17], the relationship between strength gains and other functional improvement has been more difficult to establish. Brown et al. noted a significant relationship between summary lower-limb extensor strength score (normalized to body mass) and functional performance measures of preferred gait speed, chair rise, and walking a 12-foot obstacle course [18].

Several functional performance measures have been associated with prospective disability. Guralnik et al. studied summary performance prospectively among 1,122 community-dwelling elders [19]. Summary scores were constructed from three performance tests (standing balance, gait, and chair rise). These scores were found to be significantly related to disability at the 4-year follow-up. The authors concluded that lower-limb function predicted subsequent disability in the nondisabled elderly.

Positive health-status outcomes have also been associated with strength training in the elderly. Jette et al. completed a randomized control study with 215 functionally limited elders to study functional and health status outcomes following a strengthening intervention [16]. The exercise group demonstrated a statistically significant increase in lower-limb strength (range 6% to 12%) compared to nonexercise controls. Functionally, the exercise group had a 20 percent improvement in tandem gait steps. Physical disability also decreased 15 percent, and overall disability decreased 18 percent in the experimental group at 6 months posttest. Krebs et al. reported that even these modest strength improvements resulted in more stable walking patterns [20]. In the current study, isometric lower-limb hip and knee extensor strength was used to represent leg strength and was examined in relation to lifting performance.

Although much research has focused on strength, joint power may be an important factor in functional performance. Schultz noted that the performance of many daily activities do not require large joint torques [5], but rather may rely on the ability to develop joint torque rapidly. His overview of various studies demonstrates that healthy older adults generally have adequate joint torque needed for most ADL. However, he also cites work by various authors that illustrates age declines in the ability to develop joint torques rapidly, which can be of obvious functional consequence, particularly in activities requiring balance control such as lifting.

Lifting

Many different methods have been described to analyze lifting outcomes, but past interest has focused primarily on the spine and lower limbs [21–32]. Lifting per se may also be an important performance measure, and the effects of strength training may have important functional implications, particularly in disabled elders. Lifting requires multijoint coordination to lift a load while maintaining balance and stability to complete the task. Toussaint et al. noted that multijoint coordination was required to maintain balance in lifting [23]. Posture, balance control, and neuromuscular coordination are important factors to be considered in lifting, since they contribute to motor control. Hogan and Flash proposed that mean squared jerk represented the smoothness or “gracefulness” of movement and that this was a reasonable criterion function for volitional movement [33]. “Jerk” is defined as the rate of change of acceleration. Although strength would appear to be one requirement in lifting, efficiency of movement is often a goal in function; self-selected walking velocity is one example.

Boston et al. quantified coordination by documenting the relationship between time to hip and knee mid-range of motion to total range of motion or rise time [27]. Control subjects exhibited a coordinated lifting pattern where the hip and knee joint completed their rotations at the same time, whereas knee motion terminated before hip motion in subjects with low back pain. The authors considered this latter pattern to be uncoordinated.

Recently, Puniello et al. studied lifting characteristics in functionally limited elders [9]. They reported a positive correlation between trunk angular momentum to hip torque and to hip plus back torque. Hip strength and hip plus knee strength were found to be correlated to hip torque, back torque, and hip plus back torque. In addition, a positive correlation was noted between initial momentum in lifting and momentum in chair rise, while a negative correlation was reported between lifting momentum and free speed gait.

Many researchers have studied the biomechanics of various lifting tasks. However, few studies have focused on the elderly, especially elders with functional limitations. Little research has investigated the role of lower-limb power in disabled elders. Recently, Puniello et al. identified differences in leg power (ankle plantar flexor power) that distinguished between the gait of healthy versus functionally limited elders [9].

The relationship between strength and functional improvement has often been elusive. Power may be an important factor in functional performance, since it incorporates speed. In this study, power is the product of joint torque and joint angular velocity during a common lifting task. Prior studies have not examined the relationship between strength training, leg power, and timing or coordination outcomes in lifting in functionally limited elders. Lifting may be a valuable outcome performance measure in the elderly. Resistance training may facilitate function by improving coordination and muscular recruitment in common lifting tasks. This study (1) determined the effects of resistance training on outcome measures of coordination in lifting in functionally limited elders and (2) investigated the role of leg extensor power in functional lifting in disabled elders.

The hypotheses were that resistance training would result in changes in the pretest-posttest lifting characteristics of functionally limited elders as indicated by—

1. A significant posttest decrease in the rate of change of acceleration of the box (peak squared jerk), during the initial period of lifting the box from the floor to knee height in the experimental group as compared to the control group [33].
2. A significant difference in vertical lift time between weak subjects who underwent strength training as compared to those who did not.
3. Improved muscular coordination at the hip and knee joints as measured by a shorter time to peak hip power and peak knee power and a decreased time period between these two peaks at posttest [27].
4. A significant decrease in posttest vertical total lift time in subjects with a significantly increased total lower-limb power score (summary score for hip extension and knee extension power during lifting).

METHODS

Subjects

The parent population for the present data consisted of 120 community-dwelling volunteers with at least one functional limitation who were enrolled in a separate study to investigate the effect of strength training on functional limitations and disability status [16]. The parent group was randomized into an experimental group who participated in a home-strengthening exercise program and a control group that continued with their normal routine. Jette et al. and Duncan et al. have previously reported the disability status for these subjects [16,34]. Disablement terminology used in the current study is consistent with the generally accepted terminology from the World Health Organization (WHO) and the International Classification of Impairments, Disabilities, and Handicaps (ICIDH), whereby functional impairments are believed to lead to disability in life roles, such as work or leisure activities [34]. Subjects in this study were considered "functionally limited" as defined by reporting a limitation in at least one of nine possible functional areas listed on the Short-Form Health Survey physical function scale (SF-36), with the exclusion of vigorous activity [16]. Approximately half of the subjects (56%) reported three or more limitations, while the other half reported one to two limitations. One hundred six subjects participated in the pretest lifting task, and of these, eighty-nine elders met all the inclusion criteria and had two complete trials of both pretest and posttest data. The study group consisted of these 89 elders. Most subjects had several comorbidities but were assigned primary diagnoses, which were considered to be most related to their functional limitations. Of these 89 elders, 27 had a primary diagnosis related to decreased strength or disuse, 20 subjects had a primary cardiopulmonary or circulatory diagnosis, 18 had a joint-impairment-related diagnosis (such as arthritis, bursitis, or joint replacements), and 7 had back-related diagnoses. Nine subjects had peripheral neurological problems, such as neuropathy or diabetes, and only one subject had a central neurological problem (cerebrovascular accident [CVA]) as the primary diagnosis. The remaining seven subjects mainly consisted of individuals with general shortness of breath, vision deficits, or behavioral problems (such as depression or fear of falling). Inclusion criteria for this study were that subjects were at least 60 years old, ambulated independently with or without an assistive device, had intact cognition, had the presence of at least one functional limitation, and had permission of the primary care physician. Exclusion criteria included failure to pass an exercise tolerance test, unstable medical status, severe neurologic disease, significant cardiac disease, or presence of rheumatoid arthritis. The subjects' physicians provided the medical information. All subjects signed informed consent forms that were approved by the institutional review board. The sample consisted of 62 female and 27 male subjects with a mean age of 74.4 ± 6.7 years old (range 60.3 to 89.8 years old). Subject characteristics are summarized in **Table 1**. There were no statistical differences between the control and experimental groups in subject characteristics of age, height, weight, or strength at baseline.

Since subject randomization was performed on the parent population of 120 elders, the lifting subgroup resulted in an uneven number of subjects in the lifting exercise and control groups. The distribution by gender was also unequal, but these were the available data for lifting task analyses (**Table 1**). The experimental group consisted of 39 elders who participated in a 6-month video-facilitated home-strengthening program [16,20]. The exercise intervention consisted of a 35 min. videotaped program that the subjects were to perform at least three times a week. The entire program consisted of a strength component of 11 exercises with the use of elastic bands and lasting 25 minutes. There was a 5 min. warm-up and cooldown period of active range of motion. The strengthening exercises were performed in a seated and standing position and incorporated upper-limb and lower-limb resistance training with Theraband™ in modified proprioceptive neuromuscular facilitation (PNF) patterns. Subjects were instructed to proceed to the next level of Theraband resistance after they could perform 10 repetitions of each exercise without significant fatigue. There were nine different levels of resistive bands. The control group had 50 subjects who were instructed to continue their normal daily routine. All lifting measurements were taken with the investigators blind both to experimental group and to strength data.

Instrumentation

Four SELSPOT® II cameras collected kinematic data, and two Kistler™ piezoelectric forceplates recorded ground reaction forces. Kinematic and kinetic data were sampled at 150 Hz, and each lifting trial was sampled for 7 s. The cameras tracked the movement of 64 infrared light-emitting diodes, three to five per array. The arrays were secured to 11 body segments: both feet, shanks, thighs, arms, pelvis, trunk, and head. In addition, the box had one array, located on the left side of the box, 12 cm from the top of the box [9,35]. Kinetic and kinematic data collection details are provided by Riley et al. and Krebs [36,37]. The box was a square plastic case, 33 cm in width and length and 28 cm in height, and was lifted with the use of two side handles located 7 cm from the top of the box. A 4.55 kg disk-shaped weight was placed on a lightweight aluminum pole in the center of the box, providing a total mass of 5 kg for the lifting task. Box movement was measured from displacement of the center of the attached array [9,35].

Telemetered Rapid Automatic Computerized Kinematic (TRACK©) software was used to obtain and analyze kinematic data. Array-to-body segment relationships were determined with a standardized procedure, a "pointing trial," which was done before the lift testing [36]. Each segment was modeled as a rigid body with 6 degrees of freedom (three translations and three rotations) [36].

The precision of the array positions was previously determined to be <1 mm for linear displacement and <1° for angular displacement and <1 percent of full scale for the force plates [38]. All kinematic data were low-pass filtered at 6 Hz [39]. Inertial parameters for each body segment were derived from regression equations [35,40,41]. We used estimated body segment masses and center of mass velocities to calculate joint torques, using Newton-Euler inverse dynamic method [35,41]. We calculated powers by multiplying the joint torque by angular

Table 1.
Subject pretest characteristics.

Subjects	Sex (M = male, F = female)*	Age (yr)	Height (m)	Weight (kg)	BMI (kg/m^2)	Knee Plus Hip Extension Strength (kg)
Control, n = 50	M = 9, F = 41	73.64 ± 5.89	1.62 ± 0.09	73.05 ± 13.18	27.91 ± 4.66	26.06 ± 8.06
Experimental, n = 39	M = 18, F = 21	75.31 ± 7.68	1.65 ± 0.09	73.63 ± 13.50	27.07 ± 4.23	27.09 ± 8.08
Total, n = 89	M = 27, F = 62	74.37 ± 6.74	1.63 ± 0.09	73.30 ± 13.25	27.55 ± 4.47	26.51 ± 8.04

*$p < 0.05$
BMI = body mass index

velocity, i.e., the first derivative of the angular displacement. The integral of the power curve from initiation of the lift through the maximum vertical box displacement was used for the calculation of the work.

Pretest and posttest isometric hip and knee strength measurements were made with a Nicholas hand-held dynamometer (HHD) (Lafayette Instruments, Lafayette, Indiana) with the use of a standardized protocol [9,16,20].

Procedures

Subjects performed the lifting task (**Figure 1**) from a standing position and were required to be in shorts and barefoot so that the arrays remained secured and were easily visible. The box was placed on the floor in front of the each subject, with the box corners located just medial to the distal end of the first metatarsal of each foot. The feet were positioned at the posterior of the corresponding left-right force plate with the heels 30 cm apart, measured at midcalcanei. Subjects were required to maintain the original starting position of the feet throughout the lift, but otherwise the lift was unconstrained. The box was lifted onto a 94 cm (37 in.) high table located 3 cm in front of the box. Standardized verbal instructions were given to the subject: "Lift this 10 lb box any way you like to the table in front of you. Begin after I say, '1-2-ready-go.'" One practice trial was performed followed by two trials where data were collected. A third trial was performed if data acquisition was inadequate for either of the prior two trials.

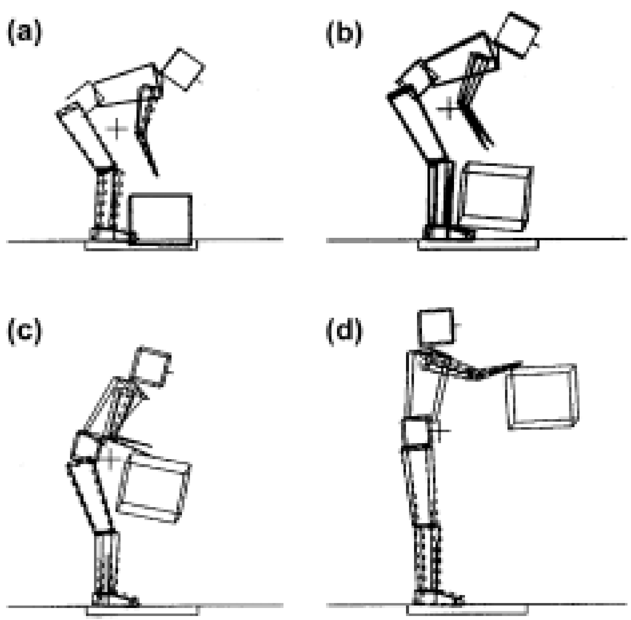

Figure 1.
Sagittal view of lifting task depicted by 3D-wire model. Model depicts four stages of vertical component of lifting task. Left limbs are represented by a solid line and right limbs by a dashed line. **(a)** Lift initiation: Defined as the time at minimum body vertical center of gravity displacement, **(b)** box at knee height, **(c)** mid-lift time (of vertical component of lift), and **(d)** end of vertical component of lift defined by maximum box vertical displacement.

Hip and knee extension isometric strength measurements were obtained at the subject's home. Subjects were tested within 2 weeks of the lifting trials. Test positions and rest periods were standardized. The examiner held the HHD stationary while the subject exerted a maximal force against it ("make test"). A maximum volitional 3 s isometric contraction was used. One practice trial was allowed followed by two recorded trials for hip extension and knee extension strength. For hip strength testing, the subject stood at 10° of hip extension. For the knee, the subject was seated at 60° of knee flexion. Two experienced physical therapists performed all strength testing. The right side was tested for most subjects, but the left side was tested in 12 subjects because of right-side pathology. Previous research has established good test-retest reliability (Pearson correlation 0.97 to 0.98, $p <$ 0.01) and interrater reliability (correlation coefficients 0.84 to 0.94, $p < 0.001$) for HHD [42,43]. The correlation coefficient for interrater reliability for strength testing was between 0.50 (knee extension) and 0.98 in the current study [44]

Data Analysis

Means and standard deviations (SDs) were used in descriptive analyses of subject characteristics. Multivariate analyses of variance (MANOVA) were used to examine pretest differences in subject characteristics between the control group and experimental group. One-way analysis of variance (ANOVA) was used to compare pretest with posttest values for mean strength and the lifting task temporal and kinetic variables. Significant ANOVA results were further analyzed with pairwise comparisons using Tukey's least significant difference (LSD). The significance level was set at 0.05. All statistical data analyses were performed with SPSS software (SPSS Inc., Chicago, Illinois). Relationships between scores for total power, total work, total strength (knee and hip extension), and lift time were analyzed with the use of Pearson correlation analysis.

We used the mean of two trials for all outcome variables. Strength was measured for hip extension and knee extension in kilograms (kg). Total strength was the sum of hip and knee extension scores. Lifting variables consisted of total lift time or the total vertical lift time (seconds) from the floor to the maximum vertical box displacement, the time (seconds) to lift the box from the floor to knee height, and the time (seconds) from knee height to maximum vertical box displacement. Integrated squared jerk (cm^2/s^7), a measure of smoothness of the lift [33], was calculated at lift initiation (**Figure 1**). Mean peak knee and hip nonrectified power (%BW∗m/s) (BW = body weight) and the time in seconds from lift initiation to these peaks were also recorded. Total power was the combination of knee and hip extension power. We calculated total work (%BW∗m) by taking the integral of total rectified power (knee extension plus hip extension) during the total lift time.

We examined outcome measures by evaluating the change between subject groupings based on the research hypotheses. First, the control group was compared to the experimental group. Next, we subdivided the study group into third's using pretest total strength scores (knee plus hip extension strength in %BW) to analyze the weakest subjects ($n = 30$, $c = 19$, $e = 11$) to compare changes in outcome measures for the weakest pretest experimental subjects to their control counterparts. Pearson correlations were done to test the hypothesis that greater leg power during lifting was related to better outcome times in lifting.

RESULTS

No significant difference was found in pretest strength scores between the control group and experimental group as determined by MANOVA. Overall, the subjects performed 89 percent of the recommended exercise sessions. We found a 16 percent relative dropout rate when considering the initial group of 106 eligible subjects, since only 89 subjects had complete pretest and posttest strength and lift data for analysis. No serious injuries or medical complications occurred because of the exercise intervention.

Experimental Group (Resistance-Trained) Versus Control Group

Experimental subjects demonstrated significant increases in knee extension strength (mean increase of 16.7% over baseline) ($p = 0.014$) and hip extension strength (mean 20.5%) ($p = 0.033$) compared to controls (**Table 2**). Experimental subjects demonstrated a trend of increased combined knee plus hip extension strength (total strength) compared to control subjects ($p = 0.056$). Though the finding was not statistically significant, experimental subjects demonstrated trends for reduced change scores for lift coordination measures of mean peak squared jerk (–118%) (**Table 3, Figure 2**), and the time between mean peak knee and hip extension power (–24%) (**Table 3, Figure 2**), while both of these outcome variables increased for the control subjects (+40% and +18%, respectively) (**Table 3**).

Although we hypothesized that the change in total lift time would be significantly reduced for the weakest subjects who underwent strength training as compared to their control counter parts, the only significant differences between these groups were in the strength variables. Subgroup analyses of the pretest weakest 30 subjects (knee plus hip extension strength as %BW) demonstrated a significant ($p < 0.05$) change in hip extension strength in weak subjects who underwent strength training compared to their weak control counterparts. Mean change in hip extensor strength

Table 2.
Strength changes. Experimental subjects demonstrated improved knee and hip extension strength after resistance training.

Subjects	Knee Extension Strength	Hip Extension Strength
Control, n = 50	0.42 ± 3.72 (kg)* 0.65 ± 5.31 (%BW)	0.94 ± 3.53 (kg)* 1.32 ± 5.19 (%BW)
Control, % Change from Pretest Strength	+2.9%	+8.3%
Experimental, n = 39	2.44 ± 4.03 (kg)* 3.51 ± 5.82 (%BW)	2.56 ± 4.47 (kg)* 3.46 ± 5.85 (%BW)
Experimental, % Change from Pretest Strength	+16.7%	+20.5%

*$p < 0.05$

Table 3.
Temporal, power, work, and squared jerk changes prepost intervention ($p < 0.05$). A trend for improved lifting coordination was found in experimental group, which is indicated by a reduction in mean peak squared jerk, while control group had a mean increase in mean peak squared jerk value [33]. This is also indicated by experimental group's reduction in time between peak knee and peak hip extension, while control group demonstrated an increase in this temporal outcome measure [27].

Subjects	Time Between Peak Knee and Peak Hip (s)	Total Lift Time (s)	Total Power (%BW∗m/s)	Total Work (%BW∗m)	Squared Jerk (1,000 cm^2/s^7)
Control, n = 50	0.03 ± 0.39	–0.09 ± 0.51	1.40 ± 6.54	–0.11 ± 3.40	382.4 ± 1223.8
Control, % Change from Pretest	+18%	–5.2%	+8.1%	–1.1%	+40%
Experimental, n = 39	–0.04 ± 0.26	–0.18 ± 0.42	2.31 ± 5.35	–0.27 ± 1.47	–1083.7 ± 13445.0
Experimental, % Change from Pretest	–24%	–10.1%	+12.0%	–2.5%	–118%

was 5.3 kg ± 4.9 kg (mean 65.4%) for the (pretest weak) experimental group and 1.6 kg ± 3.5 kg (mean 19.2%) for the (pretest weak) control group. Total mean change in knee plus hip extension strength was 12.5 kg ± 10.7 kg for the (pretest weak) experimental group and 3.7 kg ± 8.3 kg for the (pretest weak) control group. As with most of the outcome measures, the SDs were large. No significant differences were found for the lifting outcome variables for these weak subjects, but resistance-trained subjects did reduce total lift time by 14.5 percent (mean –0.270 s), as compared to a 6.9 percent (mean –0.134 s) reduction in lift time for the control subjects. Resistance-trained weak subjects also demonstrated a small 2.2 percent (mean –0.005 s) reduction in time between hip and knee peak powers, while their control counterparts had a 30.4 percent increase in this time period (mean 0.040 s).

Lower-Limb Extensor Power and Lifting

Pearson correlation between lifting change scores for total lower-limb extensor power (knee plus hip extension), total lift work, total lower-limb extensor strength (knee plus hip extension), and total lift time revealed significant fair positive correlations for work and strength (kilogram) ($r = 0.27$, $p = 0.01$) and work and total lift time ($r = 0.27$, $p = 0.01$), and as expected, correlation between work and total leg extensor power ($r = 0.63$, $p = 0.01$) was moderate. Total lift time had a small correlation to hip-knee time ($r = 0.22$, $p = 0.05$). When examined by group, control subjects demonstrated fair positive correlations between: total leg power to squared jerk ($r = 0.28$, $p = 0.05$), total lift time to hip-knee time ($r = 0.38$, $p = 0.01$), total lift time to total work ($r = 0.39$, $p = 0.01$), total leg extensor strength to total work ($r = 0.43$, $p = 0.01$), a good positive correlation between total leg power and total work ($r = 0.73$, $p = 0.01$), and a small negative correlation between total leg extensor strength and squared jerk ($r = –0.25$, $p = 0.05$). Resistance-trained experimental subjects demonstrated moderate to good negative correlations between total leg power to total lift time ($r = –0.50$, $p = 0.01$), total leg power to hip-knee time ($r = –0.60$, $p = 0.01$), and a fair positive correlation of total leg power to total work ($r = 0.37$, $p = 0.01$).

DISCUSSION

Biomechanical outcomes of functional lifting in resistance-trained disabled elders have not been previously reported. Strength training has been shown to be beneficial in both healthy and functionally limited elders [4,11–16]. Subjects in this study were functionally limited elders who underwent a home-strengthening exercise program. Hip and knee extension strength increased significantly for the experimental group compared to the control group, but no significant group differences were detected for outcome measures of lifting. These results may be confounded by some observed strength gains that were made in the control group (**Table 2**), a possible behavioral effect of being included in a study (Hawthorne effect). Results also may have been affected by the unequal distribution of men and women in the control and exercise group (**Table 1**). Also, a learning effect could have been possible with strength testing. Buchner and de Lateur cite examples of this phenomenon in their review of muscle strength and function in the elderly [3].

Prior research has noted 6 to 12 percent gains in strength and found that the weaker subjects made greater strength gains in a similar group of disabled elder subjects [16]. These subjects exhibited a statistically significant decrease of 15 to 18 percent in physical disability status and overall disability after 6 months of a home

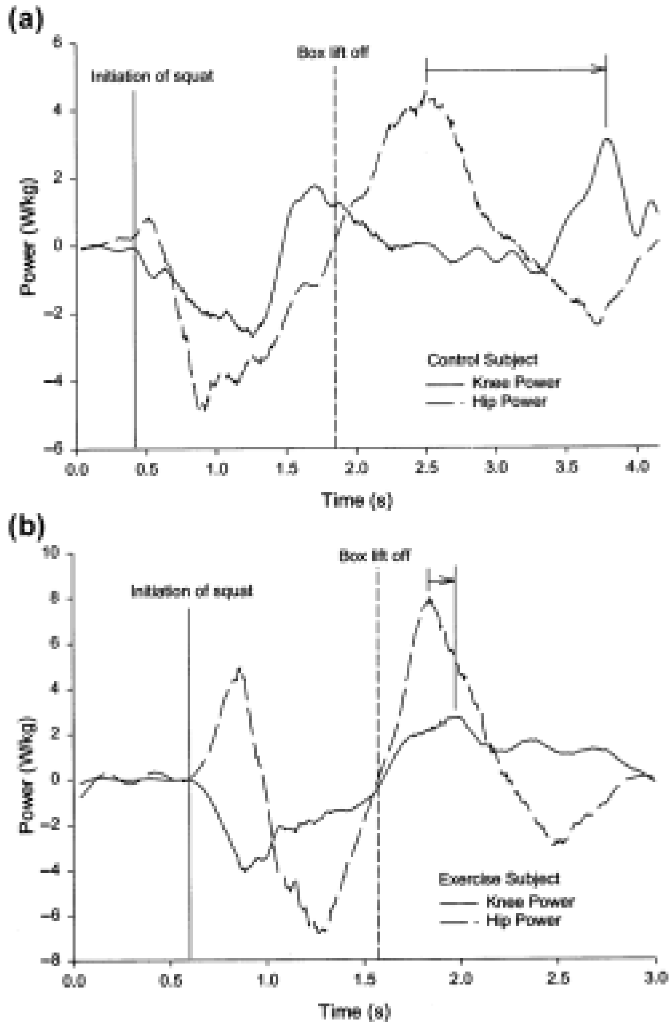

Figure 2.
Posttest power profiles during lifting, illustrating time between peak hip and knee power (defined by peak-to-peak arrow). The period depicted is from initiation of squat to end of lift. **(a)** Control subject with an increased time between peak hip and knee time, representing mean trend seen in control subjects at posttest. **(b)** Power profile of an exercise subject who demonstrates improved coordination of lift, indicated by convergence of peak hip and knee times, illustrating mean trend seen in posttest exercise subjects.

strength-training program. Strength gains of up to 174 ± 31 percent have been reported for impaired institutionalized elders [11]. In the current study, the resistance-trained elders demonstrated a 16.7 percent increase in knee extension strength and a 20.5 percent increase in hip extension strength that compare favorably to strength gains made by similar subjects in the literature.

Research has suggested that specific functional tasks may have important minimum levels of strength or thresholds [3,6–9,11,12,18]. Krebs et al. reported more stable walking patterns in a similar group of elderly subjects who underwent resistance training [20]. Puniello et al. reported a curvilinear increase in gait speed with an increase in combined knee plus hip strength that leveled off above an absolute value of 30 kg [9]. The subjects in our study had somewhat lower initial leg extension strength (knee plus hip) with a range from 18 kg to 35 kg (mean 26.51 kg ± 8.04 kg) (**Table 1**). The mean increase in leg extension strength for the resistance-trained elders was 2.56 kg ± 4.47 kg (**Table 2**). Lifting inherently requires additional strength than walking. In lifting, one must move the body's own mass against gravity while using muscular coordination to maintain balance and control. Possibly, the intensity of exercise in this study may not have been adequate to improve lifting performance. Nine different resistance levels of exercise bands were available, but exercise subjects achieved only a 3.4 ± 1.51 level of change at the 6-month posttest. Thus, the exercise stimulus may not have been adequate to obtain a statistical difference in lifting times between the control and exercise groups. However, as noted, trends for improved coordination and likely efficiency of movement were consistent for the exercise group over the control group (**Table 3, Figure 2**).

Subjects performed an unconstrained lift, although the load and the start and end positions of the lift were controlled. Thus, a variety of lifting techniques was possible (e.g., back lift, leg lift, or a combination of these) that may have contributed to lack of significant timed lifting outcome results between the control and experimental groups in this study.

Prior researchers demonstrated the importance of hip and back strength when lifting objects below the waist and of shoulder strength when lifting above the waist [45]. Expanding the scope of the present analysis to include other musculature in the total strength variable may have been beneficial; such as lower-limb hip abductor strength and upper-limb shoulder strength. Brown et al. noted a significant relationship between summary lower-limb extensor strength score (normalized to body mass) and functional performance measures of preferred gait speed, chair rise, and walking a 12-foot obstacle course [18]. Hip abductor strength may have been an important strength variable in lifting for these disabled elders, given its role in pelvic stabilization. In addition, the role of the back and trunk was not considered in the current study.

Puniello et al. reported differences in velocity profiles among disabled elders when performing a functional lifting task [9]. They found that stronger subjects (hip, knee, and shoulder musculature) had a more unimodal box velocity profile, while weaker subjects tended to have a bimodal velocity profile, which they hypothesized to be less well-coordinated. Weaker subjects were also found to use less peak momentum. Scarborough reported a similar finding in a correlational analysis of chair rise [46]. Puniello et al. concluded that weaker disabled elders used a more conservative and stable lifting strategy then their stronger counterparts [9].

Consistent with the hypothesis of smoother or improved coordination of lifting, experimental subjects demonstrated several interesting trends, including outcome scores which demonstrated a decrease in mean peak squared jerk (–118%), a reduction in the mean time between peak knee and peak hip power (–24%) [27], and a small reduction in mean total lift work (–2.5%). Control subjects, on the other hand, demonstrated trends consistent with poor coordination of movement including an increase in mean peak squared jerk (+40%) and an increase in the time between peak knee and peak hip extensor power during lifting (+18%) (**Table 3**). Although both control and experimental subjects exhibited small reductions in the other timed lift variables, reductions for experimental subjects were greater, consistent with a trend toward improved functional outcome. For example, reductions in lift time for experimental subjects were approximately three times and two times those of control subjects for the second part of the lift and for total lift time, respectively. The large variability in this population may have confounded significant findings.

The elderly have been noted to have reduced cross-sectional muscle area with the question of selective atrophy of type II, fast-twitch, muscle fibers raised by some researchers [47–49]. As hypothesized, total leg extensor power was significantly correlated to decreased total lift time, implying better muscular performance and functional ability. The ability to recruit musculature, in particular fast-twitch muscle fibers, in a more timely fashion, may have contributed to this finding.

Just as gait speed is considered an important functional outcome measure, improvement in temporal measures in other functional activities likely have similar clinical relevance [10]. As we mentioned earlier, Guralnik et al. prospectively studied summary performance measure scores in 1,122 community-dwelling elders and found summary scores of three performance tests (standing balance, gait, and chair rise) to be significantly related to disability at 4-year follow-up [19]. They concluded that lower-limb function predicted subsequent disability in the nondisabled elderly.

Mechanical work during the lift revealed a trend of a mean decrease in work for the experimental subjects (twice that of the control subjects). A reduction in lift work may indicate that the experimental subjects were more efficient in lifting. In a correlational analysis of lifting in functionally limited elderly, Puniello et al. noted that disabled elders performed excessive vertical displacement consistent with excessive work when lifting a box to a tabletop [9]. This “overshoot” may also indicate poorer motor control.

Of note, a small positive posttest correlation was found between total lift work and total leg extensor power. Quite possible, subjects with more leg power may use a leg lift type of strategy, which would result in more work. The significant correlation between posttest scores for work and leg extensor power, work and total leg extensor strength, and work and decreased total lift time would support this explanation. Past researchers have noted the importance of quadriceps muscle strength when performing a leg lift [22].

Poor ability on performance testing has been associated with future decline in function. Future research may find a similar relationship between functional lifting and future disability and thus target elders at risk for earlier intervention to prevent such declines.

Sarcopenia and decline in function are prevalent in the elderly. The performance of daily tasks may require minimum strength thresholds. Coordinated muscular recruitment is important to successful task performance and movement efficiency. When subjects perform strength training, the intensity of the effort should be considered. Exercise programs for the elderly should incorporate power and be prescribed in terms of speed, hold times, and load to optimize functional outcomes. Impairments that have developed over time may take longer to rehabilitate, but these data suggest elders do possess the potential for lifting improvement. Lifting strategies in the disabled elderly and coordination of movement deserve further investigation. Future intervention trials should focus on the role of leg extensor power and its relationship to functional outcomes in lifting.

CONCLUSIONS

In summary, we found—

- Knee and hip extension strength increased significantly after resistance training in functionally limited elders.
- Weaker subjects who underwent strength training significantly increased hip extension strength over their control counterparts.
- Resistance-trained subjects demonstrated several trends consistent with improved coordination in lifting [8,9,25,27,33], including a reduction in squared jerk and a decreased time between peak knee and peak hip power times, while the control group had an increase in both of these values. These trends are consistent with the hypothesis of smoother movement and improved muscular coordination after strength training.
- Leg muscle power appeared to be related to better functional performance and coordination in lifting as indicated by the significant correlations between total leg extensor power and other outcome measures of lifting, including total lift time and time between peak hip and peak knee extension powers.

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Submitted for publication August 7, 2002. Accepted in revised form February 13, 2003.