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High-Speed Cycling Intervention Improves Rate-Dependent Mobility in Older Adults

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Abstract

PURPOSE—The aim was to determine the feasibility of a six-week speed-based exercise program that could be used to initiate new exercise behaviors and improve rapid movement in older adults approaching frailty.

METHODS—The intervention group included 14 older adults (3 males, 11 females, mean (SD) age: 70 (7.6) years, height: 1.6 (.11) m, mass: 76.8 (12.0) kg, BMI: 27.7(4.7)). The control group included 12 older adults (6 males, 6 females, mean (SD) age: 69.2 (6.9) years, height: 1.7 (.09) m, mass: 78.2 (10.9) kg, BMI: 25.3 (2.7)). Subjects included active older adults, including regular exercisers, but none were engaged in sports or exercises with an emphasis on speed (e.g. cycling spin classes or tennis). Stationary recumbent cycling was selected to minimize fall risk and low pedaling resistance reduced musculoskeletal and cardiovascular load. Two weekly 30-minute exercise sessions consisted of interval training in which subjects pedaled at preferred cadence and performed ten 20-s fast cadence intervals separated by 40-s of active recovery at preferred cadence.

RESULTS—Significant Group by Time interactions ($p<.05$) supported a 2-s improvement in the timed up and go test and a 34% improvement in rapid isometric knee extension contractions in the exercise group but not in controls. Central neural adaptations are suggested because this lower extremity exercise program also elicited significant improvements in the untrained upper extremities of the exercise group (elbow extension RFD-SF and 9-Hole Peg Test, $p<.05$).

CONCLUSION—These results demonstrate that a relatively low dose of speed-based exercise can improve neuromuscular function and tests of mobility in older adults. Such a program serves as a sensible precursor to subsequent, more vigorous training or as an adjunct to a program where a velocity emphasis is lacking.

Keywords

neural; neuromuscular; exercise; power training; aging

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Introduction

The physical slowness of older adults has implications for postural stability, fall prevention, and activities of daily living (24,32). Current exercise recommendations for older adults predominantly aim to improve balance, flexibility, strength, and endurance (8,9,34). While the emphasis on these specific components of fitness is prudent and evidence-based, it does not represent emerging knowledge about the important contribution of muscular power to function. Reduced muscle power has a greater impact on functional declines than reduced muscle strength and muscle power is lost earlier and at a faster rate than muscle strength in aging adults (38).

Mechanical power is the product of force and velocity. In general terms, force can be attributed to the quality and amount of muscle tissue and a high *amount* of neural activation while velocity can be attributed to the velocity at which muscle fibers shorten and a high *rate* of neural activation. While muscular power is a quantifiable component of fitness and a useful predictor of function (38), isometric muscular contractions offer a strong foundation of knowledge that increasingly differentiates between the muscular and neural determinants of rapid muscular contractions and how the determinants adapt to exercise interventions. In this study, it is assumed that the isometric rate of force development (RFD) is an informative surrogate measure for power due to shared neural and muscular determinants and meaningful relationships with tests of sport-specific and functional mobility (30).

When instructed to generate isometric forces most rapidly, the time required to achieve peak force is relatively invariant whether the contractions are small or large (4,19). This invariance is made possible by positive linear scaling of RFD with the amplitude of the pulse. This scaling is attributed to increasing rates of neural activation with increase force (10,19,25,45). Derived from RFD and peak force (PF) measures from numerous force pulses performed across a wide range of submaximal amplitudes, the slope of the linear RFD-PF relationship has support as a reliable dependent measure (4,7). The slope has been shown to decrease with age (25) or following stroke (10), and it increases with power training (45). Mathematically, the slope variable is independent of the individual’s size and strength, resulting in a measure that quantifies the scaling of rate with the amplitude of the contraction with high relevance to neuromuscular control mechanisms. Although this measure requires further development, the likely contributors to its change include neural activation, fiber type, antagonist co-contraction and changes in series elastic component stiffness, but not the quantity of muscle tissue. Thus, the rate of force development scaling factor (RFD-SF) was used to evaluate the performance of rapid isometric contractions in the present study following a brief and low-force training program that was designed to emphasize neural adaptations.

Physical exercise can achieve high mechanical power through combinations of high-force and low-velocity movements (analogous to strength straining), or low-force and high-velocity movements (analogous to speedwork and the basis of the current program). The latter combination, which is sometimes named high-velocity power training (42), represents numerous exercise modalities that are not often considered as ‘power training’ in the popular use of the term, such as high cadence bicycling, dance, boxing and tennis. The importance of low-force, high-velocity power training has been emphasized because these types of movements are more related to activities of daily living (ADLs) than maximal force contractions (42). Considering that vigorous neural activation is a mutual contributor to strength, speed and balance, one could predict the high value of an exercise strategy that, first, induces rapid neural adaptations in older adults prior to progressive overload (3) towards greater strength, balance and endurance stimuli.

A growing body of evidence supports the use of high-velocity exercises to enhance power in older adults (17,32). With the older adult who is approaching frailty in mind, we sought to design a practical (e.g. time-efficient, accessible and safe) high-velocity exercise program that an older adult could use as they initiate new exercise behaviors. Whereas a previous 16-week intervention successfully improved strength, power and function through a combination of high pedaling cadence and moderate (40% 2RM) or high (80% 2RM) resistance (29), the novelty of the present program is that it used a much lower exercise dose regarding both time and intensity. To prevent muscle soreness and constrain the heart rate response, individuals pedaled at a high cadence against the minimal resistance settings offered by commercial grade recumbent exercise bicycles. A shorter six-week duration was selected in order to seek benefits primarily from rapid neural adaptations (33) and exercise sessions were only 30-minutes in duration. The interval training approach (3) was used to elicit high rates of neural activation and allow periods during which heart rates could recover. We prioritized high neural activation, comfort and brevity in the design of this program over more aggressive stimuli that would favor greater hypertrophy and metabolic adaptations. Our rationale was that this program is intended to be used at the initiation of new exercise behaviors that will later be followed by higher power activities within the progressive overload framework (3). Ideally, early functional improvement and the avoidance of exercise discomfort or subsequent soreness would promote adherence into the later stages of a sustained program.

The aim was to test a practical velocity-based exercise program that was designed to induce rapid neural adaptations that would result in improved rates of muscular force development and function. It was hypothesized that there would be improvements in, and retention of, the ability to produce rapid isometric contractions in the lower extremity, a timed test of whole body mobility, and perceived health and functional status. Considering the possibility of central neural adaptations, it was further hypothesized that rapid force production in the untrained upper extremity and a timed test of hand dexterity would also improve.

Methods

Participants

Participants were recruited via newsletter announcement from a local senior center and were divided into two groups. Although participants were randomly assigned to the intervention or control groups at entry, resource and scheduling constraints resulted in an unbalanced gender distribution in the intervention group. The intervention group included 14 older adults (3 males, 11 females, mean (SD) age: 70 (7.6) years, height: 1.6 (.11) m, mass: 76.8 (12.0) kg, BMI: 27.7(4.7)). The control group included 12 older adults (6 males, 6 females, mean (SD) age: 69.2 (6.9) years, height: 1.7 (.09) m, mass: 78.2 (10.9) kg, BMI: 25.3 (2.7)).

There were no significant differences in these subject characteristics between groups (all F<2.4, all p>.13). Both groups included individuals who ranged from sedentary to moderately active (walkers and gardeners) based on self-report. None of these individuals were currently engaged in weight lifting or activities with a high velocity component like dance, stationary bicycling (spin) classes or tennis. All participants were right hand dominant and, for standardization purposes, the left side was used for all assessments during testing. Exclusion criteria included regular exercise within the past six months that involves activities with a high-velocity component, injury to the lower or upper extremity within the past six months that required medical treatment, low back pain, or uncontrolled hypertension. Participants were asked not to change their physical activity or exercise routines throughout the duration of the study. All participants signed an institutionally approved informed consent document and completed a Physical Activity Readiness Questionnaire (PAR-Q) (3) to identify possible contraindications to exercise participation. If participants answered ‘yes’ to any items on the PAR-Q or if they were over the age of 69 they were asked to provide written documentation of their physician’s clearance to participate.

Schedule

Participants in the exercise group were tested before and after the six-week exercise program and again during a four week retention test. The control group was similarly tested at weeks one and six and were instructed to continue their normal daily activities between tests. The inclusion of this time control group was intended to elucidate whether any potential improvements were due to increased familiarity with laboratory tests, rapid neural adaptations or due to the exercise program under investigation. It is known that serial assessment of strength can elicit meaningful strength increases due to rapidly adapting neural factors (20). At both visits to the laboratory, testing was conducted in the following order: questionnaires, functional measures, and then the rapid force pulse protocol within the lower and then upper extremity.

Questionnaires

In addition to the PAR-Q that was used during subject recruitment, participants completed two standard questionnaires related to physical function, disability, and quality of life. The Activities-specific Balance Confidence (ABC) Scale asks a person to rate their level of confidence that they will not lose their balance doing different activities on a scale from 0% (not confident) to 100% (completely confident) (37). ABC was also shown to be an effective tool in predicting future falls (31). The Short Form-36 Health Survey (SF-36) assesses a person’s perceived health status related to physical, social, mental, and emotional health (46).

Functional measures

With the exception of isometric grip strength (Jamar Plus, Patterson Medical, Warrenville, IL 60555) and consistent with hypotheses related to movement speed, participants were instructed to perform functional tests “as fast and as safe as possible”. After practicing the tests, participants performed three timed trials of each test with the best time being used for data analysis. The Timed Up and Go Test (TUG) was used to assess overall functional mobility with strength, speed, and balance components (36). The 9-Hole Peg Test is a quantitative test of upper extremity function (15).

Rapid isometric muscle contractions

The knee and elbow extensors were chosen for their functional relevance to activities of daily living and prevalence in mechanistic and rehabilitation research. Knee extension is relevant in walking and sit-to-stand tasks. Elbow extension is a primary action in the upper extremity utilized frequently for reaching and support tasks. The hardware arrangement (Figure 1) and methods are similar to those used in a prior reliability study (4). Isometric knee extension forces were obtained with participants seated on a bench with their distal leg affixed to a strain gauge force transducer (SM-250, Interface Inc., Scottsdale, AZ, USA). Participants were seated in an upright position with back support and with both the hip and knee flexed at 70°. The transducer was coupled to the distal leg with a rigid plastic cuff. A small segment of cloth was wrapped around the leg for comfort. The cuff was secured with hook and loop fastener. These materials were selected to minimize the effect of material compression on the resulting force measures (13). Isometric elbow extension forces were recorded from an instrumented wooden pole that subjects pressed against the ground (SM-50, Interface Inc., Scottsdale, AZ, USA). Subjects were seated on the same testing bench. With the shoulder in a neutral position, the pole was grasped at a height to create an elbow angle of 90°. The pole was held in a vertical orientation and the forearm was parallel to the ground. Unlike single-joint mechanistic studies that isolate elbow extension forces or torques in their measurements, the instrumented pole used here simultaneously requires adequate grip force. The combined requirements produce a measure of upper extremity function more than pure elbow extension strength. Aiming for ecological relevance, the pole had a circumference similar to that of a standard garden tool and the frictional characteristics were enhanced with cloth athletic tape. The ability to generate reaction forces in the anti-gravity direction also has relevance to fall avoidance.

A Grass Instruments Model 15LT (West Warwick, RI, USA) bioamplifier system was used to amplify and filter (low pass cutoff at 30 Hz, −6 dB) signals from each of the force transducers. Analog signals were digitized at 2 kHz using a 16-bit acquisition board (PowerDaq Series, United Electronics Industries, Walpole, MA, USA). Data acquisition and the visual display of force was controlled using Dasylab software (Measurement Computing Corporation, Norton, MA, USA).

Isometric maximal voluntary contractions (MVC) were measured in both knee extension and elbow extension. Subjects were instructed to use about three seconds to gradually increase their effort to its maximum. MVC force was defined as the greatest value of the three maximal effort contractions. There was 60 seconds of rest between attempts. Visual feedback of force was provided to the participant on a computer monitor at eye level as a percentage of maximal force (%MVC). This relative force was depicted as a vertical bar graph with clear markings at 20, 40, 60, and 80 %MVC.

The rate of force development scaling factor (RFD-SF) and corresponding R^2 values were obtained by analyzing rapid isometric force pulses using a similar approach to that of others (19,25). The reader is directed to Bellumori et al. (4) for a detailed description of the method and reliability information. For both knee and elbow extension, subjects were instructed to produce several discrete isometric force pulses, each one performed as quickly as possible with immediate relaxation to the resting force level. After observing a demonstration performed by the experimenter, participants practiced until they could perform rapid force pulses as instructed. During practice and throughout testing, the experimenter checked the force recordings for evidence of unwanted flexion counter-contractions prior to the extension contractions. When necessary, subjects were given corrective instruction. Participants performed five trials that consisted of sets of five pulses to each amplitude of 20, 40, 60 and 80 %MVC (20 total pulses per trial). The experimenter stated the force level for each set and these were presented in a counterbalanced order across trials. Subjects were cued by a metronome to produce a pulse every two seconds. There were two minutes of rest between trials. Five trials resulted in 100 force pulses and 75 or more pulses are adequate to obtain a reliable RFD-SF (4).

Isometric force recordings were processed using National Instruments Labview software to obtain peak force and peak RFD measures from each isometric force pulse. RFD was computed as the first derivative of force over overlapping 0.1 s intervals. Linear regression was used to quantify the relationship between the peak force and corresponding peak RFD and to obtain R^2 values (Figure 2). The slope of the regression line obtained from the peak force and peak RFD provides the RFD-SF and R^2 represents consistency in the performance rapid muscular contractions (4).

Exercise intervention

Exercise sessions occurred in a local senior center fitness center. Participants trained for six weeks under the supervision of the experimenter (2 days per week = 12 total sessions). Exercise was performed on a stationary recumbent bicycle (Life Fitness, Platinum Club Series Recumbent Lifecycle) with no added resistance (Level 1). During the first session, participants were instructed to pedal at a comfortable cadence. This was determined to be their preferred pedaling cadence and values ranged from 40–80 revolutions per minute (RPM) between participants. These cadences correspond to 25–50 watts of power output on the specific bicycle used. Each exercise session began with a five minute warm up at preferred pedaling cadence. Then participants alternated between periods of fast and slow pedaling. This included 10 intervals of fast pedaling for 20 seconds followed by 40 seconds of slow pedaling at preferred cadence. Heart rate was monitored throughout exercise. When necessary, cycling cadence was adjusted to keep exercising heart rates below 70% of age predicted maximum determined as 220-Age (3). In rare instances at the beginning of the training program, longer recovery was given if heart rate exceeded 70% of the participant’s age predicted maximum or if the experimenter’s assessment of breathing rate and the overall response to exercise indicated more than moderate strain. Skipping and interval to provide an additional minute of active recovery was adequate. Fast cycling was initially defined as 20% faster than preferred pedaling cadence and then subjects were encouraged to increase their fast cadence thereafter throughout training. The session concluded with a five minute cool down at preferred pedaling cadence. Each session lasted 30 minutes.

Statistical analysis

Statistical tests were performed using SPSS (version 22, IBM SPSS Statistics, Armonk, NY). To ascertain whether significant overload was accomplished in the training program, a single factor repeated measures ANOVA was used to test for significant changes from training session one to training session twelve in the fast pedaling cadence (FPC) that was achieved during intervals. For each dependent measure related to a potential training effect, a two factor repeated measures (within-between) analysis of variance was used to test the group (control, exercise) by time (pre, post) interaction as a test of whether changes due to training were different from any changes in the control group. In the presence of a significant interaction, Bonferroni-adjusted pairwise comparisons were made. Where significant training effects were observed, paired samples t-tests were used to test for significant changes during the 4-week retention phase. An alpha level of .05 was used as a threshold for statistical significance.

Post-hoc power estimates were calculated for the three main dependent measures (RFD-SF of the knee extensors, TUG and the 9-hole peg test). Estimates were computed in G*Power for the ability to detect a significant Group x Time interaction according to the methods of Faul et al. (16) with an alpha level of .05 and power of .80. With a total sample size of 24 subjects and test-retest correlations that favored greater statistical power (r = .86 to .93) the study was adequately powered to detect Group X Time interaction effect sizes from f=.11 to f= .16 (between Cohen's small and medium (12)). This would be a 2 unit change in the RFD-SF, a .8 s change in TUG and a 5 s change in the 9-hole peg test.

Results

Table 1 presents means and standard deviations for the control and exercise groups. In the exercise group, preferred pedaling cadence ranged from 40–80 RPM (mean (SD): 57.3 (8.8) RPM, 36.6 (10.3) Watts) with no significant difference between the first and last session (F=.06, p>.05). The average fast pedaling cadence was 67.9 (22.8) RPM (49.2 (13.9) Watts) at the first training session and increased by 56% to 106.1 (29.5) RPM (62.6 (11.9) watts) at the last training session (F=14.7, p<.001).

Figure 2 shows the training effects in the rate of force development scaling factor data from one subject. Following training, this subject was able to achieve submaximal force levels at a greater rate and there was a favorable increase in the scaling of RFD (RFD-SF) with the amplitude of the corresponding force pulse. There was a significant Group by Time interaction in the RFD-SF of the knee extensors (F=5.19, p=.032), within which there was a 34% improvement in the exercise group (p<.001) and no change in the control group (p=.57). There was a significant Group by Time interaction in the RFD-SF of the untrained elbow extensors (F=10.8, p=.003), within which there was a 47% improvement in the exercise group (p<.001) and no change in the control group (p=.65). The corresponding R^2 values from the regression of RFD against PF increased in both groups at both joints (Knee: F=16.8, p<.001, Elbow: F=5.7, p<.001). There were no significant Group by Time interactions or group differences in R^2 (F=1.5, p=.23).

There was a significant Group by Time interaction in the TUG (F=11.8, p=.002), within which there was a 23% improvement in the exercise group (p<.001) and no change in the control group (p=.133). There was a significant Group by Time interaction in the 9-hole peg test (F=4.76, p=.039), within which there was a 13% improvement in the exercise group (p=.002) and no change in the control group (p=.87). There was no significant Group by Time interaction for isometric grip strength (F=.13, p=.73) and no significant main effect of Group (F=2.48, p=.13) or Time (F=1.82, p=.19). The average grip strength in the sample was 27.9 (9.2) kg. There was no significant Group by Time interaction for the movement ABC (F=1.3, p=.26) and no significant main effect of Group (F=.16, p=.70) or Time (F=.26, p=.62). The average ABC score in the sample was 91.7 (9.5). There was no significant Group by Time interaction for the SF-36 (F=2.0, p=.18) and no significant main effect of group (F=.001, p=.98) or time (F=.34, p=.57). The average SF-36 score in the sample was 81.1 (11.2). There was no significant Group by Time interaction for the MVC scores in the knee extensors (F=.3, p=.59) and no significant main effect of Group (F=.104, p=.75) or Time (F=2.4, p=.13). There was no significant Group by Time interaction for the MVC scores in the elbow extensors (F=1.69, p=.21). There was no effect of Group (F=1.8, p=.20) but there was an effect of Time (F=10.4, p=.21) such that there was a 12% increase in elbow extension strength from test one to test two in both groups combined.

Due to recruiting and scheduling challenges, our sample contained an unbalanced gender distribution in the exercise group. Although the sample is not suitable for a statistical analysis of the gender by time interaction, there was a noteworthy pattern in the magnitude of exercise effects. Both males and females exhibited improvements following training and females exhibited a greater improvements than males (RFD-SF Knee Extension: male 27%, female 35%; RFD-SF Elbow Extension: male 28%, female 52%; TUG: male 14%, female 25%; 9-hole peg test: male 4.2%, female 16%).

Four week retention tests were performed only for measures that improved in the exercise group, as participants in the control group were not tested at this time point. Among the four measures that significantly improved at test 2 (TUG, 9-hole peg test, RFD-SF of the knee and elbow; Table 1), all remained significantly better than the pre-training (test 1) value except the RFD-SF of the elbow extensors, which was no longer significantly different from the test 1 value (p>.05).

Discussion

The aim was to design and test a practical speed-based exercise program for older adults that would require high rates of neural excitation and improve the ability to perform rapid muscular contractions, mobility and perceptions of health and balance. The results supported our hypotheses that the program can improve the ability to produce rapid isometric force pulses across range of submaximal forces - a valid probe into neuromuscular system function. These improvements were paralleled by improvements in a functional test of whole body mobility (TUG) that is known to require adequate strength, balance and speed for favorable scores. However, results did not support the hypothesis that this program would improve one’s perception of their health status (SF-36) or their confidence in tasks that require balance (ABC).

Although the consistency (R^2) in performing rapid isometric pulses improved in both groups and limbs and there was a similar 12% increase in the elbow extension strength (MVC) in both groups, the primary variables of interest (RFD-SF, TUG, 9-hole peg test) did not change in the control group. The improvements that were observed in the RFD-SF of the knee extensors, TUG and 9-hole peg test were retained four weeks after the training program had ended. That this leg-based exercise program elicited improvements in the upper extremity tests of isometric force production and hand dexterity suggests that central adaptations may have occurred.

A model high-speed low-resistance cycling program

There was complete compliance from participants in this study and no mention of muscle strain or discomfort during or after exercise sessions. Some participants who entered the study with high pedaling cadences wished to have greater resistance. Although increased resistance would be sensible for individualized exercise prescription and may have resulted in greater training effects, the resistance settings were maintained at the lowest value due to our interest in designing a program for older adults approaching frailty. Due to the interval nature of the exercise, a total of 3.33 minutes of high-speed cycling was completed during each exercise session. Even though it is notable that such a short duration of high effort resulted in significant benefits, one should also consider that 3.33 minutes at 85 RPM produces over 283 rapid muscle contractions involving the extensor and flexor muscles of both legs. Such a number of repetitions would be impractical to achieve with a weight-lifting modality.

In two review papers (28,42), authors highlight the utility of exercise programs that target power rather than strength alone and others have demonstrated that muscle power correlates well with function (43). Previous studies have shown simultaneous improvements in muscle power and function with resistance training. Although we did not measure peak power directly in this study, the large increases in maximal cycling cadence and the improvements in rates of force production provide surrogate indicators that power and function (TUG) improved together. Among prior studies that applied the high-velocity power-training concept to older adults, our study is most comparable to that conducted by Macaluso et al. (29) who demonstrated the efficacy of a cycling modality. Compared to their study, a novel aspect of the present exercise program was its brevity. Whereas many training studies in older adults ranged from 10–16 weeks in duration with three exercise sessions per week (28), we obtained significant benefits after only six weeks with two, 30-minute, sessions per week.

Another departure from the approach of Macaluso et al. (29) was the use of very low resistance during our high-speed cycling intervals which allowed a greater velocity of movement. We used the lowest resistance setting of a commercial grade stationary recumbent bicycle with average low power of 36 W during preferred pedaling cadences and a post training average high power of 63 W during the fast cadence intervals. Macaluso et al. (29) used 40% and 80% 2RM load conditions as the basis of their resistance settings. Explaining a lack of differences between their slow speed (~4 rad/s) and fast speed (~8 rad/s) exercise groups, they stated that both of their speeds were relatively slow compared to what would be achieved with an unloaded cycling condition (approximated at ~12 rad/s). They further suggested that different adaptations might occur if movement speeds approached the maximal speed of muscle fiber shortening. Indeed, our present results are consistent with their thoughts on greater velocities because our exercise group achieved a movement velocity of 11.1 rad/s (106 RPM) and experienced improvements in rapid force production and mobility. Future research is required further clarify this velocity effect as well as the relative contributions of muscular and neural mechanisms of adaptation.

While not diminishing the findings of Macaluso et al. (29), the current results suggest something closer to a minimal effective dose of high-velocity power training that could be used at the beginning of an exercise program. The present program was designed to ‘reawaken’ the nervous system by inducing rapid neural adaptations and while minimizing discomfort and injury risk in an older population who may be unaccustomed to exercise. The introductory nature of the design might not lead one to expect large effect sizes in the outcomes. However, a two second improvement in TUG on top of favorable baseline values relative to the prediction of frailty (41) is meaningful. Others have reported minimal detectable change (MDC) values for TUG of 1.14 s (2) in the study of knee osteoarthritis. Furthermore, the observed RFD-SF improvements of 1.6 units in the knee extensors and 2.5 units in the elbow extensors approaches or exceeds the 2.3 unit improvement that was observed following 12 weeks of power training of the ankle dorsiflexors in young adults (45). Participants noted that this exercise was relatively easy due to the low resistance and the average rating of perceived exertion (6) during training was 14 which lies between the descriptors of ‘somewhat hard’ and ‘hard’. Some participants also commented that the task of high speed cycling against minimal resistance was complex and this was consistent with observations by the experimenters including instances in which the foot would slip out of the pedal straps. These participants were simply instructed to work on the smoothness of pedaling while attaining the high speeds. This may raise further scientific questions regarding motor learning and coordination. Although not measured in the present study, it might be the case that smooth pedaling emerged at the higher cadences when participants improved the direction of force application on the pedal through improved muscle activity patterns (22). Lastly, due to the brevity of the exercise session and the accessibility of the required equipment, the program under investigation is easy to implement outside of the laboratory or clinic and still allows time for an appropriate complement of other exercises to make a more complete fitness program.

Interpretation of the RFD-scaling factor

Physical quickness is an important movement quality in the contexts of aging, pathology, and rehabilitation. Under the instructions to produce isometric muscular force pulses most rapidly (21) and across a range of submaximal amplitudes, there is a positive linear relationship between the peak force of a pulse and the corresponding peak rate of force development (RFD). The slope of the regression quantifies how well RFD is scaled with contraction amplitude and is termed the RFD-scaling factor (4). In healthy young adults, a greater RFD-SF results in relative invariance in the time required to achieve peak force regardless of the strength of the muscular contraction (19). While this measure still requires further development in its mechanistic foundation and functional significance, published evidence supports the notion that greater values represent better neuromuscular function. The R^2 value from the same linear regression equation represents the amount of variability in rapid force production across force levels and is an indicator of consistency of force control. In an age-group comparisons involving elbow extension contractions, the R^2 derived from the RFD-SF protocol was significantly less in older adults (R^2=0.80) than in young adults (R^2=0.97) (5).

Together with muscle fiber type (26), rates of muscular force development and movement speed are determined by the rate at which the nervous system activates muscle tissue (19,45). The rapid isometric force pulse model (19) has been informative in this context, demonstrating the relationship between initial motor unit firing rates and the rate of EMG rise (45), the decline of both measures in older adults (25), and the trainability of these neural factors in the young (45). Making the important link between these neural factors and an important speed-based activity of daily living, Clark et al. (11) demonstrated that the rate of muscle activation (EMG rise) in the triceps surae was 38% lower in well-functioning older adults who exhibited slower maximal walking speeds. Fortunately, and consistent with the present results, neural factors can adapt very quickly to exercise stimuli, even in older adults (20).

In recent work from our laboratory we have established the reliability of the RFD-SF measure in young adults, explored differences between muscles (4), found that the RFD-SF is less in older adults (5), and markedly impaired in the paretic limb of people with chronic stroke (10). In the present study, we sought to improve the RFD-SF in older adults using an exercise program designed to emphasize neural excitation of muscle. Figure 2 represents the hypothesized shift in the relationship between peak RFD and peak force for one individual in the exercise group. The benefit of looking at rates of force production in this way is that we can see changes in rates of force production across force levels that represent the activities of daily living that we are most interested in improving. An increase in the RFD-SF has been linked to increases in initial motor unit firing rates and rates of EMG rise in young adults (45).

Transfer as indirect evidence of central mechanisms

In a dataset that includes both young and older adults, a strong correlation (r = .87) was observed between the RFD-SF of elbow extensors and index finger abductors (5). This suggests that the RFD-SF describes a general neuromuscular characteristic of an individual, rather than providing information that is only joint specific. The present results showed that training the legs resulted in improved RFD-SF in both the legs and untrained arms. The exercise group also demonstrated a significant improvement in the timed 9-hole peg test of hand dexterity that did not occur in the control group. The brevity of the protocol and the absence of mechanical load on the upper extremity muscles is consistent with the proposition that the mechanisms of adaptation were neural. We speculate as others have in related contexts (1), that improvements may have occurred in the upper extremity because rapid movements are controlled by shared central nervous system structures. In healthy adults, voluntary exercise in the upper (27) or lower (35) extremities has been shown to increase motor cortical activation, which may stimulate neuroplasticity. Activity dependent scaling of GABAergic synapse strength is regulated by brain derived neurotrophic factor which is enhanced with exercise (18). If exercise alters central motor processes generally rather than with peripheral anatomic specificity, it could be expected that training one set of limbs would transfer benefits to non-exercised limbs (39).

Another interesting finding related to transfer was the greater response in the RFD-SF of the untrained upper extremity (47%) compared to that in the trained lower extremity (34%). With the present data, our explanation can only be speculative. If the RFD-SF is centrally determined, the mechanical manifestation of its improvement might be greater in anatomical structures that are optimized for high-velocity power (upper extremity) than for low-velocity power (lower extremity). The basis of this speculation is the significance of throwing in human evolution and the resulting anatomical design (40).

Changes in Strength Scores

The significant 12% increase in the MVC of the untrained elbow extensors in both groups was not surprising. Repeated assessment of maximal strength is known to elicit strength increases of similar magnitude even without explicit exercise training (20,23). Although one might expect a greater strength gain in the exercise group, the training program was designed to elicit improvements in speed and not strength. Interestingly, strength improvements were observed in the upper but not the lower extremity in the present study. One might consider whether different patterns of use in activities of daily living result in more deconditioned upper extremities and a greater potential responsiveness to stimuli that are relatively novel. The greater increase in the RFD-SF of the elbow extensors (47%) compared to the knee extensors (34%) in the exercise group is consistent with this possibility. Greater improvements in the upper extremities were also observed in the outcomes of an intense twelve-week resistance training program involving older adults (44). The authors similarly suggested that the greater trainability of the upper extremity is perhaps due to a pattern of use that results in more deconditioning and greater potential for improvement.

Balance confidence and perceived health

Although scores on the SF-36 and ABC trended toward improvements after the intervention, the changes did not reach a significant effect size. Considering the relatively mild dose of exercise in this study and the intentional minimization of cardiovascular and musculoskeletal strain, small effect sizes related to the perceived effects are not surprising. These results do not challenge the positive outcomes in the objective measures but they do raise questions about the ability of this program, on its own, to improve balance or promote exercise adherence through improved self-efficacy (3).

Even though the exercise program targeted neural factors and abilities that would logically contribute to improved balance, balance was not specifically trained. Furthermore, the relationship between speed and balance was not explicitly stated to the participants and they had no knowledge of their improvements in functional measures (mastery component of self-efficacy) when the post-training surveys were administered. Thus, the contributors to improved self-efficacy (14) were limited. In future studies and in practice, an educational component that instructs participants on the relationship between speed-based exercise and balance and periodic feedback should be considered. It is also important to note that while the TUG test does require some balance, the improvement in this test could have been due to other factors such as increased power during the rising phase or walking speed. There were no direct measures of balance in this study. Related to the perception of overall health status (SF-36), we believe that the specificity and minimal dose orientation of this exercise program did not provide a potent enough stimulus to improve scores across the eight health domains queried in this instrument.

Limitations

There was an unequal distribution of males (n=3) and females (n=11) in the exercise group. This raises a question about the possibility of different responsiveness to this training program in older women compared to older men. Group-specific means improved in both men and women but the size of the response was greater in the women. In the absence of an adequately powered statistical comparison, the gender effect remains inconclusive but interesting. The reader should also consider the possible outcomes that may have been observed if retention data were collected in the control group. For example, these data would have made it possible to determine whether repeated testing alone could have elicited meaningful practice effects. If a practice effect was observed, its magnitude could have been compared to the size of the training effect.

Conclusion

The exercise program tested here elicited improvements in the ability to produce rapid isometric muscle contractions across a wide range of forces. Rapid submaximal muscular contractions are especially relevant to older adults in activities of daily living such as fall prevention, typing, catching an object before it falls, and crossing the street quickly. This exercise program also resulted in improvements in the TUG which is a standardized measure of whole body mobility. Improvements in the RFD-SF of the untrained elbow extensors and faster 9-hole peg test performance suggest that training one set of muscles may induce general adaptations in the central nervous system. Whereas the exercise program tested here was designed as an introductory program, one might consider further potential value of this program as an adjunct to ongoing programs that do not include an emphasis on movement speed.

Future studies should a) utilize a second control group that performs the preferred pedaling cadence alone without the high speed intervals, b) further elucidate the mechanistic basis of these improvements, c) explore whether timed tests of executive function are also enhanced with high-velocity power training and d) ascertain whether this program is effective in a sample of older adults who are classified as frail e) determine whether progression to greater cycling resistance at similar power will further improve the RFD-scaling factor and mobility, and f) explore the potential to enhance training outcomes from this program by applying principles of the self-efficacy framework for behavior change.

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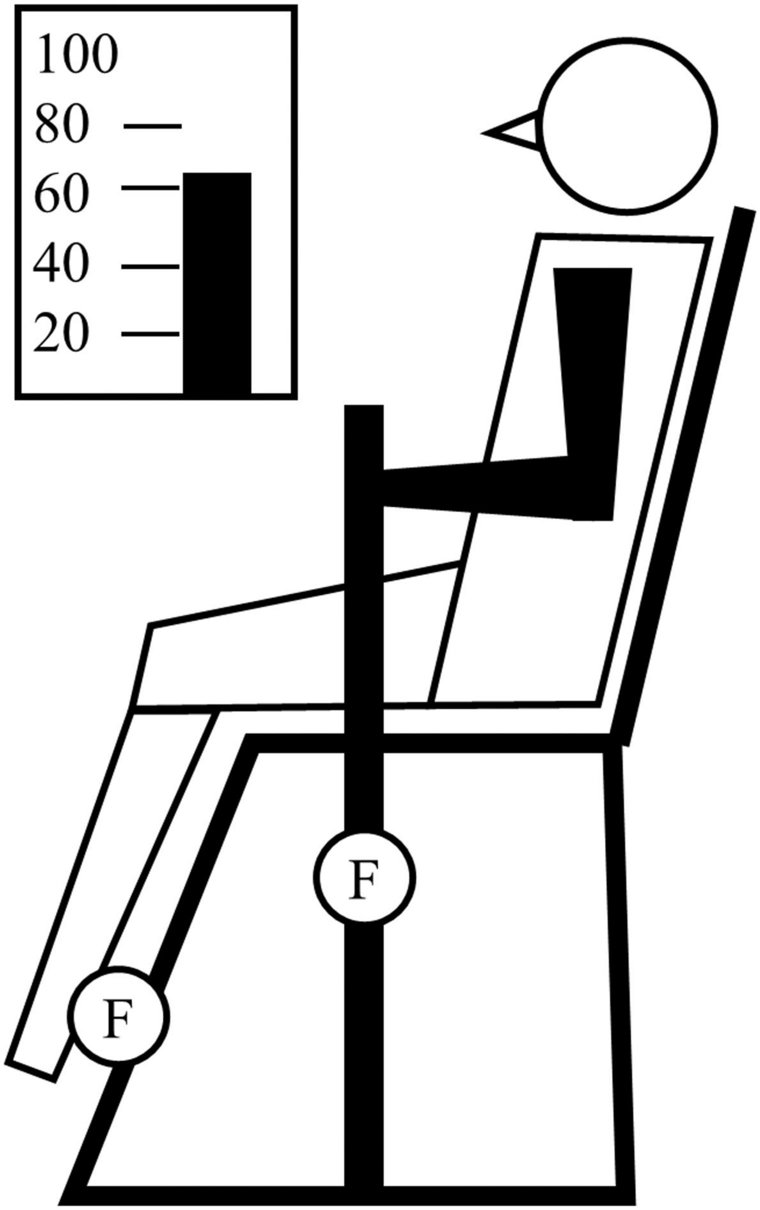

Figure 1.

Experimental arrangement for the measurement of rapid isometric force pulses in elbow extension and knee extension. F indicates the approximate location of force transducers that were rigidly coupled to the distal leg or interfaced with a vertical pole that is pressed against the ground. Participants viewed real time feedback of isometric force (scaled to their maximal voluntary contraction force) on a computer monitor at eye level. Participants were instructed to produce multiple brief force pulses (see inset Figure 2) to approximate force levels of 20, 40, 60 and 80% MVC. Upper and lower extremity force pulses are measured separately as described in methods.

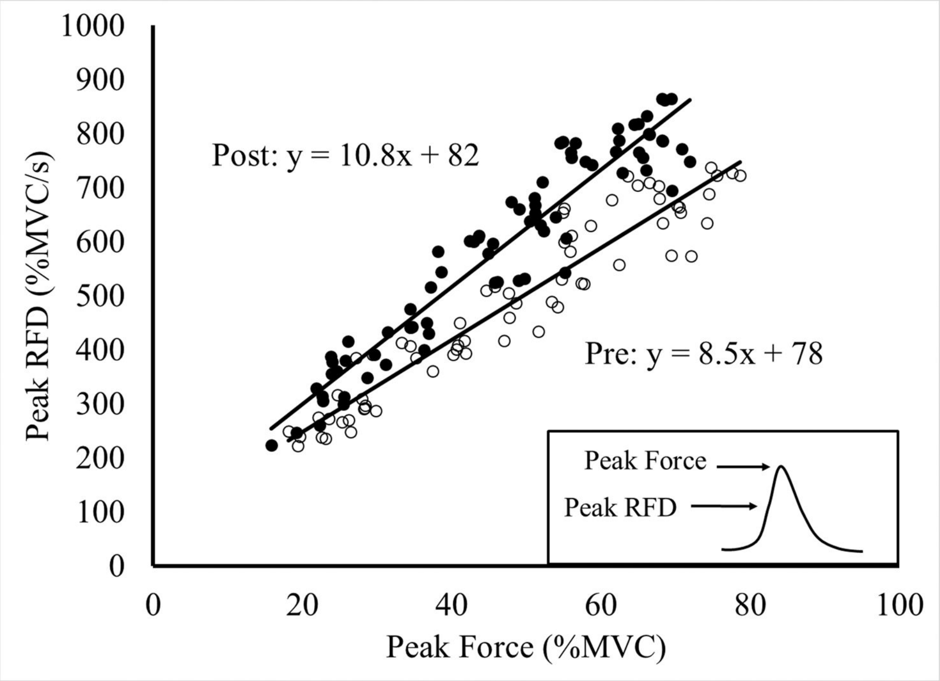

Figure 2.

The rate of force development scaling factor (regression slope; RFD-SF) of one representative subject who improved from 8.5 to 10.8 units after six weeks of exercise. The RFD-SF is computed from the linear regression of peak RFD and peak force values taken from several isometric muscle contractions (depicted in inset) produced to a range of submaximal force amplitudes. See methods for further detail.

Table 1

Means (SD) for the control group (n=12) and exercise group (n=14) before and after the six-week intervention period and at a four-week retention test. RFD-SF = rate of force development-scaling factor, R^2 values are from the individual RFD-SF regression equations, MVC = maximal voluntary contraction force, RPM = cycling revolutions per minute.

		Time		
	Group	**Test 1**	**Test 2**	**Follow-up**
Grip Strength (kg)	Control	30.5 (10.4)	31.3 (10.1)	
	Exercise	24.8 (7.3)	26.1 (8.2)	26.0 (8.0)
Timed Up and Go (s)[a]	Control	7.1 (1.9)	6.6 (1.8)	
	Exercise	9.1 (3.1)	7.0 (2.1)[b]	6.8 (2.0)[c]
9-Hole Peg Test (s)[a]	Control	27.8 (8.9)	27.6 (6.9)	
	Exercise	30.9 (7.7)	26.8 (6.6)[b]	26.3 (5.1)[c]
RFD-SF Knee[a]	Control	7.1 (3.7)	7.4 (3.1)	
	Exercise	4.7 (2.5)	6.3 (2.6)[b]	6.0 (2.4)[c]
RFD-SF Elbow[a]	Control	8.0 (3.2)	7.8 (3.5)	
	Exercise	5.2 (2.6)	7.7 (3.6)[b]	6.5 (2.9)
R^2 Knee	Control	.63 (.20)	.71 (.12)[b]	
	Exercise	.58 (.23)	.72 (.16)[b]	.73 (.17)[c]
R^2 Elbow	Control	.70 (.19)	.77 (.18)[b]	
	Exercise	.62 (.19)	.69 (.19)[b]	.76 (.18)[c]
MVC Knee (N)	Control	255 (99)	302 (176)	
	Exercise	253 (101)	276 (116)	268 (109)
MVC Elbow (N)	Control	102 (30)	109 (32)[b]	
	Exercise	85 (17)	100 (27)[b]	101 (23)[c]
ABC Scale	Control	96.8 (3.4)	91.5 (10.6)	
	Exercise	88.7 (12.5)	92.9 (5.9)	91.7 (6.7)
SF-36	Control	83.0 (13.2)	80.0 (12.0)	
	Exercise	78.8 (10.6)	83.7 (11.2)	84.5 (10.1)
Cadence (RPM) Exercise Group Only	Preferred	57.1 (8.2)	57.6 (9.5)	
	Fast	67.9 (22.8)	106.1 (29.5)[b]	

[a] Significant Group x Time interaction.

[b] Significant differences between Tests 1 and 2.

[c] Significant differences between Test 1 and follow-up.