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BioDensity™: A Novel Resistance Training Approach and Learning Effects in 1,685 Males and 2,689 Females

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Abstract

Traditional Resistance Training (RT) using free-weights or cable-pulley machines has well-documented health, rehabilitation, and activity of daily living benefits. RT is commonly prescribed for primary/secondary prevention of osteoporosis, sarcopenia, cardiopulmonary diseases, and balance/locomotion impairments. Insuring safety and efficacy of RT programs often requires supervision and can be costly and time intensive. Technology is constantly reshaping modes and RT, and in 2009, bioDensity™ was developed and marketed internationally. Developing a safe and efficacious mode of RT that induces multiple body weight loading to the musculoskeletal system underpinned bioDensity™ development. High-intensity loading is one mechanism to induce therapeutic bone remodeling which is foundational to attenuating osteopenia and osteoporosis. With traditional RT, it is difficult to safely elicit high osteogenic loads (multiples of body weight), and for at-risk populations, moving such loads through a full range of motion may not be possible or prudent. BioDensity™ is novel and warrants researching for several reasons. It is low-volume: four exercises, once per week, 5-seconds per contraction (low time commitment). It is high-intensity: users exert voluntary-maximal force for each exercise and exercises target common osteoporosis sites. Safety is achieved through individualized positioning that is near optimal joint angles for maximal force production. Force is generated through a limited-range – approximately 5 cm – and is measured via load cells and patented software. Users receive real-time visual feedback about force generation to promote and prompt a maximal effort during subsequent training sessions. The potential implications and applications of bioDensity™ RT are broad and clinically-significant; however this methodology has not been introduced to the scientific/clinical communities to generate rigorous research. Accordingly, the purpose of this communication was to first introduce this novel mode of RT and then report on a large cross-sectional data set that informed recommendations for handling sex-difference learning effects inherent with this unfamiliar mode of RT.

Keywords: Learning effect; Resistance training; Sex-differences; Musculoskeletal; Novel; Health

Introduction

Resistance training (RT) is known to elicit many important health benefits. Higher levels of muscular strength are associated with significantly better cardio metabolic risk factor profiles, [1,2] lower risk of all-cause mortality [1,3,4], fewer cardiovascular disease events [1,5], lower risk of developing functional limitations [6,7], and prevention or delay of osteoporosis [8,9]. RT intervention studies have demonstrated significant and functionally meaningful strength gains across diverse populations, e.g., healthy young to frail elderly [10-14]. Despite age- and/or sex-differences in absolute strength, strength and more global health improvements resulting from RT are well-documented [12,15].

A maximal strength assessment/test is necessary to establish baseline strength from which the changes resulting from a RT program can be compared and is also central to prescription of initial and progressive loads/resistance [2]. The one-repetition maximum (1RM) test is a common method to measure maximal strength. However, variability in 1RM strength assessment, occurring over the first few testing sessions, is not uncommon [16-18]. Therefore, repeat/multiple 1RM assessments may be necessary to accurately quantify baseline strength due to variability resulting from familiarization or learning effects that may also be age- or sex-related [16,17,19,20]. It is generally recommended that strength be tested more than once to eliminate or minimize the learning/familiarization effects and to establish a baseline that accurately reflects the initial levels of strength and serves as a referent for subsequent training-induced changes.

BioDensity™ is a relatively new mode of RT that is accessible in commercial health/fitness and rehabilitation settings worldwide; bioDensity™ equipment is currently in 154 U.S. and 9 international sites with a 200% increase in installations over the past 24 months [21]. As described by the manufacturer, the bioDensity™ RT approach is a once per week near total body maximal neuromusculoskeletal loading event that uses four exercises (multiple joints and muscle groups) performed at optimal joint loading angles [21]. Each of the four high-intensity RT exercises is performed once per week for five seconds. The combination of all four exercises is intended to safely elicit a high-intensity osteogenic stimulus and neuromusculoskeletal load that is unachievable (safely) with more conventional forms of RT. Theoretically, the health and performance benefits of the bioDensity™ RT approach are likely to be aligned with those of traditional RT [14,22] and may include improvements in muscular strength/power, bone mineral density, neuromuscular activation, functional status, and others. If such health/performance improvements result from this high-intensity and low-volume (frequency and duration) approach, the bioDensity™ mode of RT may diminish the commonly reported "lack of time" barrier to engaging in regular health-promoting physical activity (including muscular strength training) [23-25].

With the growing popularity and use of bioDensity™, it is critical that this novel RT equipment and approach be empirically evaluated and accurately described and reported to the clinical and scientific communities. From 2007 through 2012, the manufacturer of bioDensity™ remotely collected de-identified force production (strength) data for all four exercises in participants who consented to share their information and were using bioDensity™ in commercial health/fitness or rehabilitation settings. This cross-sectional data (~50 users per location) serves as a starting point for evaluation and description of the bioDensity™ approach. The overarching objective of this communication is take the first step to describe the bioDensity™ equipment/approach, and secondarily, to investigate the stability of consecutive maximal effort sessions. Accordingly, we first describe the equipment, approach, and manufacturer-recommended application/use. Second, the available cross-sectional data was analyzed for stabilization of familiarization/learning effects in males and females, hypothesizing that multiple/repeat weekly bioDensity™ exercise sessions may be required to achieve a representative and stable baseline force production. Achieving these objectives is intended to create a foundation for future controlled validation and evaluation of the health and physiological adaptations of this low-volume, high-intensity mode of RT.

Methods

Experimental approach: The methods are divided into two sections: 1) description, explanation, and contextual reference for the bioDensity™ equipment and approach; and 2) research design for the cross-sectional analysis of bioDensity™ force production data to account for learning effect that may influence quantifying a stable baseline in males and females.

What is bioDensity™?

BioDensity™ (Performance Health Systems, Inc., Northbrook, IL) is both the name of the novel RT equipment/modality and a commercially developed approach to neuromuscular and osteogenic loading [21]. At the foundation of its design and development in 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 [21]. It appears evident from the manufacturer and equipment development that the guiding health-related applications of bioDensity™ were to promote bone and neuromuscular health [21,26]. The bioDensity™ equipment is depicted in Figure 1, and a more detailed explanation of the equipment, theoretical underpinnings and approach can be found elsewhere [21].

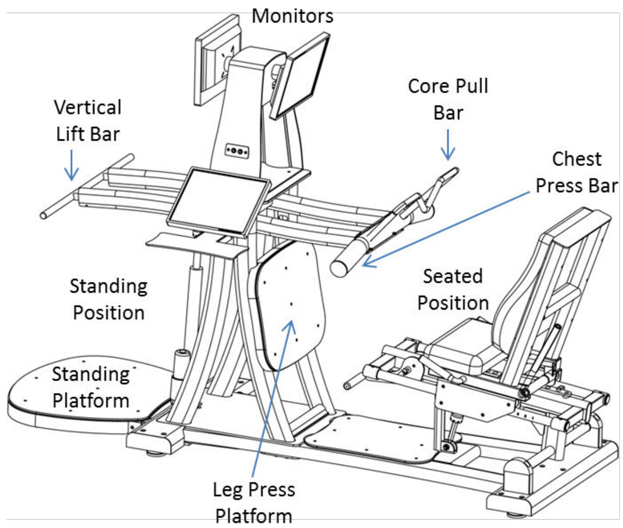

Figure 1: Bio Density™ equipment (line art and photo) and the four exercise positions: 1) chest press (CP); 2) leg press (LP); 3) core pull (Core); and 4) vertical lift (VL).

According to the manufacturers, each exercise is designed to be performed at or near "optimal biomechanical positioning" (i.e., joint angles) to facilitate maximal force production/application through multiple motor unit recruitment [21]. Theoretically, performing muscular contractions in "optimal biomechanical positioning" allows for self-induced skeletal loading up to multiples of body weight. To date, this has not been empirically proven, however the results presented in next section appear to support that multiple body weight loading is occurring for at least three of the four bioDensity™ exercises (see pounds of force production achieved, Figure 2, Panel A, B, and D). All four exercises are limited-range muscle contractions near the optimal force production joint angles. This approach is intended to facilitate safe and self-induced force production that exceeds the user's 1RM level for a similar type full-range of motion RT exercise. 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 bioDensity loading event is entirely self-induced voluntary activation of the neuromusculoskeletal system. Because loading occurs through a limited-range of movement at/near the strongest joint angles, users are able to induce skeletal loading and maximally recruit neuromuscular activation at forces that are near or exceed body mass. Wolff's Law and evidence summarized in the 2004 Surgeon General's Report indicate that activities involving or simulating impact loading are most useful to increase or maintain bone mass [27-29]. This evidence was cornerstone to bioDensity™ development such that impact-like loads could be safely self-induced to improve and/or maintain bone health. The following sections explain the manufacturer recommended use and application (exercise prescription) of this novel RT modality.

BioDensity Use and Application

Conventionally, RT exercise prescription can be described according to frequency (sessions/week), intensity (e.g., percent of maximal capacity), duration (e.g., sets and repetitions), and mode (type of activity, e.g., static, dynamic, concentric, eccentric). Applying this established exercise prescription approach to bioDensity™, Table 1 describes and details the manufacturer's recommended use and application. The novelty of bioDensity™ and absence of population-specific research currently limits any recommendations for modifying the manufacturer-recommended application. In rehabilitation settings or disease-specific conditions, for instance, there is a clear need for consideration and research pertaining to prescription modification to meet individualized needs/goals. The following sections provide additional detail about the bioDensity™ mode and intensity that are intended to complement and extend Table 1.

Component	**bioDensity™ RT Approach***
Frequency	Once per week
Intensity	Voluntary-maximal effort
Duration	5-second sustained contraction
	Software contains an option to increase to a 10-second contraction, but there is no progression recommendation (e.g., number of sessions completed) provided by the manufacturer**
Mode	4 bioDensity™ Exercises: Chest Press (CP): seated Leg Press (LP): seated Core Pull (Core): seated Vertical Lift (VL): standing
Progression	Unlike conventional RT in which progression may be based on manipulation of any of the four exercise prescription components, the bioDensity™ approach to progression hinges on intensity. Specifically, users receive visual feedback about their voluntary-maximal effort (intensity) from the previous session and have to achieve a similar level but attempt to exceed their previous output at each weekly session for each exercise. Achieving a "similar" level is defined as users achieving at least 75% of their previous week's force production. Frequency, duration, and mode are constant.
* Manufacturer recommended/prescribed approach [21,26] ** All male and female participant data analyzed in this study included only five-second contractions according to the manufacturer recommendations.	

Table 1: Manufacturer recommended use and application (exercise prescription)

Mode: The bioDensity™ mode is comprised of four near total-body exercises that are performed while seated or standing. Our observation and experience suggests that the only major muscle groups that are not directly engaged by the four exercises are the knee flexor (hamstring) and hip abductor/adductor muscle groups. However, these muscle groups are likely activated as secondary hip and knee stabilizers during the lower limb exercises (leg press and vertical lift). A needed area of research for the bioDensity™ approach is EMG studies assessing muscle group activation across all four exercises at the recommended joint angles. The standing position platform and seated position are depicted in Figure 1 (line art and photo images). Beginning in the seated position, the four exercises are performed in series: 1) seated chest press (CP); 2) seated leg press (LP); 3) seated core pull (Core); and 4) standing Vertical Lift (VL). Each exercise involves activating multiple large and small skeletal muscle groups across multiple joints. For example, the VL exercise occurs from a high-hang position (gripping the bar with knees slightly bent and hands just below the hip crease) and engages calf, knee extensor, hip extensor, upper and lower back, and forearm muscles across the ankle, knee, hip, wrist, and shoulder joints – similar in position and activation to the end range of motion of a deadlift. The CP exercise is similar in loading and musculoskeletal recruitment to a bench press; the LP exercise is similar to a leg press or squat, and the Core exercise reflects a combination of an underhand pull-up (chin-up), abdominal crunch, and bent-knee hip flexor exercise. All four exercises are limited-range static load contractions with minimal change in joint angle – approximate range of motion is five centimeters.

The CP, LP, and VL exercises employ a ramping neuromuscular activation protocol in which users progressively increase/ramp force application over 1-2 seconds, briefly hold this submaximal force while inhaling deeply, and then immediately apply maximal-voluntary force for five seconds while exhaling. The Core exercise is performed using a ballistic protocol in which users inhale deeply from a relaxed position and then exert maximal force at the start of the exercise and attempt to maintain this force production for five seconds while exhaling. The four exercises induce stimulation and loading across much of the body – particularly areas susceptible to age-related bone loss and skeletal muscle atrophy (e.g., bones and major muscle groups of the arms, chest, back, core, hips, and legs).

As individuals reflexively absorb impact, certain commonalities exist in most impact positions (13). Long bones are arranged in an axial format such that the force/loading is presented end-on-end to the bone, and muscles involved in the contraction that absorb the impact are in their most powerful positions. The four bioDensity movements were designed to mimic these impact positions: 1) CP – arms outstretched to protect from impact when falling forward; 2) LP – knees slightly bent to absorb force from landing from a vertical jump; 3) Core – rib cage moving towards pelvis and arms covering the face moving into a fetal position to protect the core from impact; and 4) VL – arching of the low back and slight bend of the knees to absorb force through the spine, reflecting the posture that would be taken if an individual were jumping or experiencing a high fall. These "impact positions", operationally defined by the manufacturers [21], are aligned with protecting against osteoporotic-related fractures of the hip, lumbar spine and wrist.

The four exercises are also intended to simulate real-life functional activities that relate to both sport-performance activities (pushing away from, jumping away from or pulling oneself toward an object) and activities of daily living (rising from a seated position and pushing or pulling objects). Each exercise session requires supervision and coaching by a technician (1:1 technician to user ratio) to insure safety, correct breathing technique, equipment positioning, and performance efficacy – defined as verbal encouragement to users to achieve/exceed voluntary-maximal force compared to previous sessions. A complete exercise session requires only 20 seconds of direct exercise time (4 exercises x 5 seconds/exercise), and including user login, device set-up, and positioning time, can reasonably be completed in 7-10 minutes. The one-time per week participation (i.e., limited repetition and low duration) may impede between-session user recall about how to perform the exercises, what they are doing, and safely and efficaciously performing the exercises. The one-on-one supervision is intended to overcome these barriers. Additional technician responsibilities include: 1) correct positioning of the adjustable seat location, chest press bar, core pull bar, and vertical lift bar; 2) calibration (nulling) of the load cells to account for user body weight; and 3) operation of the software at the computer kiosk where the user's data and force production are controlled and graphically displayed on the two monitors viewable in each of the four exercise positions.

After correct positioning and calibration for each exercise, users are instructed on breathing techniques (e.g., avoid breath holding), correct biomechanical positions during the exercises, and reminded to exert as much force as possible for the duration of each exercise. For the four exercises, the anatomical positioning and recommended verbal cues to the users include: 1) CP – bar positioned at center of pectoral muscles, upper border of CP bar horizontally aligned with the shoulder joint, seat adjusted so that elbows are flexed at ~120°. Users are reminded to keep elbows up and in-line with the bar; 2) LP – feet shoulder width apart with seat and heels positioned to achieve ~150° of knee flexion. Users are reminded to push with their legs maximally exerting force through the heels while gripping two hand hold bars positioned lateral to the hips; 3) Core – arms/hands positioned at shoulder width, using an underhand grip on the bar, seat and bar positioned at an elevation causing ~95⊠ of elbow flexion, seat belt attached. Users are reminded to pull down with the arms and lift upward with the knees trying to bring the elbows and knees together (activating hip flexor, abdominal, bicep and lattisimus dorsi muscles); 4) VL – hands positioned at the lateral edge of the thighs, bar positioned at the tip of fingers in an extended position. The user bends knees keeping a straight back and grips the bar at approximately the level of the pelvic bone using an overhand, underhand, or inverse (Olympic) grip. Users are reminded to push with their legs lifting upward with a straight back while pulling/rotating the shoulders in a posterior direction.

Intensity: Intensity for all four exercises is standardized as maximal-voluntary effort for five seconds. Intensity is measured as force production (i.e., strength) for each exercise in either pounds or kilograms. Force production is measured by two load cells; one connected to a vertical column below the seat for the CP, LP, and Core exercises and one to a vertical column attached to the standing VL grasp bar (Figure 1). The load cells have low nonlinearity occurrence (0.15%), are nulled/tared before use to remove body and equipment weight from the measurement, and interface with a central processing unit where user force production data is recorded and temporally compared to previous values via proprietary software. The software uses a patented algorithm that is intended to optimize real-time and repeat training exposures by monitoring and reporting force productions to users via e-mail and providing immediate feedback via bar graphs that report and compare force productions from current and previous exercise sessions for each exercise.

During each of the four exercises and in real-time, a computer monitor that is viewable by users in both the seated and standing positions provides visual feedback during exercise performance to support and encourage voluntary-maximal force production for five seconds. Force production is visualized as a needle moving around the speedometer-like force-production gauge. For repeat training sessions (e.g., consecutive weekly sessions) referent force outputs and a 75-100% range are seen on the gauge. This allows users to know when their force production is approaching, within, or exceeding their previous performance – promoting maximal-voluntary effort with each session. The 75% referent threshold is customizable and is calculated from previous exercise sessions. When users exert force that exceeds their individualized 75% threshold, the 5-second duration countdown begins and the screen turns red (indicating completion) when 5 seconds of effort have been achieved above this force production threshold. For first time users, without a previous force production reference value, the software defaults to a low force production threshold that is thought to be achievable by the general population; however to our knowledge, this has not been validated. Additionally, thresholds can be manually lowered if a user is unable to achieve the default first-time threshold for a particular exercise.

McKenzie and Gandevia analyzed muscular performance of maximal voluntary contractions [30,31] and the ability to voluntarily engage muscles at fixed positions [30]. While complete motor neuron activation was possible in a muscle's shortest possible position, the results showed that repeat force production in these fixed positions declined by 21 to 49% [30]. It was concluded that complete motor neuron engagement and the highest possible force production are possible with limited range of motion but force production declines with repeat bouts. The bioDensity™ approach capitalizes upon these findings in two ways. First, biomechanical positions employed for all four bioDensity exercises attempt to achieve optimal muscle positions and joint angles to yield maximal force production. Second, limited range of motion occurs during the exercises and the aforementioned work of Gandevia and McKenzie suggests that complete motor neuron engagement and maximal force production are achievable.

Introducing and reporting the bioDensity™ approach to the scientific, clinical, and sport communities is critical to generating evidence-based research and validation of the technology and approach. As with any new mode of exercise, the use and implications may be diverse, e.g., rehabilitation, general fitness/wellness, chronic disease prevention/treatment, sport performance. However, application and recommendation for use of bioDensity™ must be underpinned in evidence. This technology is unfamiliar and novel but includes a high-intensity, low-volume, limited-range of movement mode. Thus, addressing common RT questions of safety, efficacy and learning/familiarization effects are central to informing future longitudinal controlled studies. To date, no prospective/controlled studies using bioDensity™ as an intervention have addressed safety or efficacy. However, the available cross-sectional data from a large cohort of males and females allows a retrospective investigation of learning effects. This is an important first step for future longitudinal training studies and allows demonstration of the high force productions achieved with bioDensity™.

Retrospective study to determine how many bioDensity™ sessions are necessary to achieve a stable baseline force production in males and females.

Design and Sample: Between January 1, 2007 and July 26, 2012, data was centrally collected on 31,851 bioDensity users across 121 rehabilitation and fitness/wellness centers. Applying inclusion criteria of 10-99 years of age, sex indicated, completing at least four training sessions, and less than 21 days between repeat sessions, de-identifiable data on 4,374 users was available and shared by the manufacturer with the authors. While the data set contains up to 114 individual training sessions for some users who met the inclusion criteria, this analysis is specific to users who completed at least four training sessions, because the intent was to determine how many sessions are needed to overcome learning/familiarization effects and to achieve a stable baseline.

Musculoskeletal force production capacity has well-documented sex differences, with males typically exhibiting greater absolute muscle strength [32,33]. Combined with the fact that bioDensity™ training is a novel/unfamiliar mode of activity, it is necessary to investigate the potential sex-specific learning effect(s) that may influence accurate quantification of baseline force production. To achieve this, the absolute and percent differences in force production (in all four exercises) and intra-class correlations between consecutive sessions were determined using the available data. The research was approved as "exempt" by a representative Institutional Review Board at the University of XXXX. Because this was a retrospective study and users agreed to let their non-identified data be shared, informed consent was not required.

Statistical Analyses: Due to unequal variance and absence of normal distribution for the majority of data (age and force production), non-parametric and parametric analyses were conducted [34]. Statistical significance was based on non-parametric findings at an alpha level of P<0.05. Because the sample size is sufficiently large enough to minimize errors based on violation of normality and equal variance assumptions, results from parametric analyses are reported for ease of interpretation and communication [35]. Comparisons of females and males were determined using the Mann-Whitney rank sum test and two-sample independent t-test. Within-sex comparisons employed the Wilcoxon Signed Rank test and paired t-test. Change in force production across the four repeated sessions (time) within groups (females and males) was analyzed via one-way analysis of variance on ranks (ANOVA; Kruskal-Wallis) with Tukey pairwise post-hoc analyses. Sex differences in force production over the four sessions (time) were analyzed by two-way repeated measures analysis of variance (sex x session number) with Bonferroni pairwise test for multiple comparisons (post-hoc analyses). Percent change between consecutive training sessions was computed for females and males and compared between sexes according to the aforementioned procedures. Intra-class force production correlations within sex and between consecutive sessions were computed. Data are presented for both parametric and non-parametric analyses, mean ± S.D. or S.E.M. and median and 25% and 75% confidence intervals, respectively. Statistical analyses were performed with Sigma Plot 11.0 (Systat Software Inc., 2008) and significance was set a priori at P<0.05.

Results

Descriptive Characteristics: Users meeting the inclusion criteria were 61% female (N=2,689) with a mean age of 53.9 ± 16.6 years and 39% male (N=1,685) with a mean age of 47.4 ± 18.8 years; males were younger than females (P<0.05). Women ranged in age from 11-92 years and men ranged from 10-96 years.

Force Production by Sex: All force production analyses included and compared sessions 1-4. Across all four exercises and at each of the four exercise sessions, males had greater absolute force production than females (Figure 2, Panels A-D). In females, there was a statistically significant increase in force production between consecutive exercise sessions 1-3 for all four exercises. Force production of females was significantly higher between sessions 3 and 4 only for LP (Figure 2, Panel B). In males, there was a statistically significant increase in force production between consecutive exercise sessions 1-2 across all four exercises (Figure 2, Panels A-D). Similar to LP in females, male's also demonstrated significantly higher LP force production between sessions 2 and 3 (Figure 2, Panel B). In contrast to females, males did not significantly increase LP force production between sessions 3 and 4 (Figure 2, Panel B). Figure 2 also shows that with the exception of LP, the plateau or absence of statistically greater force production between consecutive sessions occurred between sessions 2 and 3 for males and sessions 3 and 4 for females.

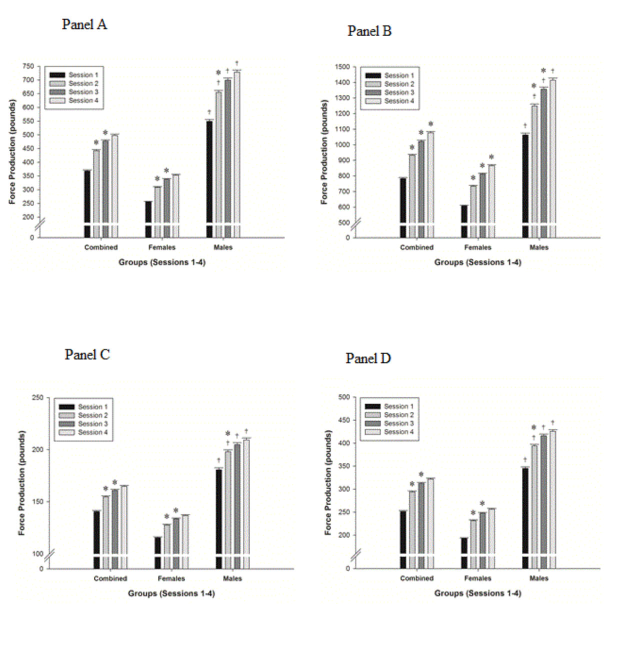

Figure 2: Force production changes across four sessions of bioDensity™ training in males, females, and combined sample. † P<0.05 compared to females for the same training session. *P<0.05 compared to the previous session within group (combined; females only; males only). Mean ± S.E.M. Panel A. Chest Press (seated), Panel B. Leg Press (seated), Panel C. Core Pull (seated), Panel D. Vertical Lift (standing)

Table 2 demonstrates that force production percent change between consecutive sessions declined progressively and consistently from the first to the fourth session in both sexes across all four exercises. While females consistently exhibited larger relative percent change between sessions compared to males, sex differences were significant only for LP and VL, and for CP between sessions 2 to 3. For both sexes, the overall reduction in force production percent change across sessions 1-4 was similarly attenuated-approaching or less than 5% change between sessions 3 and 4 (Table 2). The singular exception to stabilization of force production between sessions 3 and 4 occurred for LP in females (5.2% mean or 6.1% median increase; Table 2 and Figure 2, Panel B).

Exercise	Session Level	Males Mean % Change	Females Mean % Change	Males Median % Change	Females Median % Change
Chest Press	2-Jan	14.7 ± 32.7	15.1 ± 29.9	15.3 (5.7;26.2)	15.4 (5.4;27.9)
(CP)	3-Feb	1.9 ± 62.5	6.7 ± 25.3*	6.7 (-0.29;14.3)	8.0 (0.0;16.1) *
	4-Mar	-1.5 ± 68.5	2.2 ± 28.2	3.9 (-1.8;10.4)	4.16 (-3.2;11.8)
Leg Press	2-Jan	13.5 ± 26.8	15.2 ± 21.3 *	14.0 (6.0;23.5)	15.5 (7.1;24.9) *
(LP)	3-Feb	5.5 ± 32.4	8.5 ± 19.5 *	7.7 (1.5;14.6)	9.3 (2.9;15.9) *
	4-Mar	-0.8 ± 56.6	5.2 ± 19.6 *	5.1 (-0.1;10.5)	6.1 (0.2;12.3) *
Core Pull	2-Jan	4.0 ± 49.0	6.2 ± 32.2	8.2 (-2.2;19.8)	8.4(-2.0;20.5)
(Core)	3-Feb	-1.2 ± 44.2	2.0 ± 28.3	3.6 (-5.6;12.6)	3.8 (-5.0;13.0)
	4-Mar	-3.6 ± 52.3	-0.7 ± 30.8	2.5 (-6.4;11.4)	2.4 (-6.5;10.8)
Vertical Lift	2-Jan	6.0 ± 109.1	13.6 ± 41.2 *	12.7 (3.6;22.8)	15.7 (5.4;28.0) *
(VL)	3-Feb	-0.2 ± 69.3	2.4 ± 50.2 *	5.0 (-1.8;11.4)	6.4 (-0.9;15.0) *
	4-Mar	-3.9 ± 107.3	-2.4 ± 60.8 *	3.2 (-3.3;9.3)	3.8 (-3.1;10.9) *
Light Grey:	Represents diminishment of learning effect approaching or less than 5% change between sessions. * P<0.05 compared to males. Mean ± S.D. and Median (25% and 75% C.I.'s)				

Table 2: Percent change in chest press, leg press, core pull, and vertical lift force productions across sessions 1-4 for males and females.

Panels A, C, and D of Figure 2 demonstrate the onset of a plateau in absolute force for CP, Core, and VL occurring between sessions 3 and 4 in females and sessions 2 and 3 in males. In males, the onset of a plateau for LP occurred between sessions 3 and 4. Although LP force production change between sessions 3 and 4 is 61% less than the change between sessions 1-3 in females, the LP force production in females was significantly greater at session 4 compared to session 3 (P<0.05; [2, Panel B).

To further confirm the aforementioned findings indicating a force production plateau, session 4 force production in all four exercises was subsequently compared to all available session 5 data (1,366 males; 2,248 females for a combined sample of 3,614). This secondary validation between sessions 4 and 5 revealed force production changes that were less than 5%, ranging from 0-2.9% change for all four exercises. Percent changes in females were: CP=0.01%; LP=2.3%; Core=1.5%; and VL=1.6% (P>0.05 for all exercises). In males, session 4 to 5 percent changes were: CP=2.0%; LP=2.4%; Core=2.9%; and VL=0.01% (P>0.05 for all exercises). Additionally, Table 3 indicates that the between session correlations for force production are achieving high agreement for CP, LP, and VL in males and females. For the Core exercise in males and females, the between session correlations (sessions 2-3 and 3-4) remain significantly high but are not as strong as those seen with the other three exercises for respective session comparisons.

Discussion

This is the first communication to describe and detail the novel bioDensity™ RT equipment, technology, and recommended approach/use. Others have demonstrated functional [36,37] and physiological [38] benefits with short-term (4-12 weeks) isometric RT. Whether exercise training with the bioDensity™ equipment and high-intensity low-volume approach possesses similar health-related or performance efficacy remains to be determined. With 163 national/international sites employing the bioDensity™ approach/equipment and continued growth likely, consistent use/application, understanding the technology and controlled research is needed. Additionally, understanding factors, such as sex differences, that may impact accurate quantification of baseline strength and account for familiarization and learning effects are central to future validation and training studies.

For the cross-sectional study, the primary finding is that the learning effect inherent with the bioDensity™ mode of RT plateaued at session 3 in females and session 2 in males for CP, Core and VL. For LP, males stabilized between sessions 3 and 4, while females continued to increase force production between sessions 3 and 4, albeit minimal. There are no standards or guidelines that establish duration or number of repeat sessions needed to reach a plateau with maximal strength testing, and criteria used to establish stability or a plateau vary. A number of studies have shown 5% to 10% variation over two testing sessions but this varies considerably [16-18]. In a maximal strength testing study by Wallerstein et al., stability was considered achieved when individual results varied by less than 5% because this "seems to be the normal inter-day variation in strength assessments" [39]. Unfortunately, the two references cited (Bazzucchi et al. and Cannon et al.) did not investigate daily variation. Instead, they also tested subjects until variation was less than 5% [40,41].

		Males (N=1,685)			Females (N=2,689)		
Exercise	Session	2	3	4	2	3	4
Chest Press (CP)	1	0.90	0.86	0.82	0.84	0.78	0.75
	2	--	0.92	0.88	--	0.88	0.84
	3	--	--	0.92	--	--	0.91
Leg Press (LP)	1	0.90	0.85	0.79	0.88	0.83	0.80
	2	--	0.93	0.86	--	0.92	0.89
	3	--	--	0.91	--	--	0.93
Core Pull (Core)	1	0.70	0.68	0.63	0.73	0.68	0.64
	2	--	0.82	0.73	--	0.77	0.74
	3	--	--	0.80	--	--	0.81
Vertical Lift (VL)	1	0.78	0.79	0.75	0.80	0.75	0.71
	2	--	0.86	0.79	--	0.86	0.79
	3	--	--	0.85	--	--	0.84

Table 3: Intra-class force production correlations for consecutive weekly sessions in males and females

From session 1 to 2, the average of male and female force productions increased about 15% for CP, 14-15% for LP, 4-6% for Core and 6-14% for VL. From session 2 to 3, however, the variation was much less (2-7%, 6-9%, -1-2%, and 0-2%) for CP, LP, Core and VL, respectively. From session 3 to 4, variation in all exercises was less than 5%, with the exception of LP in females (5.2%). If 5% is a reasonable criterion for establishing a stable baseline, then 2-3 sessions were adequate in this large sample of males and females. This is in agreement with studies that suggest that 2-3 sessions are needed [17,18,42].

Benton et al. tested 19 untrained females with a mean age of 35 years and reported that chest press increased 3% from trial 1 to 2 and 3% from trial 2 to 3, while LP increased 7% between trials 1 and 2 and between trials 2 and 3 [42]. They concluded that three sessions are needed for a plateau in chest press but that more sessions were needed for LP, which is in agreement with the 5% or less between session variability criterions. However, they tested the subjects only three times and cannot answer the question about how many sessions are needed for LP. The findings of Benton et al. are similar to our CP findings with plateau/stabilization occurring at session 3, and we extend the LP evidence indicating that four sessions appears to most accurately quantify baseline strength devoid of familiarization/learning effects in females. This was also supported by the comparison of data from sessions 4 and 5 in which there was a minimal and insignificant change.

Amarante do Nasciamiento et al. tested 45 older women on three occasions for CP, leg extension (LE) and arm curl (AC) strength [16]. Percent changes from trial 1 to 2 were 3.5% for CP, 3.8% for LE and 5.4% for AC. From trial 2 to 3, changes were insignificant for CP (0%), LE (1.2%) and AC (2.7%). They also concluded that consistent 1 RM strength values can be achieved in 2-3 test sessions. In these older women, this evidence further supports the need to account for learning/familiarization effects and that such effects may be exercise- or muscle-group dependent. Specifically, there was a 50% or greater reduction in the percent change between sessions 1-2 compared to 2-3 but this decline varied across the different exercises. With bioDensity™ training, the Core exercise most closely resembles the AC exercise of Amarante do Nasciamiento et al. Our findings for Core percent change differ from theirs with respect to smaller percent change between sessions 1-2 for Core compared to CP and LP change between sessions 1 and 2. However, our findings are in agreement with stabilization of learning effects for the Core exercise between sessions 2 and 3 in both males and females. In addition to the modest sex differences reported here, our findings and those of others suggest that stabilization of maximal force production and how many repeat exposures are needed to overcome learning effects may also be exercise- or muscle-group dependent.

While it was expected that males would have higher absolute values of strength, it is interesting that females seemed to have more variation in CP, LP and VL when expressed as a percent change. In fact, the absolute increase in force production over testing sessions was less in females, but because their initial levels were so much lower than those of males, the relative increase was greater. Nevertheless, females and males both reached a plateau within three sessions, with the exception of the minor difference of 5.2% in females for LP.

Caution is warranted with over-generalization of the findings reported here due to the following limitations. Presently, body mass is not collected as a descriptive variable when users initiate bioDensity™ training and create their personalized accounts. Therefore, it was not possible to provide descriptive information for body mass or normalize force production for body mass. Inclusion of body mass into the account set-up for new users with a re-assessment at future intervals (e.g., 6 or 12 months) would be a valuable addition. It is possible that the seated position load cell could accurately record body mass at the time of first use and automatically re-assess at desired intervals. Despite the large sample size and age range, the youngest males and females are under-represented. Males 17 years and younger comprised 4.5% of the sample (N=75), and females 17 years and younger comprised only 2.1% of the sample (N=57). Therefore, caution is warranted in generalizing the findings to adolescents and youth. Another important consideration impacting our findings is the well-documented association between age and maximal force production. It is well-established that maximal force production declines with age [2,12] and the on-set of this age-related decline may vary based upon factors such as sex, physical activity level, and mode of physical activity. It is plausible if not likely that age may also be a moderating factor of learning effect, and data analysis for both males and females grouped by age is underway. This future research is anticipated to provide additional guidance regarding the number of sessions necessary to achieve a stable and representative baseline maximal force production in males and females. The experience, expertise, and consistency of trainers/technicians supervising and conducting the RT exercise sessions are unknown and related variability could be influencing the data. However, the sample size and power are sufficiently large enough to account for such variability and minimize the chance of statistical errors. Additionally, this variability may represent "real world" applications.

Establishing criteria for obtaining stable and representative baseline muscular strength assessments that are devoid of learning effects is foundational to intervention studies and efficacy testing of new modes of RT, such as bioDensity™. Aligned with others, we propose that a variation of 5% or less is a reasonable criterion given the number of studies that have used this level. Using this criterion in the present study with a large number of subjects, we found that all four exercises varied less than 5% after three sessions with one exception. The exception (5.2% variation in LP for females) is very close to the 5% threshold and could be considered a stable plateau, given the minimal and insignificant change (0% to 2.6%) for all four exercises in both sexes between sessions 4 and 5.

In light of the findings of this research, it is recommended that the bioDensity™ software be modified to establish sessions 2, 3, or 4 based on sex and exercise as the baseline force production, because this procedure accounts for familiarization and learning effects. Given that the mean percent changes from session 1 to session 3 were about 20% for CP and LP, about 6% for Core and 11% for VL and that these changes are influenced by learning and familiarization and not entirely attributable to "improved strength", another alternative could be to standardize the baseline as the mean of sessions 3 and 4. Even more accurate sex-specific quantification of baseline force production could be achieved by translating the evidence provided here for males and females, i.e., average of sessions 2 and 3 for males and average of sessions 3 and 4 for females. A consideration, worthy of empirical validation, that the manufacturers might consider is to modify their instructions and initial use protocols to include multiple unmeasured practice sessions in each of the four exercises. For example, in the first familiarization session, maximal force application would be applied in all four exercises over 4-5 repeat bouts with adequate rest between trials. This familiarization session (e.g., week one) would be not be reported/recorded and then the next consecutive training session (e.g., week two) could be used as the baseline force production measurement having had 4-5 opportunities for familiarization previously. Clearly, stabilization of learning effects would need to be assessed, but it is plausible that this modified approach, providing repeat practice trials, may overcome the learning effects in less time (two weeks) versus three weeks in males and four weeks in females.

It would be interesting to see results from a study on daily variation in 1RM strength after a true baseline has been established in untrained, inexperienced subjects. If the variation is indeed 5% or less, this would support the findings of the present study and add credibility to the proposed criterion. Research on experienced subjects shows little or no variation, e.g., 0-2% in trained male and female athletes in the study by McCurdy et al. [43] and 0-3% in experienced males in the study by Ritti-Dias et al. [17].

Conclusion

Use of the bioDensity™ RT approach is increasing world-wide. With introduction of this novel mode of RT and a sex-specific procedure to establish a stable baseline for use in future longitudinal studies, it is critical that the potential health and physiological benefits of bioDensity™ be researched. While this time-sparing, high-intensity approach may offer an alternative to traditional RT, more research is needed to establish the efficacy of bioDensity™ across the continuum of RT contexts, e.g., primary and secondary prevention of osteoporosis, sarcopenia, Type 2 Diabetes; injury rehabilitation; sport performance.

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