

# Effects of bioDensity Training and Power Plate Whole-Body Vibration on Strength, Balance, and Functional Independence in Older Adults

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Reduced strength, balance, and functional independence diminish quality of life and increase health care costs. Sixty adults ( $82.2 \pm 4.9$  years) were randomized to a control or three 12-week intervention groups: bioDensity (bD); Power Plate (PP) whole-body vibration (WBV); or bD+PP. bD involved one weekly 5-s maximal contraction of four muscle groups. PP involved two 5-min WBV sessions. Primary outcomes were strength, balance, and Functional Independence Measure (FIM). No groups differed initially. Strength significantly increased 22–51% for three muscle groups in bD and bD+PP ( $P < .001$ ), with no changes in control and PP. Balance significantly improved in PP and bD+PP but not in control or bD. bD, PP, and bD+PP differentially improved FIM self-care and mobility. Strength improvements from weekly 5-min sessions of bD may impart health/clinical benefits. Balance and leg strength improvements suggest WBV beneficially impacts fall risk and incidence. Improved FIM scores are encouraging and justify larger controlled trials on bD and bD+PP efficacy.

**Keywords:** risk of falling, ADL, learning effect

Twenty percent of today's population is aged 60 years or over in developed countries, and this proportion is expected to rise to 32% by 2050 (Secretariat, 2005). Aging is associated with an increased risk of falling (Hu, Xia, Jiang, Zhou, & Li, 2015), diminished balance (Howe, Rochester, Neil, Skelton, & Ballinger, 2011), reduced ability to perform activities of daily living (ADL), and impaired functional independence (Dong, Chang, & Simon, 2014; Sakari-Rantala, Heikkinen, & Ruoppila, 1995). It is estimated that by 2040, 44 million Americans will have at least some physical limitation and, of those, 16 million will have at least one ADL limitation (Waidmann & Liu, 2000), such as eating, bathing, dressing, and remaining mobile. The Administration on Aging's 2012 report indicates that 28% of Medicare beneficiaries aged 65+ reported difficulty performing one or more ADL (U.S. Department of Health and Human Services, Administration on Aging, 2012). ADL are a component of functional independence (Ostbye, Tyas, McDowell, & Koval, 1997; White, Wilson, & Keysor, 2011), but have also been used as a measure, e.g., the 30-s chair-stand test is a reliable and validated measure of lower body strength (Jones, Rikli, & Beam, 1999; Rikli & Jones, 2013). Functional independence is multifactorial, integrating several physical abilities such as muscular strength and balance, as well as social and cognitive components.

Safe and efficacious interventions that combat age-related declines in functional independence and its components are needed and have a long and ongoing research history. Over the past decade, advancements in scientific knowledge and technology have introduced new interventions that warrant investigation and validation. In the areas of preserving and improving muscular strength and balance, high-intensity resistance training and technologies such as

eccentric stepping have demonstrated encouraging findings across diverse populations. Studies comparing standard exercise programs to eccentric stepping (30–40% greater force production than a concentric contraction) have shown greater strength improvements in Parkinson's disease patients (Dibble et al., 2006), type 2 diabetes patients (Marcus et al., 2008), frail elders (LaStayo, Ewy, Pierotti, Johns, & Lindstedt, 2003), and total knee arthroplasty patients (LaStayo et al., 2009). The latter two studies also demonstrated improvements in mobility tasks and fall risk, respectively. Hagerman and colleagues (2000) found that older men (60–75 years) not only tolerated a 16-week high-intensity resistance training program (2x/week at 85–90% of 1-repetition maximum), but lower body strength increased 50–83% across different muscle groups; these results were supported by increased cross-sectional area of all fiber types. Similarly, balance improvements have been reported in older men performing 8–12 weeks of low, moderate, and high-intensity power resistance training (RT) programs (Orr et al., 2006) and in older men and women performing high-intensity functional weight-bearing exercises (Littbrand et al., 2011).

BioDensity (bD) is a relatively new high-intensity, low-volume approach to RT (Smith, Moynes, Rockey, Conviser, & Skinner, 2014). To date, it has not been empirically validated. If efficacious, this low-volume approach (5 min per week) may overcome exercise adherence/compliance issues related to "lack of time" and could impart multiple benefits (i.e., strength, balance, and functional independence) that are aligned with previous high-intensity RT evidence (Hagerman et al., 2000; Hayes, Gappmaier, & LaStayo, 2011; Littbrand et al., 2011; Orr et al., 2006; Singh et al., 2012).

Whole-body vibration (WBV) is another technology that has received attention in the areas of balance, mobility, and fall prevention/incidence in older adults. A 2012 meta-analysis by Lam, Lau, Chung, and Pang found that WBV improved Tinetti Total Balance score, Tinetti Body Balance score, and timed get-up-and-go test, but the evidence for other balance, mobility, and fall-rate measures was inconclusive. They concluded that WBV may be effective in improving relatively basic balance abilities and mobility among older adults. Another review reported that WBV significantly improved knee isometric strength, muscle power, and balance

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control (Sitja-Rabert et al., 2012). They concluded that these effects were similar to those seen with conventional exercise programs and significantly better than effects seen in the control group.

Because muscular strength and balance are contributing factors to functional independence (mobility and self-care) and fall risk in older adults (Adamo, Talley, & Goldberg, 2015; Binder et al., 2002; Chin A Paw, van Uffelen, Riphagen, & van Mechelen, 2008; Narici, Reeves, Morse, & Maganaris, 2004), we were interested in assessing the efficacy of low-volume and high-intensity bD training, WBV, and the combination of the two training modes in older adults. Accordingly, the primary purpose of the current study was to determine whether 12 weeks of bD training, WBV training, or the combination would improve muscular strength, balance, and functional independence in older adults. A secondary purpose was to assess the association between the hypothesized bD-induced increases in strength and changes in balance and functional independence.

## Methodology

### Design and Participants

This was a 12-week randomized control trial. Participants were between the ages of 65–90 and resided in two assisted-living centers in New Jersey; participants were free from uncontrolled cardiometabolic disease, respiratory disease, neurological disease, osteoporosis, and acute illness/injury, unless approved by a health care provider to participate. Participants had no limitations/contraindications to exercise and voluntarily consented to participate. The research was approved by a human research institutional review board at the University of Wyoming.

Participants were randomly assigned to one of four groups: (1) control (maintain existing lifestyle); (2) two 5-min sessions per week of WBV (PowerPlate, PP); (3) one 5-min session per week of bD training (bD); or (4) one 5-min session of bD training combined with two 5-min sessions of WBV (bD+PP). Blood pressure and heart rate (after 5 min of rest), height/weight/body mass index, and functional independence measures (Stineman, Jette, Fiedler, & Granger, 1997) were collected at baseline and 12 weeks. At baseline, six weeks, and 12 weeks, the following measures were performed: (1) maximal chest press, leg press, core pull, and vertical lift force production via bD equipment; (2) static and dynamic balance total score via Korebalance (Med-Fit Systems, Fallbrook, CA).

### bioDensity (bD)

According to the manufacturers, bD (Performance Health Systems, Inc., Northbrook, IL) is the brand name for the RT equipment and a commercially developed approach to “neuromuscular and osteogenic loading” (Jaquish, Singh, Hynote, & Conviser, 2012). Although the bD equipment and approach have been previously described in detail (Smith et al., 2014), a brief description and background are warranted. At the foundation of bD’s design and development (2005) was the need for a “safe, self-induced, osteogenic loading stimulation” inducing a neuromusculoskeletal stimulus that provides levels of loading up to multiples of body weight (Jaquish et al., 2012; Smith et al., 2014). It appears evident from the manufacturer and equipment development that the guiding health-related applications of bD were to promote bone and neuromuscular health (BioDensity, 2012; Jaquish et al., 2012).

bD is being used across the country in rehabilitation, fitness, clinical, and research settings (two universities known); the reported injury incidence is low (Jaquish et al., 2012) and appears to be below rates for traditional RT approaches (2–12 injuries per 100 training

sessions) (Pollock et al., 1991). The equipment appears similar to a traditional cable-pulley, weight-training machine, but there are no weights, cables, or pulleys. The bD apparatus is equipped with a technician control station (laptop computer) and two monitors viewable by participants from two exercise positions. Three exercises are performed in a seated position and one exercise is performed in a standing position. The seated exercises include a “chest press”, “leg press”, and combination chin-up with abdominal/hip-flexor crunch or “core pull”. The standing exercise is similar to a high-hang (handgrip bar at the upper thigh) deadlift or “vertical lift”.

All four bD exercises were performed once a week and consisted of a 5-s maximal voluntary exertion with encouragement by the technician. This approach differs significantly from more customary RT prescriptions of multiple sessions per week, intensity below the one-repetition maximum, and multiple sets/repetitions. Achieving “maximal-voluntary exertion” is supported by real-time visual feedback to the user on the monitor. The monitors display the previous sessions’ peak force and 75% of peak force while the 5-s bout is being performed (real-time). The goal is to achieve or exceed the previous session’s peak force production for each exercise and to load the neuromusculoskeletal system at multiples of body weight.

The exercise position is customized for each user so that all four exercises are performed at or near “optimal biomechanical positioning” (i.e., joint angles) to safely facilitate maximal force production (Jaquish et al., 2012). In addition, all four exercises are limited-range (1–2 cm of movement) muscle contractions. Unlike most conventional RT equipment where load is imposed by holding a weight, moving a weight through space, or managing the movement of a load via a system of cables and pulleys, the bD loading event is an entirely self-induced maximal-voluntary activation of the neuromusculoskeletal system.

### Accounting for bioDensity Learning Effect

Familiarization and learning effects have been found to influence strength performance and quantification of maximal strength in novice and experienced weight trainers when performing/learning a new RT exercise (Amarante do Nascimento et al., 2013; Levinger et al., 2009; Ritti-Dias, Avelar, Salvador, & Cyrino, 2011; Rydwik, Karlsson, Frandin, & Akner, 2007; Smith et al., 2014; Soares-Caldeira et al., 2009). The collective recommendations from this evidence are that strength be tested more than once to eliminate or minimize the impact of learning/familiarization on accurate quantification of baseline strength and/or multiple practice opportunities should be provided before performing a maximal strength measurement. To account for this in the current study, a two-session bD familiarization protocol was employed for all participants during the baseline measurement period.

In session 1, participants were introduced to the bD equipment and performed a familiarization trial after correct positioning was determined for each of the four exercises (recorded in the software application for repeat training sessions). The first practice trial included performing all four bD exercises at a light exertion level in sequence (chest press, leg press, core pull, and vertical lift). Participants then repeated the sequence twice more, escalating the level of effort (intensity) with each sequence and working toward a near maximal effort for each exercise in the third and final sequence. No data were recorded from the first familiarization session. Session 2 was done a week later and included performing the exercise sequence at a moderate-to-high (but not maximal) effort level. After allowing the participants to rest as long as they wished, a final sequence of four maximal-voluntary efforts was performed and recorded as the baseline measure of strength. Because the bD

and bD+PP groups returned the next week for their first group-specific training sessions, force production data between baseline and the first formal bD training session were compared to determine whether the familiarization protocol minimized learning/familiarization effects.

### Static and Dynamic Balance Tests

Balance tests were performed on the Korebalance equipment. Each test was preceded by three preliminary trials to familiarize participants with the equipment and to minimize any learning effects. Participants stood on a variable stability platform and viewed the display monitor. The static test was a 1-min stand with eyes open, moving the platform to keep the center of pressure dot on the target at the center of the screen. The dynamic test was 1 min with eyes open, moving the platform to track a slow-moving, large target in a circular motion. For both tests, time and distance from the target were measured and displayed as an absolute number ranging from 0 to 5,000. The lower the score, the closer the participants were to the target and the better their balance.

### Functional Independence Measure (FIM) Assessment

The FIM scale assesses physical and cognitive disability (Stineman et al., 1997). In a cross-sectional analysis of 93,829 patients discharged from 252 rehabilitation hospitals, the FIM instrument has been shown to have high subscale internal consistency (96.9%) and high item discriminant validity; reliability for the physical and cognitive subscales ranged from 0.86 to 0.97 (Stineman et al., 1996). The scale focuses on the burden of care (i.e., the level of disability). It also is used to measure progress and assess rehabilitation outcomes. Items are scored on the level of assistance required for an individual to perform ADL. The scale includes 18 items, of which 13 items are physical domains and five items are cognition domains. Each item is scored from 1 to 7 based on level of independence, where 1 represents total dependence and 7 indicates complete independence.

### Intervention Programs

**bioDensity Training (bD).** Participants in the bD and the bD+PP groups completed one session per week for 12 weeks. Each session required approximately 5 min to complete, during which participants were physically active for only 20 s (four 5-s maximal contractions). Before and during sessions, participants were instructed/educated on proper form, technique, and breathing to avoid and prevent injury. Every session was supervised by a technician who positioned the participant, and participant performance data were electronically recorded for each of the four exercises by the software.

**PowerPlate Training (PP).** The PP group completed two 5-min sessions per week for 12 weeks. The bD+PP group also had two sessions per week, with one session performed after the bD session. Participants were in a static, semisquatting position. While lightly holding the supporting handles, they lifted one foot, then the other for 60 s, followed by 60 s of rest. This was repeated for a total of 3 min during a 5-min session. There was a minimum of two days between PP sessions each week. During the first two weeks, the Power Plate was set on its easiest perturbation setting: 30 Hz with 1-mm amplitude. Vibration was then increased to 2 mm of amplitude/vibrational displacement, providing a greater level of destabilization and stimulating more reflexive muscular activity.

### Statistical Analyses

Due to unequal variance and absence of normal distribution for some of the variables, nonparametric and parametric analyses were conducted. A  $2 \times 2$  (group  $\times$  time) repeated measures analysis of variance (ANOVA) was used to test for main and interaction effects for change in: (1) force production (strength); (2) balance (static and dynamic); (3) FIM subcomponent scores (mobility, self-care, communication, and social cognition); and (4) participant descriptors. Bonferroni *t* test (corrections) were employed as post hoc analyses for data that met assumptions of normality and equal variance. Kruskal-Wallis analysis of variance on ranks was used for data that failed tests of normality or equal variance. Percent change (baseline to 6 or 12 weeks) was calculated for some of the variables of interest and compared between groups (one-way ANOVA) and used to describe the data. Linear and multiple linear regression analyses were employed to assess associations between variables of interest. For the bD learning effect analyses, Pearson product moment correlations were also calculated to determine agreement between the first two consecutive force production sessions, which informed the extent to which the familiarization protocol minimized learning effect. Data are presented for parametric and nonparametric analyses, mean  $\pm$  SD or standard error of mean (SEM) and median, and 25% and 75% confidence intervals, respectively. Statistical analyses were performed with Sigma Plot 11.0 (Systat Software Inc., Chicago, IL) and significance was set a priori at  $p < .05$ .

## Results

### Participant Descriptive Characteristics

Seventy-three older adult participants responded to recruitment advertisements, expressed interest in participating, and qualified for participation. Thirteen participants failed to complete intake or had incomplete data due to: (1) failure to complete assigned group-specific obligations (intervention group(s) adherence;  $N = 8$ ); (2) failure to complete required 6- and 12-week assessments (compliance;  $N = 2$ ); (3) drop out/attrition due to no reason or lack of time ( $N = 2$ ); and (4) death (unrelated to the research study or interventions;  $N = 1$ ). Complete data were acquired and analyzed for 60 participants (60% female). Table 1 presents descriptive characteristics for the sample according to random group allocation (control, bD, PP, and bD+PP) and by sex. Overall, there were no significant differences in baseline descriptive characteristics between groups (Table 1). In all four groups and in males and females, there were no statistically significant changes at 12 weeks for body mass index, systolic and diastolic blood pressure, and heart rate. The only notable observation was in the bD group, where diastolic blood pressure at 12 weeks trended toward a significant reduction ( $73 \pm 8$  vs.  $69 \pm 6$  mmHg;  $p = .059$ ).

### Accounting for Force Production Learning Effect

Analysis of consecutive bD force production sessions (baseline and training session 1) in the bD and bD+PP groups revealed no differences in absolute force production between the groups or between sessions (Table 2; *F*-statistics and *P*-values). Change between the consecutive sessions (bD and bD+PP groups collapsed) for each of the four bD exercises ranged from 0.65% to 7.8%. With exception of the core pull exercise, correlation coefficients between consecutive sessions were significant and showed high agreement (Table 2).



**Table 1 Participant Descriptive Characteristics by Group and by Sex (N = 60)**

Characteristic	Group				Sex		Between Group <i>p</i> -value	Between Sex <i>p</i> -value
	bD (n = 16)	bD + PP (n = 17)	PP (n = 13)	Control (n = 14)	Females (n = 36)	Males (n = 24)		
Age (years)	80.5 ± 6.2	83.4 ± 5.0	82.2 ± 5.0	81.7 ± 5.7	81.0 ± 5.7	83.4 ± 4.1	.5	.08
BMI (kg/m <sup>2</sup> )	24.3 ± 3.3	26.2 ± 3.6	26.2 ± 3.6	27.2 ± 6.1	25.2 ± 4.4	27.0 ± 3.8	.3	.1
Weight (kg)	66.8 ± 6.8	74.5 ± 6.7	75.4 ± 7.8	72.3 ± 7.4	65.6 ± 3.8	82.1 ± 4.6	.07	< .01
SBP (mmHg)	134 ± 11	130 ± 15	131 ± 10	132 ± 15	132 ± 12	132 ± 14	.8	.9
DBP (mmHg)	73 ± 8	67 ± 8	74 ± 9	74 ± 7	72 ± 9	71 ± 8	.06	.8
RHR (bpm)	69 ± 7	69 ± 9	71 ± 11	72 ± 7	71 ± 8	69 ± 8	.7	.4

Abbreviations: bD = bioDensity; PP = Power Plate; BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure; RHR = resting heart rate.  
*Note.* Mean ± SD.

**Table 2 bioDensity Force Production Learning Effect Analyses (N = 33; bD and bD+PP Groups)**

bD Exercise	Force Production bD versus bD+PP		Percent Change Baseline to Session 2*		Correlation Baseline and Session 2*	
	<i>F</i> -statistic	<i>P</i> -value	Median	CI	Coefficient	<i>p</i> -value
Chest press	0.015	.9	.65	0.0;24.2	.8	< .01
Leg press	0.519	.47	7.8	-1.6;16.7	.87	< .01
Core pull	0.026	.87	4.2	-5.1;12.2	.28	.11
Vertical lift	0.043	.84	6.3	-10.8;24.7	.82	< .01

Abbreviations: bD = bioDensity; PP = Power Plate; CI = confidence interval.

*Note.* \* bD and bD+PP groups collapsed due to similar ( $P > .05$ ) force productions at baseline.

## Force Production (Strength)

At baseline, the chest press, leg press, core pull, and vertical lift force productions were similar across all four groups (control, bD, PP, and bD+PP; Figures 1–3). For the core pull exercise, there were no main or interaction effects (group × time) for force production ( $F = 1.75$ ;  $p = .12$ ). In addition, no change in force production occurred in the control or PP groups for chest press, leg press, or vertical lift exercises over time (baseline to 6 and 12 weeks; Figures 1–3).

Significant group-by-time interactions were observed for the chest press ( $F = 4.11$ ;  $p < .01$ ), leg press ( $F = 5.29$ ;  $p < .01$ ), and vertical lift ( $F = 5.24$ ;  $p < .01$ ). Post hoc analyses demonstrated that strength increased from baseline to six weeks and baseline to 12 weeks ( $p < .05$  for both time points), but strength at 12 weeks was not greater than that at six weeks in the bD group. These findings are consistent for the chest press, leg press, and vertical lift (Figures 1–3). Overall, vertical lift force production change in the bD group was significantly greater than that seen in the control group but not in bD+PP or PP groups. Across the 12-week intervention period, increases in chest and leg press force production in bD were significantly different from those seen in PP, but the improvements were not different from those in control or bD+PP.

For bD+PP, chest press strength improved from baseline to six and 12 weeks, and 12-week strength was significantly greater than that at six weeks (Bonferroni *t* test 2.6;  $p = .03$ ). The overall improvement was significantly greater than that seen in control and PP but not in bD (Figure 1). Similar findings were observed for the leg press and are presented in Figure 2, but force production at six

and 12 weeks was not different ( $p > .05$ ). The bD+PP group also had an overall improvement in vertical lift force production (baseline to 12 weeks) that was significantly greater than that of the control group (Figure 3).

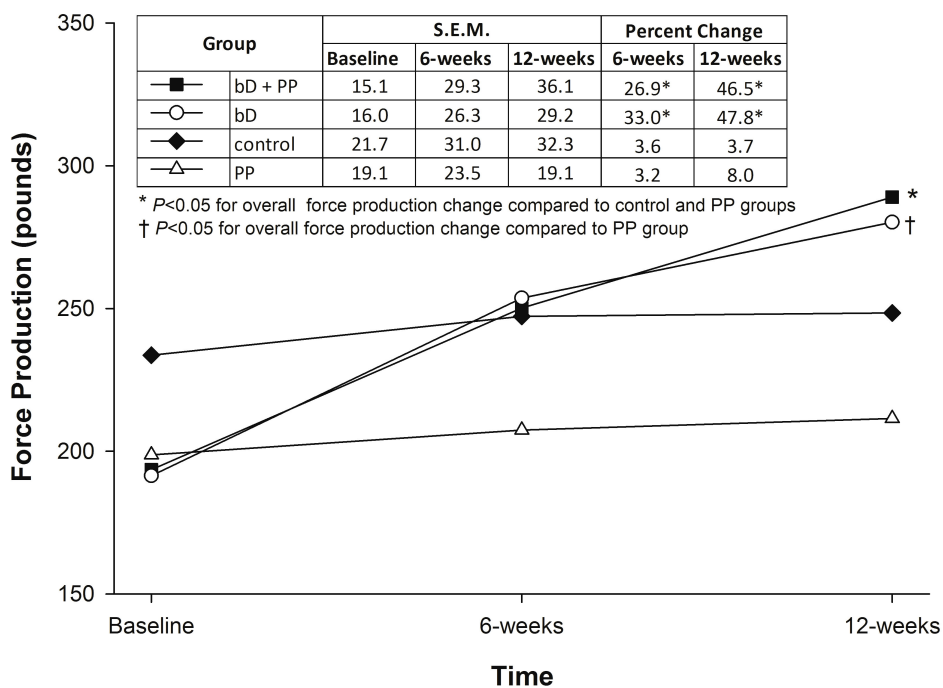
WBV (PP group) did not significantly change chest press, leg press, core pull, or vertical lift force productions (Figures 1–3). Comparison of force production percent changes from baseline to six and 12 weeks in all four groups are reported in Figures 1–3 table inserts. For bD and bD+PP, percent changes in chest and leg press force productions at six and 12 weeks were significantly higher than those of control and PP. For vertical lift, percent change at six and 12 weeks was only significant in bD compared with control; this is attributable to the lower (albeit not statistically different) baseline in bD and the significant increase in force production at six weeks (Figure 3 and table insert).

## Balance

At baseline, static balance was similar in all four groups (Figure 4). A significant group-by-time interaction was found for static balance ( $F = 2.48$ ;  $p = .02$ ). Post hoc analyses revealed no significant changes in the control, bD, or PP groups at six or 12 weeks (Figure 4). Static balance improved 24% in the bD+PP group at 12 weeks (Figure 4); this improvement was significantly different from that seen in the control group at 12 weeks. Change in static balance was not associated with force production.

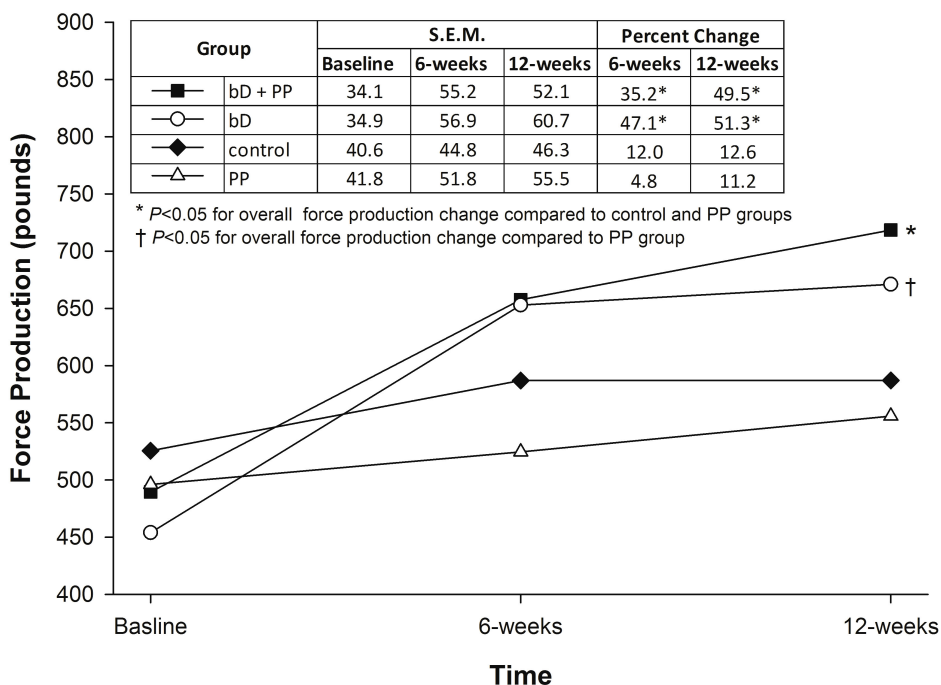
Dynamic balance was similar among groups at baseline (Figure 5). While no group-by-time interaction was found, there was a main effect of time in PP and bD+PP. The PP group had improvements of 27% and 24% at six and 12 weeks, respectively (Figure 5). Dynamic

## Chest Press



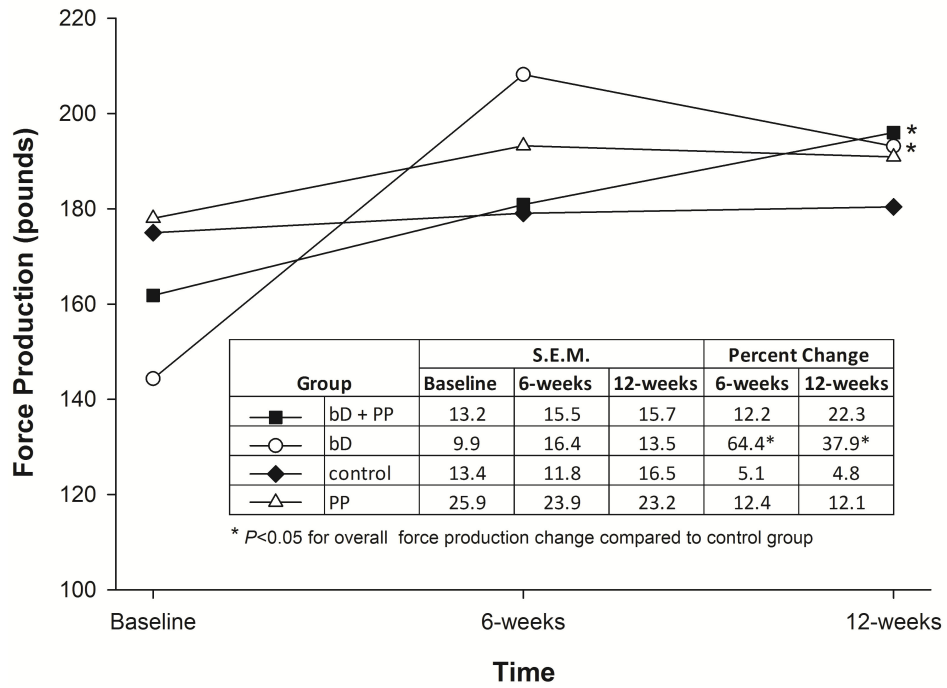
**Figure 1** — Chest press (CP) force production and percent change at 6 and 12 weeks ( $N = 60$ ). bD = bioDensity; PP = Power Plate; SEM = standard error of mean.

## Leg Press



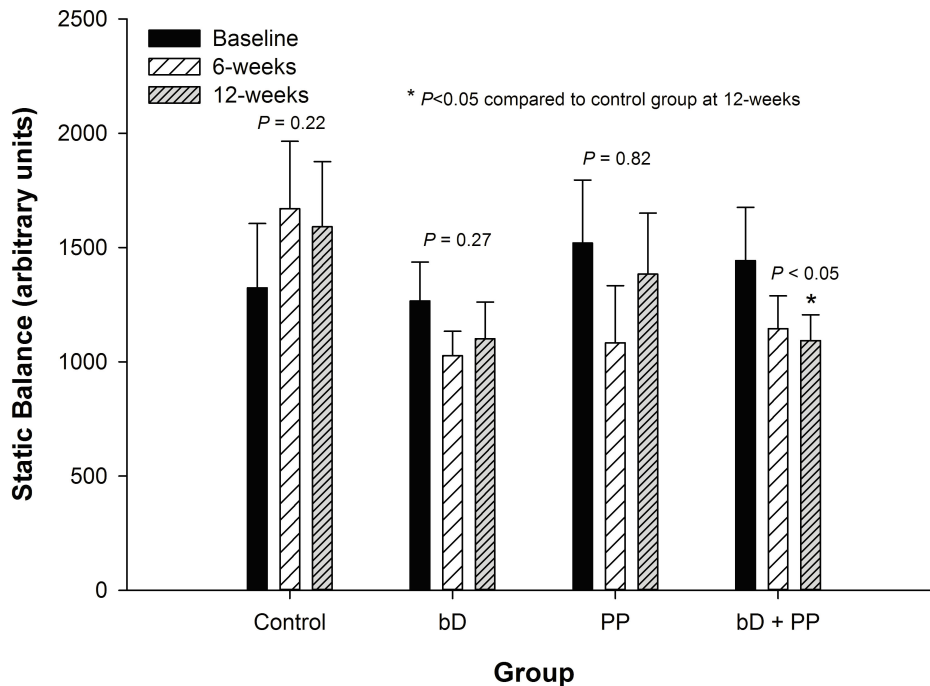
**Figure 2** — Leg press (LP) force production and percent change at 6 and 12 weeks ( $N = 60$ ). bD = bioDensity; PP = Power Plate; SEM = standard error of mean.

### Vertical Lift



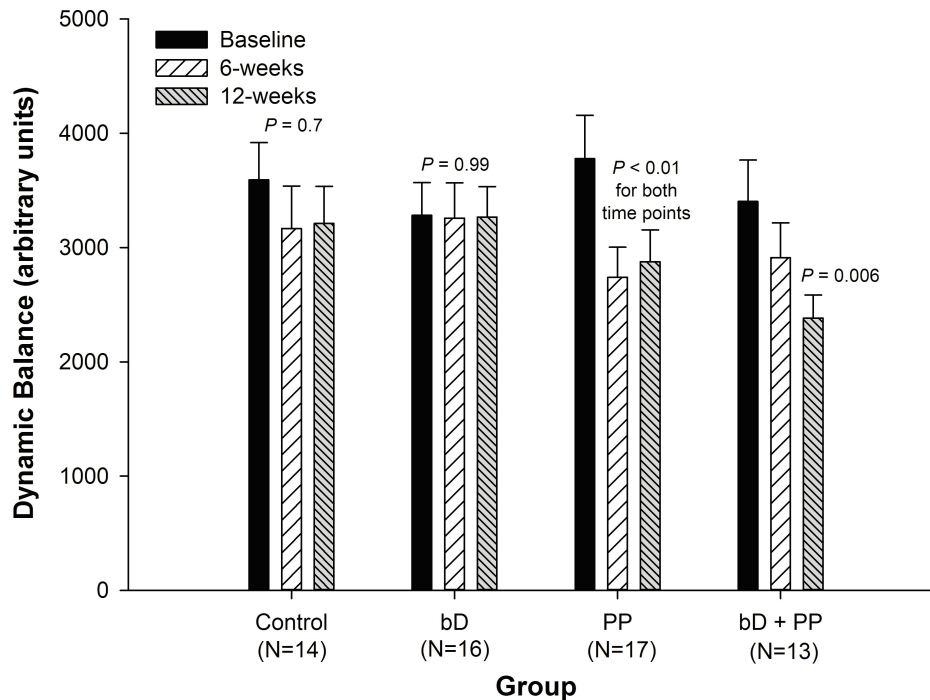
**Figure 3** — Vertical lift (VL) force production and percent change at 6 and 12 weeks ( $N = 60$ ). bD = bioDensity; PP = Power Plate; SEM = standard error of mean.

### Static Balance



**Figure 4** — Static balance at 6 and 12 weeks ( $N = 60$ ). bD = bioDensity; PP = Power Plate.

## Dynamic Balance



**Figure 5** — Dynamic balance at 6 and 12 weeks ( $N = 60$ ). bD = bioDensity; PP = Power Plate; SEM = standard error of mean.

balance in the bD+PP group improved 30% but only at 12 weeks (Figure 5). The respective changes at six and 12 weeks by PP and bD+PP were not significantly different from those seen in the other groups (i.e., no effect of group). Weak but significant associations were present for dynamic balance percent change and vertical lift force production at 12 weeks ( $R^2 = .12$ ;  $p < .01$ ) and vertical lift percent change (baseline to 12 weeks;  $R^2 = .08$ ;  $p = .03$ ).

**Functional Independence Measure.** At baseline, there were no differences in any of the four FIM subcomponent scores (self-care, mobility, communication, and social cognition) across the four groups ( $p > .05$  for all) (Table 3). Two-way RMANOVA demonstrated group-by-time interactions for self-care ( $F = 4.33$ ;  $p < .01$ ) and mobility ( $F = 6.15$ ;  $p < .01$ ) but no effect of intervention group or time for the communication or social cognition subcomponents.

Post hoc analyses revealed that self-care improved significantly in the bD+PP group compared with the control group at 12 weeks (Bonferroni  $t$  test = 3.18;  $p = .01$ ); however, the improvement was not different from that seen in the bD or PP groups. bD also improved self-care from baseline to 12 weeks (Bonferroni  $t$  test = 2.43;  $p = .02$ ), but the change was not different from that seen with any of the other groups. Change in leg press force production (across the entire sample) was positively associated with improved self-care, albeit explaining only 17% of the change ( $p < .01$ ). Change in leg press force production was also weakly associated with absolute self-care scores at 12 weeks ( $R^2 = .09$ ;  $p = .03$ ). Similarly, change in vertical lift force production was positively associated with change in self-care ( $R^2 = .09$ ;  $p = .03$ ). Multiple linear regression combining leg press and vertical lift force productions as predictors of change in self-care at 12 weeks did not improve the univariate models. Change in chest press force production (previously described) was not associated with self-care percent change or 12-week scores.

Similar findings were observed for the FIM mobility subcomponent in the bD+PP group but were also extended to include the bD and PP groups. Compared with the control group, mobility improved from baseline to 12 weeks in bD+PP (Bonferroni  $t$  test = 3.39;  $p < .01$ ) and bD (Bonferroni  $t$  test = 3.04;  $p = .02$ ). While there was no statistically significant group  $\times$  time interaction effect for mobility in PP from baseline to 12 weeks, mobility at 12 weeks in PP was significantly better than mobility of the control group at 12 weeks (Bonferroni  $t$  test = 2.76;  $p = .04$ ). Across the sample, both chest press ( $R^2 = .13$ ;  $p < .01$ ) and leg press ( $R^2 = .13$ ;  $p < .01$ ) force production changes were weakly but independently associated with change in mobility. Multiple linear regression incorporating chest and leg press force productions as predictors of change in mobility minimally improved the weak but positive association ( $R^2 = .14$ ;  $p = .02$ ).

## Discussion

Interventions that favorably impact physical strength, balance, and functional independence of older adults may have significant value at the individual and health care cost levels. The primary findings from this 12-week study in older adults, with a median age of 82 years, are as follows. First, chest press, leg press, and vertical lift strength increased as a result of once-per-week bD training with or without concomitant weekly WBV. For chest press and vertical lift strength, the addition of twice-weekly WBV appears to have augmented the improvements, such that the increases in strength were significantly greater than those seen in the control and WBV-only conditions. Vertical lift strength improved as a result of bD training but was not enhanced by twice-weekly WBV.

**Table 3 Functional Independence Measure (FIM) Subcomponent Scores (Median [25;75% CIs])**

FIM Component	Control (N = 14)		bD Group (N = 16)		PP Group (N = 13)		bD+PP Group (N = 17)	
	Baseline	12 weeks	Baseline	12 weeks	Baseline	12 weeks	Baseline	12 weeks
Self-care	6.6 (6.4;7.0)	6.6 (6.4;6.9)	6.7 (6.6;6.8)	6.8* (6.7;7.0)	6.9 (6.6;7.0)	7.0 (6.8;7.0)	6.8 (6.6;6.9)	6.9*† (6.8;7.0)
Mobility	6.6 (6.2;6.8)	6.6 (6.3;6.7)	6.6 (6.6;6.8)	6.8*† (6.8;7.0)	6.8 (6.6;6.8)	6.9* (6.6;7.0)	6.7 (6.4;6.8)	6.9*† (6.8;6.9)
Communication	7.0 (6.3;7.0)	7.0 (6.0;7.0)	7.0 (7.0;7.0)	7.0 (7.0;7.0)	7.0 (7.0;7.0)	7.0 (7.0;7.0)	7.0 (6.5;7.0)	7.0 (7.0;7.0)
Social cognition	7.0 (6.3;7.0)	6.7 (6.5;7.0)	7.0 (6.7;7.0)	7.0 (6.7;7.0)	6.7 (6.3;7.0)	7.0 (6.3;7.0)	7.0 (6.4;7.0)	7.0 (7.0;7.0)

Abbreviations: bD = bioDensity; PP = Power Plate; CI = confidence interval.

\*  $P < .05$  compared with baseline (0 weeks) within group.

†  $P < .05$  compared with control group at 12 weeks.

Second, the combination of bD training and WBV improved static balance at six weeks, with continued improvements at 12 weeks, compared with no intervention (control). WBV alone and combined with bD training improved dynamic balance over 12 weeks, but the gain in dynamic balance did not achieve sufficient magnitude to be greater than that seen in the control group.

BioDensity training with and without WBV elicited favorable but different changes in functional independence measures—self-care and mobility. Self-care improved at 12 weeks as a result of bD training, but was only different from the control group when accompanied by twice-weekly WBV sessions. BioDensity training with and without WBV produced improvements in mobility at 12 weeks that were significantly better than those seen in the controls. While WBV alone resulted in a small and insignificant change in mobility over 12 weeks, mobility in this group was significantly better at 12 weeks when compared with no intervention. The scores for the cognitive attributes (social cognition and communication) were 7 at baseline and did not change (i.e., ceiling effect). This finding is not surprising, because if participants had problems communicating or understanding what they were asked to do, then they would not have been admitted into the study. In addition, we have no reason to believe that the physical interventions tested in this study would impact cognition or communication of already well-functioning older adults.

Finally, the observed improvements in dynamic balance, self-care, and mobility were positively associated with increases in force production. While all of the relations were weak, the evidence indicates that strength improvements resulting from one weekly session of bD training (with or without WBV) explains a small but statistically significant improvement in dynamic balance and functional independence measures (self-care and mobility). WBV appears to augment static and dynamic balance improvements when combined with bD training and also independently improved dynamic balance. However, the improvement was different only from that seen in the controls when WBV was combined with bD. These associations clearly warrant confirmation and replication in similarly controlled but larger studies.

In a three-month randomized control trial, balance training and isokinetic lower body weight lifting improved both balance and strength, but there was no association between the two (Wolfson et al., 1996). The intervention consisted of 90 min of combined balance and strength training three times per week and is similar to that of a three-month, three-times-per-week for 60 min tai chi exercise intervention in which balance and muscular strength improved at six weeks, with further increases at 12 weeks (Taylor-Piliae, Haskell, Stotts, & Froelicher, 2006). The findings of these two studies are similar to the three-month improvements in strength (chest press, leg press, and vertical lift) and balance reported here. However,

there is stark contrast in the weekly volume (frequency and duration) required to achieve similar results. The weekly interventions of 270 min and 180 min per week in the Wolfson et al. (1996) and Taylor-Piliae et al. (2006) studies, respectively, were significantly greater than one 5-min bD session, two 5-min sessions of WBV, or a combined 15-min session per week for bD+PP. Likely underpinning the similar findings across the studies but with different training volume is the high-intensity imposed by bD and the WBV destabilizing platform that requires reflexive muscular activation at a rate 30 Hz over an amplitude that progressed from 1–2 mm at two weeks.

In one of the earlier studies in this area, Fiatarone et al. (1994) trained the hip and knee extensors of elderly men and women (mean age 87 years). The participants performed three sets of eight exercises at 80% 1RM for a total of 45 min per session, three days per week for 10 weeks. They found significant improvements at all ages studied. Because of the very low strength values at baseline, they found improvements of 167% and 210% in knee extension and of 78% and 95% in hip extension in the two exercise groups. The only measure that was the same as in the current study was the leg press. The two exercise groups had baseline values of about 64 lb and 42 lb, with improvements of 30% and 75%, respectively. By comparison, participants in the bD and bD+PP groups in the current study began with mean values of 450 lb and 535 lb and improved 50%. Again, the time required each week (one 5-min session per week for 12 weeks) was much less than that in the study by Fiatarone et al. (1994; three 45-min weekly sessions for 10 weeks) for similar percent improvements but much greater absolute improvements.

Stineman and colleagues (1996) reported “no major ceiling effects” for the FIM in a large sample of patients discharged from rehabilitation hospitals. This population is different from the well-functioning (physical and cognitive) sample in the current study in which ceiling effects were encountered but predominantly isolated to the cognitive domain. Despite high functional independence (physical) of our participants, bD, with and without PP, favorably but differentially benefitted mobility and self-care outcomes. In a study dissecting the structure and stability of the FIM, researchers indicated that separate analyses of the cognitive and physical domains provides more useful information (Linacre, Heinemann, Wright, Granger, & Hamilton, 1994). Moreover, there is stability in the domains across different time points (e.g., pre and post), “permitting a valid quantitative comparison of measures at two time points” (Linacre et al., 1994).

The findings reported in this study should be interpreted in context of the following limitations. A priori power calculations were performed to determine necessary group sample size to achieve 80% power at an alpha level of .05 for change in force production



and the FIM. A minimum sample size of 15 participants per group was needed to achieve the desired power level in the four group analysis of variance design. Incomplete data, lack of intervention compliance, and general attrition resulted in a 28% overall attrition rate and the control and PP groups had less than 15 participants. While this minimally impacted force production and FIM analyses, power for the balance outcomes measures was less than desired, increasing the likelihood of not detecting a difference when one exists. Therefore, absence of statistically significant findings should be interpreted with caution, especially for static balance in the bD group and dynamic balance in the bD+PP group. As 94% of the participants were between 70–90 years, their ages were relatively homogeneous. However, it is well-established that maximal force production declines with age (Fleck & Kraemer, 2004; Lowndes et al., 2009). Group sample sizes prevented a more specific analysis to determine whether the outcomes varied (i.e., were more pronounced or different) among the younger older adults compared with the oldest older adults. Participants were predominantly Caucasian and, as indicated by the baseline FIM scores, they were functioning independently. Future studies in more racial/ethnically diverse and lower functioning populations are warranted to validate and potentially expand the generalizability of these findings. Participants were likely motivated volunteers, and bD, PP, and bD+PP participants interacted (weekly) with the intervention training staff. It is plausible that both could have impacted the findings; although the measures employed were objective, and the FIM has been demonstrated to be both reliable and valid (Linacre et al., 1994; Stineman et al., 1997; Stineman et al., 1996).

The collective findings suggest that the low-volume and high-intensity bD, PP, and bD+PP exercise intervention approaches may yield clinically and individually meaningful improvements in muscular strength, functional independence, and balance. They also may overcome the often-cited lack of time as an exercise barrier. Force production significantly increased 47–48% for chest press, 50–51% for leg press, and 22–38% for vertical lift, respectively, in the bD and bD+PP groups. No changes occurred in the control and PP groups over the 12 weeks. Static and dynamic balance significantly improved in the PP and bD+PP groups but not in the control or bD groups. The improved static and dynamic balance in the PP and the bD+PP groups suggests that WBV may contribute to fall risk/incidence reduction. Added to the higher leg strength found with bD and bD+PP, this suggests that bD training can further reduce the risk of falls. The economic and individual impact of such changes is unknown but likely to be significant. The positive findings of this study warrant replication and future investigation.

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