

# Explosive Force Production in Older Adults Following a Traditional Strength Training Program

James W. Bellew, EdD, PT,<sup>1</sup> J.W. Yates, PhD, FACSM,<sup>2</sup> David R. Gater, MD, PhD,<sup>3</sup> Jody Clasey, PhD, FACSM<sup>4</sup>

<sup>1</sup>Assistant Professor, Louisiana State University Health Sciences Center, Program in Physical Therapy, School of Allied Health Professions, Shreveport, LA

<sup>2</sup>Associate Professor, Director of Exercise Physiology Lab, University of Kentucky, Department of Kinesiology and Health Promotions, Lexington, KY

<sup>3</sup>Associate Professor, Department of Physical Medicine and Rehabilitation, Director of Spinal Cord Injury Medicine, University of Michigan, Ann Arbor, MI

<sup>4</sup>Assistant Professor, University of Kentucky, Department of Kinesiology and Health Promotions, Lexington, KY

## ABSTRACT

**Purpose:** Age-related loss and atrophy of fast-twitch muscle fibers was associated with decline in explosive force production (EFP). Strength training with explosive and rapid muscle contractions has shown promise for increasing EFP in older adults. Current exercise recommendations for untrained older adults from the American College of Sports Medicine and Surgeon General do not include such activities. Using current strength training guidelines for older adults, we examined the effect of a 12-week strength training program on EFP. **Methods:** Subjects were 22 men and women (67.7±5.5 years) who participated in a 12-week strength training program and 5 men and women who served as controls (67.4±7.3 years). Maximal isometric strength (MVC) of the quadriceps and EFP (time to reach to 30, 60, and 90% of MVC) were recorded before and after training. **Results:** A significant 13% increase in strength was observed in the exercise group with no change in the control group. Explosive force production was unchanged in either group. **Conclusions:** Strength training consistent with current recommendations for older adults is an efficacious means of increasing strength in healthy, community-dwelling older adults but does not improve their ability to generate force quickly.

*Key Words:* strength, power, aging, training

## INTRODUCTION

The process of aging results in numerous nonpathological changes including loss of muscle mass, strength, and ability to generate force quickly.<sup>1-3</sup> Previous investigators have shown that much of the decline in mass and strength is the result of atrophy and loss of skeletal muscle fibers.<sup>4-6</sup> Furthermore, a disproportionate amount of atrophy and loss in the largest

and fastest conducting motor units and type II fibers is supported by recent data.<sup>5-7</sup>

Structural changes such as fast-twitch fiber loss and atrophy are not, however, without functional consequences. While aging is associated with loss of strength and endurance, the ability to generate muscular force quickly appears to decline to a greater extent than maximal strength with increasing age.<sup>8-10</sup> Investigators studying age-related declines in explosive force production (EFP) have shown that there is a more significant reduction in muscles possessing predominantly fast motor units<sup>11</sup> and that speed of contraction is inversely proportional to the percent area distribution of slow-twitch fibers.<sup>10-13</sup>

The slowing of EFP has significant functional consequences. The rapid development of force, especially in the anti-gravity muscles of the lower extremity, contributes to many tasks of daily living such as stair climbing, walking, and even fall prevention.<sup>14,15</sup> More recently, however, investigators have shown that age-related declines in EFP are more apparent when assessing force production to submaximal levels rather than maximal levels of force.<sup>1,2</sup> Since humans very seldom require maximal force in daily life, this greater time to achieve submaximal levels of force may underlie much of the declining functional ability of older adults.

Research over the past 20 years has shown that the response of older adults to strength training is similar to that of younger individuals.<sup>16,17</sup> Assertions that strength training may improve or attenuate the decline of EFP seen with aging are supported by recent data.<sup>7,18-20</sup> However, reports of training-induced increases in EFP in older subjects have included activities of a fast, explosive nature performed as fast as possible. The effectiveness of traditional resistance training programs has been questioned since these protocols, advocated for use in untrained older adults, do not include fast, explosive activities.

Resistance training guidelines for untrained old, very old, and frail old adults from the American College of Sports Medicine,<sup>21,22</sup> Surgeon General's Report,<sup>23</sup> and experts in the area of resistance training<sup>24,25</sup> do not include rapid, explosive activities but rather recommend exercises performed "slowly through a full range of motion."<sup>25</sup> The extent to which resistance training of this type affects EFP is unclear. The question remains whether traditional resistance training, often used in clinical settings and independent exercise programs to increase strength and functional ability, yields improvements in EFP. Thus, it was the intent of this investigation to examine the effects of a 12-week traditional strength training protocol on EFP in untrained older adults. Based on previous literature, it was hypothesized that a strength training program consistent with current guidelines for older adults would result in increased quadriceps strength without concomitant improvements in EFP.

Address correspondence to: James W Bellew, PT, EdD, Louisiana State University Health Sciences Center, Program in Physical Therapy, School of Allied Health Professions, 1501 Kings Highway, P.O. Box 33932, Shreveport, LA 71130. Ph: 318-675-6821, Fax: 318-675-4208 (jbelle@lsuhsc.edu).

## METHODS

### Experimental Design

A pretrial post-trial control group design was used. Measurements included maximal voluntary isometric strength (MVC) and EFP of the quadriceps before and after 12 weeks of strength training. All subjects participated in a pretesting familiarization session 48 hours prior to data collection to introduce each to the methods of testing.

### Subjects

Subjects were living independently, self ambulatory, and healthy, having no known neuromuscular, muscular, neurologic, orthopedic, cardiac, or any other chronic debilitating condition in which exercise would be contraindicated. Those with a known history of uncontrolled hypertension, diagnosed osteopenia or osteoporosis, transient ischemic attacks, stroke, and/or congestive heart failure, or currently on anti-coagulation therapy were excluded. Likewise, subjects with a history of hip fracture, knee osteoarthritis, of knee replacement were excluded. No subject had been involved in any form of strength training for at least 10 years and none was participating in any exercise beyond walking.

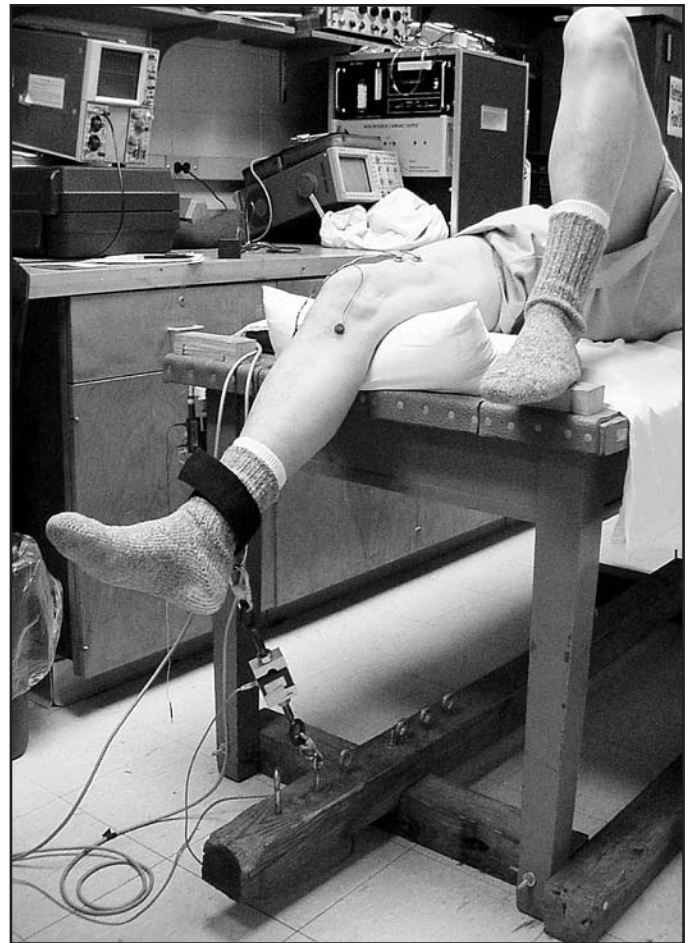
The study was approved by the Institutional Review Board of the University of Kentucky. Thirty-two subjects who volunteered underwent a physical examination and graded exercise test (modified Balke treadmill protocol) under the supervision of a physician (DRG). Of these 32 subjects, 27 met the criteria for inclusion. The experimental group consisted of 11 males and 11 females ( $67.7 \pm 5.5$  years; range 59-83). A control group of 3 females and 2 males ( $67.4 \pm 7.3$  years; range 58-76) participated in data collection but not in strength training. To contend with attrition rates of up to 40% commonly reported in training studies, randomization of subjects was not done, thus subjects were recruited with prior knowledge of whether they would be included in the exercise or non-exercise control group.<sup>26</sup>

### Maximal Voluntary Isometric Strength and Explosive Force Production

All data were obtained at 0 and 12 weeks from the quadriceps-femoris of the self-reported dominant limb. Three MVC knee extension trials were performed and maximum force was expressed relative to body weight (Newtons per kilogram). The EFP measurements were determined from the same MVC trials. Prior to testing, each subject participated in a warm-up of lower extremity stretches and marching in place for 2 minutes.

Strength was measured using an Interface SM-1000 load cell (S/N C65680) connected to a Grass P511 strain-gauge amplifier in series with the Bio-Pac Data Acquisition System. Data were stored by the Bio-Pac Data Acquisition System after converting the analog signal to a digital signal with a 12-bit A-D board. The resolution of this method of strength testing was calculated to be 0.13 lb. Weekly calibrations were conducted to maintain an error of less than 1%.

Subjects were positioned supine on a padded table with the tested limb positioned with the knee joint resting on the edge (Figure 1). The nontest limb was flexed 45° at the hip and



**Figure 1. Test position for isometric knee extension.**

90° at the knee with the foot resting flat upon the table. The load cell was connected in series with a variable length chain adjusted to allow 35° of flexion in the tested knee. Subjects were instructed to fold their arms across their chests with their head resting on a pillow. A non-elastic Velcro ankle strap was used to connect the lower leg to the chain in series with the load cell and was positioned to maintain a 90° angle of orientation between the load cell apparatus and the leg (see Figure 1).

Subjects performed 2 submaximal practice repetitions at an intensity self-estimated to be 50% of their maximum. Testing began by passively positioning the subject's knee to the test angle of 35° flexion to remove any slack in the chain. Upon a verbal signal to start, subjects extended their knee as quickly and as forcefully as possible for 3 to 4 seconds. Strong verbal encouragement was given during each repetition. Ninety seconds of rest were given between each repetition. Three maximal test repetitions were performed and MVC strength was defined as the single repetition with the greatest force.

Force data were recorded at 1000Hz permitting examination in one millisecond increments. The variable EFP was expressed as the time, in milliseconds, required to reach specific force levels corresponding to 30%, 60%, and 90% of maximal force.<sup>1,2</sup> To eliminate the effects of pretension in the test system, the time intervals to reach each force level were calculated from an onset level of 10% of maximal force.<sup>1,2</sup> Explosive force production at each force level was defined as

the first data point that met or exceeded that specified level of force, ie, the time at which force was equal to or greater than the specific submaximal percentage.

### Training Program

The strength training protocol used in this investigation was designed according to current guidelines for use in untrained older adults.<sup>21-25</sup> A single set of 8 to 12 repetitions to volitional failure was performed. Volitional failure was defined as the point at which the subject could no longer complete a repetition through the entire range of motion. When the subject was able to complete more than 12 repetitions at the specified weight, the resistance was increased so that the subject was able to complete approximately 8 but no more than 12 repetitions at the next session. If less than 8 repetitions were performed, the weight was returned to the preceding weight until the subject completed at least 8 times at that weight. A minimum of 90 seconds was allowed between exercises. The complete protocol involved 5 exercises—supine bilateral leg press, seated bilateral knee extension, seated horizontal chest press, seated rowing, and seated latissimus pull-downs.

Subjects exercised 2 sessions per week for 12 weeks with 48 hours between sessions. Prior to each session, subjects engaged in basic callisthenic and stretching exercises. The first 2 weeks of training were designed to be an introductory period in an effort to minimize the incidence of injury and condition the subjects to future progressive increases in resistance.<sup>16</sup> For the first 2 weeks, resistance was selected as an amount perceived as ‘somewhat hard’ by the subject. Following the first 2 weeks, the resistance was increased to begin the single set to failure, 8 to 12 repetitions format.

### Statistical Analysis

SPSS statistical software (v10.1 for Windows) was used for all statistical analyses. Conventional statistical methods were used for calculation of means and standard deviations. Due to differences in group size, use of parametric analyses (ANOVA) was deemed inappropriate. Therefore, nonparametric analyses were selected.<sup>27</sup> Between-group comparisons for force-time data and MVC were completed using a Mann Whitney-U test for 2 independent samples. Within-group comparisons were completed using a Wilcoxon test for 2 related samples. Because between- and within-group comparisons were completed pre- and post-training (repeated testing), the alpha level of significance was adjusted to 0.025 due to repeated single factor analysis.

### RESULTS

At the initiation of training, there were no significant differences between the groups for age, height, or weight (Table 1). The attendance for the exercise group over the 12 weeks of

**Table 1. Subject Demographics (mean±sd)**

Group	Age (yrs)	Height (cm)	Weight (kg)
Exercise (N=22)	67.7±5.5	170.4±9.8	79.1±13.3
Control (N=5)	67.4±7.3	169.4±7.9	66.6±12.9
no significant differences			

training was 98.6% with no exercise subject missing more than one training session. No subjects were lost to attrition or injury.

### MVC

The baseline measures of MVC were not significantly different between the 2 groups as shown in Table 2 ( $p=.832$ ). Within-group analysis revealed a significant training effect as the exercise group showed a significant ( $p<.001$ ) increase of  $13.0\pm12.3\%$  ( $.74\pm.62$  N/Kg). The control group showed a non-significant ( $p=.043$ ) decrease of  $10.5\pm7.62\%$  ( $.58\pm.45$ N/Kg). At the conclusion of training, between-group analysis showed the exercise group was significantly stronger than the control group ( $p=.023$ )

**Table 2. Maximal Isometric Quadriceps Strength (N/kg)**

Group	Time	Force (mean±sd)
Exercise	week 0	5.7±1.3
	week 12	6.4±1.4*#
Control	week 0	5.7±0.8
	week 12	5.1±0.9

\*= significantly greater than wk 0 ( $p<.01$ )  
# = significantly greater than Control group at wk12 ( $p=.023$ )

### Explosive Force Production

The initial measures of EFP at 30%, 60%, and 90% of MVC showed no differences between groups ( $p=.524$ ,  $.485$ , and  $.344$ , respectively). Group means are shown in Table 3. Between-group analyses at the completion of the training failed to show a training effect at the 30% ( $p=.606$ ), 60% ( $.208$ ), or 90% ( $.524$ ) levels of MVC. Furthermore, there were no significant differences noted within-groups at any of the three submaximal force levels over the 12-week period.

**Table 3. EFP: Time to Submaximal Force Levels (msec)**

Group	Time	30% MVC (mean±sd)	60% MVC (mean±sd)	90% MVC (mean±sd)
Exercise	week 0	183.5±223.2	273.7±296.2	610.0±472.1
	week 12	282.0±370.9	346.4±344.2	743.2±408.6
Control	week 0	94.2±78.2	156.6±95.7	483.2±306.7
	week 12	50.0±51.1	91.6±47.3	353.0±255.1

no significant differences between or within groups at any time

### DISCUSSION

We hypothesized that the use of a resistance training program in keeping with current guidelines for older adults from the American College of Sports Medicine,<sup>21,22</sup> Surgeon General,<sup>23</sup> and others<sup>24,25</sup> would result in increased strength but not EFP. The present data from these untrained, healthy older adults support this hypothesis as the exercise group demonstrated a significant increase in quadriceps strength over the training period but showed no change in the ability to generate forces quickly. These findings differ from some previous studies reporting improved EFP post-training.<sup>18,20</sup> However, the training program used presently and those previously reported to increase EFP must be critically examined in the context of this study’s hypothesis. Those studies reporting increased EFP included rapid, explosive training activities

as part of the training protocol, a stimulus not included in the present protocol nor contained within current guidelines for resistance training in untrained older adults.

Explosive force production was selected as the measure of interest for this study as previous investigators have shown that rapid generation of force declines more precipitously than does gross strength as a function of aging.<sup>8,10,14</sup> Furthermore, and more importantly, rapid generation of force is a critical performance characteristic shown to be crucial to several functional tasks related to daily life such as stair climbing, walking, and fall prevention.<sup>15</sup> While examination of time to maximal force is common, this study chose to examine time to submaximal levels of force. Because previous investigators have shown that age-related decreases in EFP are more apparent at submaximal force levels<sup>1-2</sup> than at maximal, and because daily activity rarely requires the use of maximal force,<sup>13</sup> this study examined EFP at submaximal force levels.

Concurrence regarding the effect of strength training on EFP is not found in the literature. As evidence, Newton et al reported no change in time required to reach force levels of 30%, 60%, 90%, and 100% of MVC but did report increased production of force in the initial 100 millisecond period of an isometric squat test.<sup>20</sup> Likewise, Hakkinen et al reported increased EFP following resistance training in women greater than 60 years.<sup>18</sup> However, EFP was recorded as the greatest force produced during 50 millisecond periods up to 500 milliseconds. In both studies, though, the increase in strength was greater than the change in EFP. While the findings of these studies can be interpreted as evidence of increased EFP, their findings provide a measure of EFP at only very limited portions of the entire physical event. Newton et al failed to note improved EFP at submaximal force levels which is consistent with the findings of our study. Similar to each of these studies, ours, and others measuring EFP is the variability in EFP data.<sup>2,28</sup> Examination of our data reveals large variability in the measures of EFP such that the standard deviations equal or exceed the mean values. However, this variability is consistent with other studies which show standard deviations in measures of EFP ranging from 25% to 100% of the mean values. This observation has not been described previously but may reflect the inherent variability in muscular activation patterns of individuals and is consistent with the findings of Newton et al<sup>20</sup> and Hakkinen et al<sup>18</sup> showing improved EFP in the initial portions of a motor task but no change in the overall time to reach specific force levels.

The lack of improvement in EFP under the present training protocol may not be surprising when considering the concept of specificity. Previous studies reporting improved explosive force production have specifically and purposefully included explosive training activities to improve EFP. In contrast, the current training protocol used slow, deliberate, and controlled isotonic exercises as advocated by Evans while the test activity for the parameter of EFP was an explosive isometric task.<sup>25</sup> Some investigators have suggested that the EFP characteristics of muscle during isometric activation are inherently different than during dynamic muscle activation because of variations in motor unit recruitment and movement patterns of the activities.<sup>19,14</sup> Izquierdo et al however,

examined EFP during maximal voluntary isometric contractions and during a dynamic squat jump task and found a strong association between the two activation patterns suggesting that EFP can be adequately examined by either mechanism.<sup>14</sup>

From previous literature, it may be postulated that had exercises involving explosive muscle activation been included, an increase in EFP may have been observed. Clinical treatment planning often involves use of current guidelines and recommendations from the literature. From the findings of this study and others, the addition of explosive dynamic activities is warranted if the desired outcome of training includes improved EFP. Current guidelines for resistance training in untrained older adults issued from the American College of Sports Medicine, the Surgeon General, and other recognized experts do not include rapid, explosive activities. The findings of this investigation and others should be considered when designing training programs for older adults.

That the rapid generation of forces contributes to functional activities such as stair climbing, walking, and fall abatement warrants consideration for preservation and improvement in older adults and investigations such as this. The limited studies available that report training induced increases in EFP have included explosive muscle contractions under isometric, isotonic, and jump-squat conditions. From a clinical perspective, many older adults may not be able to tolerate this type of stress or may have underlying joint pathology which may be aggravated. Careful selection of appropriate patients and activities is critical if training for improved EFP. Current guidelines for strength training in older adults do not address explosive muscle activation, thus programs consistent with these guidelines should be considered for increasing strength and not the ability to generate force quickly. If the desired training adaptations include improved EFP, then the selective inclusion of rapid, explosive activities is supported by these data.

## CONCLUSION

Muscle strength and the ability to generate force quickly are muscular performance characteristics which decline with increasing age. The ability to produce force rapidly is an important aspect of muscle performance that is related to many daily activities such as walking, stair climbing, and control of balance. Previous investigations with older adults suggesting improved explosive force production following strength training have included rapid and explosive muscle contractions. However, current guidelines for resistance training in older adults from the ACSM, Surgeon General, and others do not include such activities. This study assessed the effect of a traditional 12-week resistance training protocol in keeping with current recommendations for healthy, community dwelling older adults and noted improved strength but no significant change in the ability to generate force quickly.

## ACKNOWLEDGEMENT

The authors thank Mark Cullum for his assistance in data transformation and analysis.

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