Published in final edited form as:

J Am Geriatr Soc. 2010 December ; 58(12): 2363–2368. doi:10.1111/j.1532-5415.2010.03155.x.

Are Changes in Leg Power Responsible for Clinically Meaningful Improvements in Mobility Among Older Adults?

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Abstract

Objectives—Mobility as measured by the Short Physical Performance Battery (SPPB) or habitual Gait Speed (GS) is predictive of mortality and disability among older adults. Clinically meaningful changes of these measures have been identified. Among physiologic attributes commonly targeted in rehabilitation, we sought to identify those attributes in which changes led to clinically meaningful differences (CMD) in the mobility outcomes.

Participants—Community-dwelling, mobility-limited older adults (n=116) participating in a 16-week randomized controlled trial (RCT) of two modes of exercise

Setting—Outpatient rehabilitation centers

Design—Secondary analysis of data collected for a RCT of exercise using binary outcomes defined by recording a large CMD (SPPB=1 unit; GS=.1m/s). Iterative models were performed to evaluate possible confounding between physiologic variables and relevant covariates.

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Aspects of this investigation were presented at the May 2008 Annual Assembly of the American Geriatrics Society, Washington, DC.

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Sponsor's role: None; authors retained complete independence in scientific investigation and reporting

Conflict of Interest: Dr. Bean was funded by Dennis W. Jahnigen Scholars Career Development Award, American Geriatrics Society/Hartford Foundation, aNIH Mentored Clinical Scientist Development Award (K23AG019663-01A2) and by the department of PM&R, Harvard Medical School. The Clinical trial from which this analysis was obtained is registered (reg. # NCT00158119). Aspects of this investigation were presented at the May 2010 Annual Assembly of the American Geriatrics Society, Orlando, FL. None of the authors have any financial interests related to this article. None have conflicts of interest, financial arrangements, or consultancies with a company whose product is associated with the submitted manuscript.

Measures—Physiologic measures included leg power, leg strength, balance as measured by the Performance Oriented Mobility Assessment (POMA), rate pressure product (RPP) at the maximal stage of an exercise tolerance test. Outcomes included GS and SPPB. Leg power and leg strength were measured using computerized pneumatic strength training equipment and recorded in Watts and Newtons respectively.

Results—Participants were 68% female, had a mean age of 75.2 years, with a mean of 5.5 chronic conditions and a baseline mean SPPB score of 8.7. After controlling for age, site, group assignment, and baseline outcome values, leg power was the only attribute in which changes were significantly associated with a large CMD in SPPB (OR 1.48, 95% CI 1.09, 2.02) and GS (OR 1.31, 95% CI 1.01, 1.70).

Conclusion—Improvements in leg power, independent of strength, appear to make an important contribution towards clinically meaningful improvements in both SPPB and GS.

Keywords

muscle power; exercise; rehabilitation; aging; aged

INTRODUCTION

Physical performance measures are recognized for their clinical importance, not only because they are representative of limitations in mobility, but also because they are predictive of subsequent adverse outcomes. For example scores on the Short Physical Performance Battery (SPPB) are predictive of future hospitalization rates, nursing home admission, disability and mortality among older adults^{1, 2}. The SPPB is a composite measure of mobility including standing balance, chair stand and gait speed. Additionally, gait speed (GS) alone is also predictive of disability and mortality¹. Therefore, it is not surprising that physical performance tests are advocated as useful outcome measures in research settings and as screening tools in clinical settings^{1, 3}.

A significant advancement for the use of physical performance measures in research has been the definition of clinically meaningful differences (CMD) in both SPPB and GS. In a seminal report by Perera et al., a large CMD in the SPPB and GS was defined as 1 unit and .1 m/s respectively⁴. These findings have been corroborated in a more recent investigation as well⁵. These reports have informed both the design and clinical interpretation of subsequent studies. At this time, the only available therapy believed to be effective in preventing disability is rehabilitative exercise. No drug therapies exist.

Rehabilitative care is designed to correct the impairments that contribute to declines in physical functioning. Impairments are defined as defects in physiologic attributes involving organ systems such as the musculoskeletal system⁶. Impairments that are typically targeted in rehabilitative care, such as loss of strength, power, balance or aerobic capacity have been defined as *Rehabilitative Impairments (RI)*⁷. One RI attribute that is particularly important in underlying physical performance is muscle power. Whereas maximal strength refers to maximal force production, optimum power reflects the maximal product of force and velocity of movement. Cross sectional studies have suggested that though leg muscle power is related to muscle strength it has a larger influence than strength on both SPPB and GS performance⁸. Prospective studies have not adequately addressed this question. This is important because understanding which RI to target in order to achieve a CMD in physical performance can make rehabilitative care more efficacious, more cost effective and less burdensome.

One recently published clinical trial, the InVEST study, was designed with recognition of the clinical relevance of RI and physical performance testing⁹. This was a multi-site randomized clinical trial evaluating 2 modes of rehabilitative exercise for mobility-limited, community-dwelling older adults. One group performed a novel form of resistance training and the other group performed a progressive resistance training program advocated by the National Institute on Aging^{9, 10}. This study presents an ideal context in which this knowledge gap in rehabilitative care can be addressed because: 1) CMD among physical performance measures were reported among both groups after 16 weeks of training; and 2) changes in power, balance, aerobic capacity and strength were achieved. Therefore, we sought to conduct a secondary analysis of the InVEST study in order to determine which observed changes in RI attributes were associated with CMD in both the SPPB and GS. We hypothesized that when accounting for other RI, changes in leg power would be predictive of CMD in SPPB and GS.

METHODS

This was a secondary analysis of results from a single blinded, randomized controlled trial conducted at two outpatient rehabilitation facilities in the greater Boston area. The Institutional Review Boards at Hebrew SeniorLife, Harvard Medical School and the Spaulding Rehabilitation Hospital Network approved conduct of the study. A detailed description of the parent study is published elsewhere⁹.

Participants were community-dwelling older adults ≥ 65 years who scored between 4-10 on an initial screening SPPB and who were able to climb a flight of stairs independently or with use of a cane. Exclusion criteria were unstable acute or chronic disease, a score of less than 23 on the Mini-Mental State Examination¹¹, a neuromusculoskeletal impairment limiting participation in further performance testing, current participation in a resistance training program, or a submaximal treadmill exercise tolerance test with positive findings for unstable cardiovascular disease. All active medical conditions and prescription medications were recorded after completion of a comprehensive history and physical exam conducted by the Principal Investigator (JFB).

Initially, recruitment inquiries were solicited via research volunteer registries, advertising in newspapers, direct mailings and referrals from primary care providers, resulting in 493 telephone screenings. Of these, 265 people were identified as potentially eligible and attended the initial screening assessment described above. On completion of the initial screening, 99 people met exclusion criteria, and 28 chose not to commit to the study, leaving a total of 138 participants who were randomized to one of two exercise programs. One group participated in an exercise program known as InVEST training (Increased Velocity Exercise Specific to Task). This mode of training provided a series of progressive resistance training exercises using a weighted vest for resistance. These exercises were designed to mirror functional tasks and to emphasize speed of movement⁹. The other exercise group participated in a strength training program for the upper and lower limbs using free weights as advocated by the National Institute on Aging¹⁰. Only those participants who completed all 16 weeks of training were included in this secondary data analysis (n= 117).

All measures were conducted by a research staff member blinded to group assignment. Baseline assessments were conducted within 2 weeks of the screening assessment. Leg power and leg strength were measured using computerized pneumatic strength training equipment (Keiser Sports Health Equipment Inc., Fresno, CA) and recorded in Watts and Newtons respectively. Participants were tested on a seated double leg press machine. Seat positions were recorded and replicated at each testing session. Muscle strength was measured at each evaluation using the one repetition maximum (1RM) and leg power was

measured at 70% 1RM as previously described⁷. Balance was measured using the balance component of the Performance Oriented Mobility Assessment. This measure has 8 balance tasks scored between 0 (low) – 2 (high) with a maximum score of 16¹². Though other balance measures were part of the parent study, the POMA-Balance was chosen for this analysis because it is associated with falls and had the least covariance with the balance component of the SPPB. Lastly, as a surrogate of changes in aerobic capacity, we measured the product of heart rate and systolic blood pressure (RPP) at the maximal stage of a submaximal exercise tolerance test performed on a treadmill⁷.

The SPPB is a well-established, reliable and valid measure of lower extremity mobility performance. Testing involves an assessment of standing balance, a timed usual pace 4.0-meter walk and timed test of five repetitions of rising from a chair and sitting down. All times are measured to the nearest 0.01 second using a stopwatch. Each of the three aforementioned tests is scored between 0–4 and summed (0 (disabled) to 12 (independent))^{1, 2}. Gait speed (GS) was derived from the results of the 4.0 meter walk test component of the SPPB. As part of the parent study, the SPPB and GS were recorded both at the screening visit and at a subsequent baseline assessment and the two values were averaged.

Statistical analyses were performed using SASv9.0 (SAS Institute Cary, NC)¹³. Our analytic strategy was formulated to address our hypotheses and to use methods that were easily interpreted from a clinical perspective. All data were initially inspected via descriptive statistics and by visually reviewing graphic display. Descriptive information was reported as means $\pm$ standard deviations for continuous variables and as percentages and counts for categorical variables. Differences were calculated between week 16 and baseline values of both RI variables and the outcomes. We defined clinically meaningful differences as 1.0 unit on the SPPB and .1 unit on GS which is consistent with existing criteria established by Perera and colleagues⁴. Outcomes were further defined as dichotomous variables representing values as either $\geq$ CMD or. To justify inclusion in the same statistical model, correlations between changes in the RI were evaluated. Separate multivariate logistic regression models were constructed predicting CMD in both GS and SPPB. Initial models evaluated changes in Power, POMA and RPP as predictors of the outcomes after adjusting for baseline age, site and treatment group status. Though all impairment measures were treated as continuous variables within the multivariate models, RPP changes were divided into quintiles based on number of participants in order to make the odd ratios more interpretable. Cut points for the quintiles were RPP values of 808, –800, –1898 and –3620. Subsequent models included the addition of changes in strength as well as baseline values of the outcome. We also evaluated the impact of changes in strength alone without changes in power in the model. Lastly, we evaluated each of the final models adjusting for baseline impairment status..

RESULTS

As shown in table 1, among the 117 individuals who completed 16 weeks of training in the InVEST study, the mean age was 75.2 years, 68% were female and the participants manifested an average of 5.5 chronic conditions. Baseline values for the SPPB and GS were 8.7 and .93m/s respectively. Following 16 weeks of exercise training, CMD in SPPB were observed among 92 (79%) of the participants and CMD in GS were observed among 44 (38%). Baseline values for Power, Strength, POMA and RPP were 7.5 W/kg, 19.26 N/kg, 14.5, and 22,286.9, respectively. Group specific values are included. No group comparisons achieved statistical significance. Power change and RPP change approached statistical significance ($p = .06$ and $p = .08$ respectively)

We evaluated Pearson correlation coefficients for changes among the four physiologic attributes in response to training. The correlation between changes in RPP and changes in POMA was significant ($r = .21$, $p = .03$) and the correlation between changes in strength and changes in power approached statistical significance ($r = .19$, $p = .05$). The correlations between changes in power and changes in POMA ($r = .05$; $p = .61$) and changes in RPP ($r = .02$; $p = .87$) were non-significant. Likewise, the correlations between changes in strength and changes in POMA ($r = .10$; $p = .29$) and changes in RPP ($r = .09$; $p = .36$) were non-significant.

Within the multivariate logistic models (Figures 1 & 2) Power was the only attribute significantly associated with a CMD in the SPPB (OR 1.58; 95%CI, 1.15, 2.16) and a CMD in GS (OR 1.34; 95%CI, 1.06, 1.69). Additional adjustment for changes in strength and baseline values of the outcome did not meaningfully attenuate the associations between Power and CMD in SPPB (OR 1.48; 95% CI 1.09, 2.02), or GS (OR 1.31; 96% CI 1.01, 1.70). Change in strength was not a significant predictor of CMD even when changes in power was excluded from the multivariate models. Further models adjusting for gender and baseline values of the RI did not materially alter the findings (data not shown).

DISCUSSION

To our knowledge, this is the first investigation to analyze data from a study of rehabilitative exercise and evaluate impairment predictors of CMD in GS and SPPB. Among the final models leg power was the only RI in which changes were significantly associated with subsequent CMD in both SPPB and GS.

These observations are important in advancing our knowledge regarding the relevance of leg power to mobility. Earlier investigations argued the importance of leg power relative to leg strength through cross-sectional studies. However, this prospective investigation demonstrates that even after controlling for mode of training, changes in leg power were more influential in producing meaningful changes in performance based outcomes than were changes in leg strength⁸. Mechanistically, this is likely due to the fact that power is representative of not only limb force production, as is the case with leg strength, but also limb speed of movement. Previous reports have demonstrated a relationship between both strength and speed of movement with physical performance⁷. In representing both attributes within a single RI, leg power may be more reflective of improvements within both the musculoskeletal and nervous systems occurring from training. This notion that separate impairments may have a synergistic influence on mobility was first introduced in work by Rantanen et al. who coined the term “coimpairments.” In their analysis of the Women’s Health and Aging Study, they found that the combination of impairments in both strength and balance put individuals at higher risk for walking related disability¹⁴. Leg power measurement was not part of their study.

In our investigation, changes in strength were not associated with CMD. However, in a previous investigation by Chandler and colleagues changes in lower extremity strength were predictive of statistical improvements in gait speed and chair stand performance¹⁵. This inconsistency may be due to two reasons. Firstly, our study differed from that of Chandler’s in that we did not measure strength (or power) at more distal limb sites such as the ankle, where higher force and power production during gait may be observed^{16, 17}. Secondly, our sample size was relatively small. The contribution of changes in strength might achieve statistical significance in a study with a larger sample size.

Another important consideration is whether our findings highlight the need for specialized training emphasizing muscle power. Overall, our findings suggest otherwise as treatment

group status was not a significant predictor of the outcomes. This was consistent with the primary analysis of the InVEST study, which observed CMD with both modes of training and with only a non-significant .33 unit difference in SPPB changes between the two intervention groups. This between group difference was less than criteria for a small CMD (.05 units) defined by Perera and colleagues⁴. However, within a subgroup analysis of that investigation it was shown that the response to training differed between treatment groups when baseline impairment status was considered. Among individuals who were below the median for baseline leg speed of movement, the InVEST training produced a .72 unit greater improvement in SPPB compared to the NIA exercise program whereas, the treatment group difference was .09 when evaluated among individuals who were below median strength values at baseline⁹. This led us to conclude that baseline impairment phenotype may be an important factor when considering the response to a specific mode of exercise. This conclusion is reinforced by a meta-analysis of falls and exercise performed by Sherrington and colleagues in which the inclusion of balance training was found to be predictive of reduced falls among fall prone (balance impaired) participants¹⁸. Also, it may account for the relative weak associations ($r = .09-.21$) we observed between changes in the respective physiologic attributes in response to exercise. We performed analyses adjusting for baseline impairment status among all participants and did not observe a significant difference in our findings. A more ideal approach to address this question would be to evaluate whether different impairment phenotype sub-groups exist for whom the response to treatments might differ. Unfortunately, the InVEST study was neither designed nor powered to conduct such a sub-group evaluation as that would require a much larger sample size. Future studies on CMD and the relevance of changes in physiologic attributes will help clarify these questions. At this point, perhaps the best clinical take home message is that the ideal exercise program ought to emphasize exercises that prioritize both strength and speed of movement so that those who are slow can get faster and those who are weak can get stronger.

The primary analysis of the InVEST study did observe a significant difference between groups in limb power improvements, whereas this sub analysis observed differences that approached statistical significance ($p=.06$). This analysis differs in two important ways. The primary analysis was designed to measure changes in a composite measure of both upper and lower limb power, whereas this analysis only focused on leg power. Also, this analysis addressed different scientific aims requiring uses of a sub sample of the original study and employing a different analytic approach than that which was used in the original study. Both of these circumstances reduced statistical power to detect group differences. Even so, given the primary study's original findings, we felt that it remained important to control for group status within all multivariate analysis.

We did not observe an association between change in RPP, a surrogate of aerobic capacity, and physical performance. In part, this may have been reflective of the fact that neither exercise program focused primarily on aerobic exercise. However, substantive changes in RPP from baseline were observed in both groups. This finding is consistent with other investigations that showed weak associations between aerobic capacity and mobility status through cross-sectional analysis and after training^{16, 18}. In this study, RPP served as an indirect estimate for changes in aerobic capacity. Direct measurement of oxygen consumption, was not part of the InVEST study and would be the best means of determining the relevance of changes in aerobic capacity.

Other limitations of our study exist. It is important to recognize that RI are not the only factors contributing to the production of CMD, especially with respect to the SPPB. Individuals in both groups performed exercises as part of the exercise programs that were similar to the chair stand and balance tasks that comprise the SPPB. CMD may be derived

from improvements in both behavioral and physiologic factors that are reflective of task specific training and that were not adequately addressed by these four impairments. Also, it may be more clinically meaningful to categorize changes in RI by using clinically relevant cut-points. However, such analyses can only be conducted with much larger samples. We were not able to include 21 participants who dropped out of the study before week 16, which may have limited our ability to observe relationships in some multivariate analyses. A more detailed comparison between these participants and the remaining cohort is mentioned elsewhere⁹. Lastly, this was not a population-based sample but a rather homogenous cohort of mobility limited volunteers for a randomized trial. Thus we cannot generalize our findings to all mobility-limited older adults living in the community. Nonetheless, our analyses of trial results allow us to observe patterns of changes in RI and mobility performance that would not be likely to occur in an aged cohort without some form of intervention.

Despite these limitations, the strengths of our study include its longitudinal design, inclusion of a diverse cohort from the standpoints of health and physical functioning, inclusion of multiple RI and use of state of the art impairment and physical performance measures.

In summary, we found that changes in leg power were significantly associated with CMD in SPPB and GS. These relationships should be evaluated in larger studies to better understand the relative importance of different RI and the clinical significance of impairment phenotypes on changes in physical functioning.

Acknowledgments

Funding sources and related paper presentations

Dr. Bean and the project were funded through the Dennis W. Jahnigen Scholars Career Development Award, American Geriatrics Society/Hartford Foundation, aNIHMentored Clinical Scientist Development Award (K23AG019663-01A2) and by the department of PM&R, Harvard Medical School. Clinical trials reg. # NCT00158119.

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Figure 1.
Multivariate logistic models predicting clinically meaningful differences (CMD) in the SPPB among participants completing 16 weeks of training in the InVEST study (N= 117)
Model 1: adjusted for age, site, treatment group
Model 2: Model 1 + Δ Strength, baseline value of outcome
RI: Rehabilitative Impairment
CMD: Clinically Meaningful Difference
SPPB: Short Physical Performance Battery Δ Balance: Change in score on the POMA balance test
 Δ Power: Change in Leg Power
 Δ POMA: Change in Performance Oriented Mobility Assessment – Balance Score
 Δ RPP: Change in Rate Pressure Product (heart rate $\times$ systolic blood pressure)

Figure 2.

Multivariate logistic models predicting clinically meaningful differences (CMD) in gait speed among participants completing 16 weeks of training in the InVEST study (N= 117)

Model 1: adjusted for age, site, treatment group

Model 2: Model 1 + Δ Strength, baseline value of outcome

RI: Rehabilitative Impairment

CMD: Clinically Meaningful Difference

SPPB: Short Physical Performance Battery

Δ Balance: Change in score on the POMA balance test

Δ Power: Change in Leg Power

Δ POMA: Change in Performance Oriented Mobility Assessment– Balance Score

Δ RPP: Change in Rate Pressure Product (heart rate $\times$ systolic blood pressure)

Table 1

Characteristics of participants completing all 16 weeks of training in the InVEST study (N=117).

Characteristics	All Subjects		InVEST Group		NIA Group	
	Mean (s.d.) or Frequency (%)	Range	Mean (s.d.) or Frequency (%)	Range	Mean (s.d.) or Frequency (%)	Range
Age (years)	75.2 (6.7)	65–94	74.8 (6.5)	65–94	75.6 (6.8)	65–92
Female Gender	80 (68%)		40 (69%)		40 (68%)	
Chronic Conditions (#)	5.5 (2.4)	1–14	5.5 (2.2)	1–11	5.5 (2.6)	2.0–14.0
Baseline average SPPB (out of 12)	8.7 (1.5)	4.5–11	8.6 (1.5)	5–11	8.6 (1.4)	4.5–11
CMD in SPPB	92 (79%)		47 (81%)		45 (76%)	
Baseline Gait Speed (m/s)	.93 (.23)	.45–1.60	.93 (.23)	.45–1.53	.93 (.24)	.48–1.60
CMD in Gait Speed	44 (38%)		21 (36%)		23 (39%)	
Baseline Power (W/kg)	7.50 (3.28)	1.23–16.41	7.53 (2.85)	1.23–15.87	7.47 (3.67)	1.73–16.41
Δ Power	.58 (2.06)	–8.69–7.50	.95 (1.88)	–2.47–7.50	.22 (2.19)	–8.69 – 5.48
Baseline POMA	14.5 (1.9)	7.0 – 16.0	14.6 (2.0)	7–16	14.4 (1.9)	9–16
Δ POMA	.56 (1.68)	–5.0 – 6.0	.66 (1.68)	–5.0 – 6.0	.46 (1.70)	–4.0 – 5.0
Baseline Strength (N/kg)	19.26 (8.62)	6.99 – 43.99	19.36 (8.90)	6.99–43.99	19.16 (8.41)	7.22–36.50
Δ Strength	3.87 (4.50)	–14.29– 22.19	3.90 (4.29)	–14.29– 15.12	3.85 (4.72)	–6.33
Baseline RPP (HR*SBP)	22,286.9 (4882)	10,304– 34,200	21497.4 (5223.0)	10304– 32340	23062.9 (4430.0)	12600– 34200
Δ RPPmax	–1486.9 (3234)	–12,838– 7,172	–1827.7 (3383.7)	–12838– 4998	–1164.6 (3082.8)	–9210.0–7172.0

Note: Group comparisons all with $p > .05$

SPPB: Short Physical Performance Battery

Balance: score on the POMA balance test

Power: Leg Power

POMA: Performance Oriented Mobility Assessment – Balance Score

RPP: Rate Pressure Product (heart rate $\times$ systolic blood pressure)

W: Watts

N: Newtons