Colorado State University

Characterization of the Pneubounder for Lower-Extremity Power Training

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ABSTRACT
AIM: Power is a component of strength. Once considered the domain of performance athletes, it has become evident that power training is of benefit to a wider audience, including young and old, in rehabilitation to elite athletics, and for performance and health. Jump training – including stretch-shortening cycle, plyometric and ballistic exercise – has proven to be an effective bridge from strength to power and on to more sport-specific technique development. The biomechanics of the upright, multi-joint, squat motor pattern underlie so many land-based sports and activities of daily living that the squat and jump squat exercise are foundational for strength and power. Yet the impact of repeated jump landings and the potential for injury when fatigued are a limitation of jump training. The excessive eccentric loading of intense jump training can lead to delayed onset of muscle soreness and, combined with high-impact landings, overuse injuries. Providing an external load on the body during jump or squat training can be injurious during exercise and may not be tolerated by the wide audience that can benefit from power training. A novel pneumatic device (the Pneubounder) dampens impact and has been introduced to provide a means for performing squat and jump squat exercise in upright postures without external load at the shoulders. Because of the multiple safety features introduced by the machine, jump squats or rebound exercise can be sustained for both anaerobic and aerobic conditioning.

Configured with a digital pressure sensor and accelerometer, the Pneubounder can process fast, real-time data analysis for measuring and displaying a variety of attributes related to jump power and anaerobic capacity. The purpose of this series of studies was to evaluate the kinetic, kinematic, neuromuscular and metabolic attributes of exercise on the Pneubounder and its method of quantifying performance.

METHODS & RESULTS:
<u>**Study 1 – Kinematic and Kinetic Analysis**</u> – A pilot study with a single subject experienced with the Pneubounder and plyometric ground-based jumps was recorded with a 250fps high-speed camera. The subject performed a series of jumps on the ground and on the Pneubounder. Using reflective markers, vertical ground reaction force and center of mass velocity were calculated and processed on Vicon Motus software. A Bertec force platform was securely bolted to the Pneubounder platform for additional data collection. Peak and average forces were compared between each jump method and mode. **With air valves closed, Pneubounding was found to have a substantial eccentric phase, a relatively fast amortization period between eccentric and concentric quadriceps contractions and can qualify as a low-moderate intensity plyometric activity or high intensity jump trainer**. Impact dampening of the equipment was verified.

<u>**Study 2 – Neuromuscular Analysis**</u> – Fourteen channels of surface electromyography were collected on core and lower extremity muscles with a Noraxon system coupled with a Vicon Nexus software / high-speed camera system. Eight college-aged, elite-level athletes performed countermovement and tuck jumps on the ground

and on the Pneubounder while activity was recorded on agonist, antagonist, and stabilizing muscles. **The study found no statistical differences in any peak muscle activity between the Pneubounder and ground-based countermovement jumps across 14 different muscles.** These results suggest that Pneubounding is highly specific to vertical jumping.

<u>Study 3 – Power measurement and Feedback Validation</u> – The Pneubounder platform was mounted with a Bertec force platform and the equipment was connected to a pressure gage. Software formulas were examined for compliance with accepted standards of biomechanical analysis and process algorithms were analyzed in Matlab. Correlations of peak pressure to ground reaction force measurements from the force platform were found to be extremely high (r=0.947). **The Pneubounder method of measuring and reporting force, acceleration, velocity, work, and power carries similar validity as one would expect using a force platform to capture and analyze such data**.

<u>Study 4 – Metabolic Health</u> – Twenty-seven sedentary college students were randomized into 3 equal groups that performed either stationary cycling, running on a non-motorized treadmill, or Pneubounding with valves open. A total of 9 training sessions were completed by each subject within a 3 week period. Each training session required a High Intensity-Interval Training (HIIT) protocol of 4-8, 30-second maximal efforts separated by 4 minutes of active rest. Maximum oxygen consumption (VO2max), time to exhaustion at 80% VO2max, resting blood and muscle tissue samples, and a DEXA scan were all measured pre and post training for examination of metabolic changes. **Using a HIIT protocol all three modes of training were relatively equal in decreasing oxidative stress in subjects, a marker of metabolic health.** Only the running group saw an increase in bone mineral content.

CONCLUSIONS:

The Pneubounder combines the safety of a closed-chain exercise with balance aides and low impact dampening to permit a variety of upright squat and jump training exercises. This includes plyometric jumping, high velocity ballistic jumping (aka Resisted Jumps) and over-speed training with a mass at or below body weight, as found in Assisted Jump protocols using elastic bands. Pneumatic technology allows users a high degree of variety in range of motion during the exercise to improve on dynamic flexibility and generating power from a wide range of knee and hip angles. The pneumatic engineering of the device also permits accelerative leg and hip extensions through the final range of motion for potential improvements in vertical leap performance or quick propulsion on the ground.

Opening the machine valves during use increases the metabolic and cardiorespiratory intensity of the exercise, involving concentric actions of lower extremity, hip and trunk musculature and potentially the upper body. The varied safety mechanisms of the equipment permit aerobic or anaerobic training using the squat and jump squat motor pattern, potentially to a point of greater fatigue as is determined by the user's own efforts. When equipped with the Pneubounder's power measurement system, real-time, stroke by stroke feedback can be displayed to the user and recorded for increasing motivation and analyzing performance improvements, either in unilateral or bilateral modes, between users, or for monitoring an individuals improvement.

There are a variety of means, modes and exercise methods available to clinicians and strength coaches for developing dynamic flexibility, eccentric control, neural drive and explosive strength and power. Strength, power, aerobic and anaerobic capacity tend to transfer from the gym / clinical environment to actual performance when similar muscles, motions, velocities and postures are shared between the strength exercise and the movements of sport or life. The Pneubounder has demonstrated itself to be an excellent addition to existing training modes, providing an additional degree of safety, variety and flexibility of use for a wide population of users and varied training objectives.

REPORT PURPOSE

This Report summarizes the background science and research of a novel pneumatic exercise device (the “Pneubounder”) independently studied in the Human Performance Clinical / Research Laboratories at Colorado State University and in collaboration with the Human Performance Laboratory at the US Air Force Academy[1].

This series of research investigations and associative literature reviews were conducted over several years examining the underlying biomechanical, neuromuscular, and physiological / metabolic attributes of Pneubounding and its system of quantitative measurements. Plyo Systems, LLC (manufacturer of the Pneubounder) provided no direct funding for the research, literature review, or report. The content of this report conveys the opinions and conclusions of the principal investigator. This report does not constitute endorsement by Colorado State University or any other entity with which the principal investigator is affiliated.

INTRODUCTION

Lower-extremity strength, power and metabolic conditioning hold benefits for a wide variety of people. Once the selective domain of athletes, it’s become increasingly evident that lower-extremity power and the training methods that develop it are of practical application for functional mobility, injury prevention, and health and wellness.

Jump training is a proven method for developing functional strength and lower-extremity power. Plyometric jumping combines accelerative squat motor patterns with stretch-shortening cycle (“SSC”) muscle actions <u>not</u> ordinarily developed in conventional resistance training programs.

At a low intensity, people encounter SSC actions in everyday movements such as walking, running, and reacting to an unanticipated event such as a trip.

Ballistic movements are those actions that propel the body (or some other objective) up or forward without an initial stretch of the muscle before it shortens concentrically. As a result, there is less utilization of elastic energy from muscles and tendons during ballistic actions. Movements without the preceding stretch are encountered in everyday movements such as lifting a box or rising from a chair.

In performance training, superlative results come from combining various exercise techniques to target those elements of the body that contribute to power production and performance excellence, using muscles, motions, velocities and postural characteristics most similar to the performance activities. The biomechanics of squat and vertical jump motions underlie the muscles and movements of many land-based sports and activities of daily living, such as those listed above, thus promoting a higher degree of potential transference of strength gains in the gym to real-life challenges.

POWER CONDITIONING: FOR PERFORMANCE AND GOOD HEALTH

Many performance and health benefits have been demonstrated to accrue in empirical studies using High-Intensity Interval training (HIIT, aka Sprint Interval Training or SIT) protocols.

The common denominator in most all HIIT training studies is that the intensity and duration of the exercise be high enough to approach or exceed lactate threshold and the rest periods in between be low-intensity recovery intervals. That is, the sprint interval must be intense enough to tax or go beyond aerobic pathways. A heart rate at or above 86% of heart rate maximum or in the range of 80% of maximal oxygen uptake (VO2max) is indicative of the level of intensity required to create the training responses[2 3 4 5]. Furthermore, sprint durations at this intense heart rate generally fall within the 30 - 120 second range to achieve the training results most sought after. All-out efforts are by their very nature exhaustive. The sprint portion of the exercise contrasts moderate, aerobic exercise at training heart rates near 70% of an individual's heart rate maximum and last for 30+ minutes of continuous exercise.

Health benefits such as accelerated fat loss and improved insulin sensitivity in muscle have been realized in relatively short HIIT training cycles of 6 sessions of exercise lasting less than 30 minutes each (including rest) in a two week period[6 7 8 9]! Using the large muscles of the core and lower extremities in multi-joint movements and sustained all-out efforts is an effective means for activating anaerobic pathways and improving power stamina, aerobic capacity and faster recovery between bursts of intense effort.

Because energy-transfer systems (alactic, anaerobic - glycolytic, aerobic) are known to predominate at different times during exercise, an effective overall training program targets each of these physiological systems during a training session. It has been shown that high intensity interval training improves both anaerobic and aerobic energy systems, while moderate-intensity endurance training does NOT change anaerobic capacity[10]. Power conditioned people carry the potential for fast reactions, explosive movements, bigger lifts and higher levels of caloric expenditure during brief exercise periods. However, this potential tends to be optimized primarily within the muscles, motions, velocities and postures that dominate during training sessions.

In a seminal work, Saltin (1976) trained a single leg of otherwise healthy sedentary subjects in either sprint or endurance exercise on a bicycle ergometer over four weeks, with 5 workouts per leg each week. Muscle biopsies before and after training were taken to measure anaerobic enzyme levels. Training did not alter muscle fiber composition but resulted in pronounced metabolic adaptations reflected in higher glycolytic enzymes only in the trained leg. These adaptations paralleled increases in V02 max testing for sprints on the trained leg. The study demonstrated that exercise elicits highly specific conditioning adaptations in trained muscles[11]. In order to optimize activity-specific muscle performance, exercise must be tailored to match the movements and velocities of a target motor pattern. For example, if cycling is the mode of exercise, gains occurring in the cycling motion don't highly transfer to swimming, running or jumping. Therefore, **effective training programs consider not only the physiological system targeted during training sessions but the muscles and exercise modes used to activate those systems.**

FUNCTIONAL TRANSFERENCE

Because squat and jump squat exercises emphasize the muscles, motions and motor patterns of so many land-based activities, engaging them with sufficient intensity holds benefits in terms of functional transference and potentially large caloric expenditure. Yet, the high impact landings of jump training are contraindicated for people with compromised balance, orthopedic sensitivities or lacking in requisite strength (e.g. ability to perform multiple repetitions of the back squat at 150% of a one repetition maximum). Without accelerative actions and metabolic intensity many of the benefits sought from jump training and sprint interval training can be diminished.

Functional, jump squat movements provide the multi-joint, neuromuscular stimuli for increased power output and metabolic conditioning but performing the exercise in durations long enough to elicit glycolytic, anaerobic processes can multiply injury potential due to muscle fatigue around joints and a breakdown in form. **Closed kinetic chain exercise equipment that permits repetitions of the jump squat motor pattern with impact dampening could address many of the risks associated with**

traditional jump squats and upright, SSC movements.

Squat training with weights may avoid the impacts of jump training, though may load the torso and spine in a manner not acceptable to some. Furthermore, while slow-speed resisted squats build strength, their transference to power is limited as are any gains in metabolic and cardiovascular health.

The Pneubounder equipment under study addresses the limitations of traditional jump and squat training with pneumatic technology in a machine engineered for these purposes. In order to characterize the potential benefits of training on the Pneubounder, a series of laboratory investigations were conducted. The remainder of this Report describes in greater detail the methods and Major Findings of the research studies conducted across multiple experimental platforms synthesized with the available scientific literature.

SUMMARY CONCLUSIONS

Combined with an exhaustive literature review, the results of our research find that with incremental machine adjustments, "Pneubounding" can (be):

1. Low-Impact and Highly Flexible - Provide varying degrees of impact dampening, adaptable to many different populations covering a large spectrum of strength and power while safely training on one or both legs;
2. Functional Strength and Power Training - Establish a foundation of strength and increased power output using concentric and eccentric muscle actions at higher velocities and lighter loads for the core and lower extremities. For functional performance transference, exercise on the Pneubounder is a closed chain exercise, executed in an upright position using the triple extension (of hip, knee & ankle) motor pattern;
3. Plyometric or Ballistic – Alternating as either a SSC plyometric exercise or a more concentrically-focused ballistic-style training station, the findings of our research document either mode of operation may be emphasized on the Pneubounder. Pneubounding can be used as a form of "overspeed training", as has been found to be effective in Assisted Jumping apparatus for improving vertical jump performance[12] [13] and with a loading gradient similar to Resisted Jumping.
4. Prevent Injuries– The Pneubounder (or similar activities) should be part of an overall training program to progressively condition elastic tissues of muscle and tendon prior to engaging in activities involving higher velocity movements. Targeted strengthening of key joint stabilizing muscles (such as rectus abdominus, multifidus, gluteus medius and vastus medialis) have been shown to reduce injury potential in recreation and sport, especially when activated in multi-joint exercise. Our research finds that Pneubounding can provide a high-level of activation in these key muscles, statistically equal to that recorded in conventional, ground-based jumping, without high impact forces on joints;
5. Enhance Balance and Proprioception – Provide safe, low-impact progressions for improving dynamic stabilization of (jump) landings and balance training in an upright posture for improving control and reaction time from loss of balance;
6. Improve Health and Wellness- Physiologically increase caloric expenditure and reduce oxidative stress when used as a

HIIT modality, for highly efficient work sessions in less total time;

7. Provide Biofeedback and Quantification of Effort- Accurate, real-time measures of force, work, acceleration, anaerobic power and capacity can be used during exercise sessions or post-set for motivation, gauging effort, unilateral force & power and baseline testing or comparisons between individuals or oneself.

In summary, the results and observations of four different research investigations over multiple years find that exercise on the Pneubounder can be of benefit for a wide range of people and exercise objectives, including foundational strength, dynamic stability and eccentric control, circuit training, power training, performance coordination, weight-loss and metabolic conditioning. More research is anticipated for further exploring this unique modality for varied purposes. As it stands, the Pneubounder proves to be a novel and efficacious alternative to high impact jump training or to a bike, elliptical or treadmill for anaerobic and aerobic conditioning.

For greater coverage on these subjects and detailed lab data findings please refer to the **Full Report** of investigational discovery.

FULL REPORT

BACKGROUND

Lower-extremity power is a facet of strength that has long been recognized as a requisite for safe and effective participation in sports. In order to display high levels of power a person needs to be able to generate forces very rapidly to effectively accelerate the system.

These abilities go far beyond athletic success, to include safe and enjoyable recreation and functional mobility. Declines in strength and power are associated with aging, primarily due to the loss of muscle mass and the selective atrophy and deinnervation of fast-twitch muscle fibers[14]. With the loss of explosive force production comes balance impairment and increased risk for falling[15]. When it comes to the body's fast-twitch motor units, the principal of "use it or lose it" applies. This pertains to both aging populations and the detraining effects encountered by injured athletes.

Broadly speaking, muscular strength and power are determinants of health and quality of life in all adult populations. Whether it be athletes seeking an edge, "weekend warriors" that want to excel in recreational sports without injury, or seniors leading independent active lives, lower body power development should be a facet of training for athletic performance and functional mobility. Appropriate training can preserve and even enhance the capacity for powerful, quick movements or short bursts of energy, <u>at any age</u>.

Exercise practiced in functional postures -- integrating balance with movement -- promotes greater transference of capacity-to-actuality in injury prevention, sport and recreation.

An expanding body of research has found that HIIT (High-Intensity Interval Training) for power endurance not only promotes stamina but also yields many health benefits (e.g. aerobic capacity, insulin sensitivity, reduced oxidative stress, positive body composition and fat loss) in very time efficient exercise sessions [16 17 18 19].

FOUNDATIONAL MOVEMENT PATTERNS

Given that gains in strength, aerobic capacity and anaerobic power tend to be highly specific to the muscles, motions and velocities of training, conditioning squat and jump movements promote functional transference to a wide range of land-based sports and many activities of daily life.

When it comes to core and lower body strength, squats are often referred to as "the king of exercise". Strength professionals widely agree, "*Squatting movements provide excellent neural training due to the balance, timing, coordination and activation demands of the large number of muscles involved.*

The biomechanical foundations of the squat exercise are unparalleled for strengthening the prime movers (extensor muscles of the hip and knee) used in running, jumping, skating, throwing, hitting, and nearly every other type of athletic movement. Strengthening hip and knee extensor muscles improves running speed and jumping ability.

The major sources of strength in the human body are the thigh, hip and buttock areas. It's generally agreed in exercise science that the further an athlete gets from deploying these muscles the less potential for strength development" [20].

Exercises that utilize the squat motion provide a base of functional specificity for more refined, sport specific movements based on the same muscles and motor patterns. Very strong correlations have been established between squat, sprint performance and vertical jumping heights in elite athletic performance[21 22 23 24 25].

Traditional methods for lower body power development have relied on squatting motions to train across the Force-Velocity spectrum: heavy-load squats, Olympic lifts and Plyometrics.

Since powerful movement is the product of:

- Force (strength developed with high loads 65 – 100% of 1RM and low velocities), and
- Velocity (speed strength developed with light loads of 0 to 50% of 1RM and faster execution),

both capacities need to be targeted during training sessions.

FUNCTIONAL STRENGTH TRAINING

Decades of empirical data corroborate the fact that no single exercise method optimizes all aspects of strength and power. Writes Newton et. al. (1994): *"Often coaches and athletes associate the term strength only with the force that can be exerted during slow speed muscle actions. Many strength and conditioning coaches believe strength is a quality of muscle that can be expressed across all movements involving that muscle. Therefore training programs often focus on single joint exercises with low movement speeds, in the expectation that power output will be increased for the movement trained and that this will carry over to more functional multi-joint movements. However, much of the muscle's adaptation toward greater power development is neural in terms of better intramuscular and intermuscular coordination"*[26].

A well-planned strength program progressively integrates the muscles, actions, intensity, velocities and movement patterns of a sport or daily living activity with the energy system (anaerobic vs. aerobic) that predominates during competition or work. That, by definition, is functional strength training.

INTERMUSCULAR COORDINATION AND TRAINING MODE

If it is held true that strength and power can be developed and optimized by mixing methods involving slow and heavy resistance training and lighter, faster movements then it is logical to ask: does training mode matter? The evidence shows that it does.

Closed Kinetic Chain versus Open Kinetic Chain

Choice of exercise mode and postural orientation can substantially impact training effects. Rutherford (1988) studied the effects of conventional, open-chain leg extension training and its transferability to strength in other exercise modes. While weight lifting ability of that particular exercise mode improved through training, there was no improvement in dynamic force production or power output during sprint cycling[27].

In another study, strength gains made in a conventional resistance training program on a leg extension machine increased leg extension force by 107%. However, when tested for peak torque with an isokinetic dynamometer using the same trained leg, only a 10% improvement was observed, and the improvement was largely in the slow-velocity high-torque region of the torque-velocity curve[28].

Mellor (2005) compared motor unit synchronization of the vastus medialis obliquus with the vastus lateralis in an isometric contraction at 30 degrees during an open chain (e.g. leg extension machine) and closed chain condition (e.g. squatting). Study results showed significantly greater common drive and coordination between the vasti (quadriceps) muscles in the closed chain tasks[29].

These results support the assertion that coordination of different muscle groups in a training movement rather than intrinsic increases in a muscle's strength are essential for power improvement. As Rutherford posits, the implication for rehabilitation is that strength training for isolated muscle groups has limitations with regard to getting people back to functional capacity faster.

Transference of strength gains to functional mobility and greater athletic performance require progressively specific training modes and methods that promote intermuscular coordination[30], with loads and velocities that reflect actual performance conditions. Simply increasing leg muscle strength through use of an open chain leg extension machine will not necessarily improve performance in a wider application of leg movements.

Postural Orientation

The balance and coordination demands of squats and jump squats can be reduced through the use of machines. Various types of equipment allow one to perform leg presses and platform kick-offs in a seated or reclined position. Evidence suggests that while these modes can help promote strength development, there may be limitations to functional transference.

Porter (1997) put 15 healthy, active older women through an 8-week resistance-training program to strengthen ankle dorsi-plantar flexion in a standing position only[31]. At completion of the training program tests of strength were conducted of subjects in two positions, standing and supine. Post-training, significant increases of concentric ankle dorsiflexion strength (30%) were found, however only in the standing position. When the same subjects were tested in the supine position NO significant changes in strength occurred.

In this experiment improvements of strength were specific to the position of training. The implications for the transferability of strength gains to functional tasks (e.g. jumping, sit-to-stand, stair climbing, reacting, fast stabilization) can be broadly construed. Posture and body position specificity in strength development must be a consideration for functional transference.

Reclining on a leg press machine and using moderately heavy weight and faster repetitions may reduce axial loading or the complexity demands of good form and promote hypertrophy objectives. Progressive eccentric exercise in a supported position can safely promote quadriceps muscle growth in both healthy subjects and patients recovering from knee surgery[32]. But as a method for improving lower body power for movement patterns performed in erect postures, balanced on one's feet, reclined or supine exercise modes have limited applicability in terms of intermuscular coordination and functional transference of strength and quickness.

By laying on one's back balance senses, core stabilization and mechanical loading patterns on the body are not integrated with the movement pattern. Furthermore, reduced engagement of whole-body exercise with an exaggerated "flight phase" between push-off and successive landings when doing reclined platform kick-offs may reduce the anaerobic intensity of the exercise. The normal application of center of balance and ground reaction force is altered when exercising on one's back.

Accelerative Intent

Acceleration through the final range of motion is a requirement for ballistic power (e.g. bigger lifts, explosive starts, higher jumps and harder throws). Moderate to heavy resistance training can condition the opposite response.

Newton et al (1996) compared the average muscle activity and maximal power output of a traditional bench press to a bench throw where the bar is thrown into the air with hands, both using a bar weight of 45% of the subject's predetermined 1-Rep Max. The results unequivocally show higher electromyographic (EMG) muscle activity of the pectoralis major (+19%), deltoids (34%), triceps brachii (+44%) and biceps brachii (+27%) and greater average and peak power outputs during the bench throw. During the traditional bench press, deceleration begins at about 60% of the bar position relative to the total concentric movement distance. In contrast, velocity during the bench throw continues to increase throughout the range of motion (ROM) and this translates into higher power outputs[33].

One way to limit the ill effects of moving slowly is through the intent. It has been shown that even though a movement may be slow, if the intent is to move rapidly, there will be greater carryover to power development[34].

Visualization accompanied with physical training can further increase neural excitability and strength of neural response[35]. Exercise protocols that combine lifting heavy weight with higher velocity movement (e.g. Complex Training) have proven to be more effective at enhancing power production then either alone[36]. Potentiating muscle fibers by first activating larger motor units with heavy weight and then immediately unloading to engage that muscle fiber at higher velocity is an example of neural factors increasing lower body power. Various aspects of this intramuscular coordination can be refined through repetitive practice and learning. Moreover, exercise protocols that lead to greater neural drive and motor unit recruitment can increase strength and the ability to lift more weight.

POWER TRAINING METHODS

Plyometrics and Olympic-style lifts have traditionally been used to develop quickness, explosive strength and maximal vertical jump height.

Plyometrics is a term to denote explosive jump training exercises using bodyweight or light resistance. Plyometric techniques pre-load a muscle with eccentric contractions, followed immediately by rapid concentric contractions[37]. This quick reversal of motion loads muscle tendons, which store and return energy like a spring.

It's been theorized that with sufficient speed and intensity of an eccentric load, a myotatic stretch reflex can be evoked through the neural actions of muscle spindles, causing greater concentric muscle contractions, thus increasing power. Though there are no studies specifying in all cases what that intensity must be, it is commonly believed that depth jumps from boxes or very rapid hops with minimal ground contact time are indicative of requisite intensity.

A large quantity of research on plyometric training uses vertical jump squats or countermovement jumps in the experimental protocol. Those studies demonstrate that the stretch-shortening cycle (SSC), speed of movement and explosive concentric contractions of large extensor muscles of the hip and knee can improve, and in so doing improve power output and jump height. However, in many studies that have examined the countermovement vertical jump, a myotatic stretch reflex has not been documented.

It may be deduced from the preponderance of evidence that explosive jump training can improve power output and transfer to dynamic sports performance without substantial activation of a myotatic stretch reflex or the intensity of eccentric loads and speed of stretch required for evoking the reflex. In most cases vertical squat jumps (largely concentric) and countermovement jumps -- though varying in the degree of muscle elasticity utilization -- may be used, independently or together, to improve dynamic sport performance, without the risks of depth jumping or excessive high impact landings.

These methods of training are perhaps better referred to as either ballistic or high-intensity SSC movements, to differentiate them from plyometric techniques which use high impact landings to produce the requisite tension build to evoke a myotatic stretch reflex. Because these other jump training techniques (which are not depth jumps) are so often referenced in the literature as the experimental methodology used in what might otherwise be termed plyometric jumping, it is reasonable to conclude that high-impact landings are not required to get the benefits of improvement and that a wide range of countermovement jumping is sufficient for obtaining the functional power results most sought from plyometric exercise.

PLYOMETRICS AND INJURY PREVENTION

Constant adherence to slow velocities or isolated weight training movements during exercise may not adequately prepare visco-elastic tissue (i.e., tendon connecting the muscle to the bone and layers of supporting tissue within the muscle) for high velocity training exercises or competitive movements and, in fact, may increase injury potential[38].

Besides decreasing injury potential, appropriately conditioned visco-elastic tissue can enhance force production when stretched under eccentric loading and return energy like a spring when unloaded[39 40]. Utilization of muscle elasticity is a central characteristic of SSC jump training (i.e. plyometrics)

Targeted development of strength in the lumbo-pelvic musculature and lower extremities incorporating plyometrics and core strengthening has been found to be effective at reducing injury[41 42 43], particularly in female athletes who as a group are far more likely to experience anterior cruciate ligament injuries than men[44 45]. In fact, deficits in neuromuscular control of the trunk (core) have been found to be a predictor of knee injury risk[46].

It is evident that women typically utilize different muscular activation patterns during single-leg landings compared to men (i.e. decreased gluteus maximus & gluteus medius and increased rectus femoris muscle activity)[47]. Furthermore, it has been determined that a significant strength imbalance between a dominant and non-dominant leg can exist even in collegiate level athletes and this may impact both peak athletic performance and greater risk of injury[48].

Exercise that integrates core strength, balance, proper activation of the gluteals and dynamic stabilization with BOTH unilateral and bilateral jumping protocols can reduce injury risk.

While general strength training is useful for increasing muscle size and force production, core stabilization during movement is an aspect of intermuscular coordination that must be learned dynamically for successful transference to "real life" execution. Jump training can accomplish that.

Plyometric exercises are used in rehabilitation and injury prevention programs because the landing phase of these exercises requires dynamic stabilization. These movements incorporate the lower-extremity triple extension of the hip, knees, and ankles, with muscles activated with accelerative intent to achieve improved performance. Practiced in upright postures, torso control, coordination and balance are vital components of the functional transference of these exercises, improving activity performance and reaction speeds.

RISKS OF TRADITIONAL METHODS

The high-impact landings of repeated ground-based plyometric training can also lead to overuse injuries and delayed onset of muscle soreness.

Conventional running and jumping magnifies the force the body must withstand relative to standing, through the accelerations induced by the impact of the landing and the ensuing propulsion phase. The force load of jumping can range from 3 to 5 times the body mass of the jumper[49]. Unfortunately, combining high load and high velocity into one movement, such as those during typical plyometric or ballistic training, can increase the risk of injury due to high impact forces[50]. Those with orthopedic sensitivities or older joints would become more vulnerable.

As a general guideline it's estimated that athletes should not be allowed to perform intense plyometrics unless they can back squat 1.5[51] to 2.5[52] times their body weight. Without this requisite strength base many populations, including adolescent athletes[53], are cautioned against intense plyometric exercises.

Multiple sets and repetitions of jump squats or intense plyometrics in durations long enough to elicit anaerobic physiological adaptation and accompanying health benefits can lead to a breakdown in form and potential injury. Olympic-style lifts with heavy weights require expert coaching to learn proper technique and place significant loads on the upper extremities, spine, and thorax. Without increased increments in load, Olympic-style lifts can continue to improve technique and fluidity of movement but gains in strength and muscle development will level off.

NON-TRADITIONAL METHODS FOR LOWER BODY POWER

Gains in strength and power are regionally developed within the muscle's force-velocity curve and typically don't transfer highly to other regions. For example, the strength developed using slow-speed squats increases slow-speed strength the most. Since fast speeds are necessary for high power output it is clear that strength needs to be developed using high velocity concentric movements.

Many movements in sport and recreation utilize the "load to explode" principle for getting off the line or changing direction from a stop or subsequent deceleration of body mass. As timing, coordination and balance are requirements for successful application of strength and lower body power, exercising in upright postures holds advantages. Various means have evolved to provide different strategies for either dampening impact or more safely applying external loads during upright jump or squat training.

Jump Squats with External Load

Lightly loaded jump squats (0 - 30% of a 1 Rep Max squat) have been found to optimize power and improve the rate of force development[54]. Increasing the rate of force development is a neuromuscular adaptation that improves with correct practice[55].

Loaded ballistic "squat jump" training – light load vertical jumping without fast eccentric countermovements -- has proven more effective than conventional plyometrics for improvements in tests of dynamic athletic performance, such as sprint times and vertical leaps[56]. Training studies have found that light load squat jump training can improve vertical jump performance in Division I male volleyball players, principally by improving the rate of force development[57], a largely neurological adaptation.

Other studies involving loaded jump squats have demonstrated that light-load jump squats were superior to heavy-load jump squats in producing increased movement velocity capabilities, and that velocity-specific changes in muscle activity likely play a key role in the improvements[58].

In McBride et al (2002), increased surface electromyographic (EMG) activity in the lower limbs was correlated with increased movement velocity and greater performance in a battery of lower body power tests[56]. Properly periodized, light load, high velocity training has been proven to impact vertical jump performance in both pre-season training[59 60], as well as crucial end-of-season games[61]. A 12 week plyometric training program introduced late in a competitive season improved explosive strength and these improvements transferred to soccer kick performance in terms of ball speed[62]. Thus, even elite athletes thought to be neurologically well-developed may still benefit from this form of training, potentially from training novelty and improved metabolic conditioning[63].

Hansen et al (2009) performed an exhaustive literature review of research on load optimization during squatting movements and concluded "moderate load training appears particularly effective if ballistic techniques are used" and will "contribute to gains in sports specific performance"[64].

Although Wilson et al (1993) concluded that the load that maximizes mechanical power is 30% of a 1 Rep Max back squat[65], a broad effective range of resistance exists for maximizing power output. Finding any specific load that maximizes mechanical power is considered by some of less importance[66] [67].

To retain the functional specificity of upright movement, implements have been introduced to add resistance to jump squat exercise. Those may include dumbbells held with one's hands, placing a weight bar on the upper back or wearing a weight vest. While vertical jump squats have become a staple in training athletes for lower body power, placing a bar or weight vest on one's back to introduce additional load presents a risk of injury during propulsion upward, as well as upon landing and potentially alters jump mechanics. Further, external loads and fatigue can lead to a breakdown in technique, putting the spine, knees or ankles at risk during exercise.

Elastic Band Resistance Training

The use of elastic bands as a form of external resistance during jump training offers useful advantages with some unique characteristics. One principle advantage is that an external load is not applied to the shoulders, where axial loading of the spine during jumping could be injurious.

Another is that elastic bands vary resistance force along the range of motion. As one stretches the band further it becomes more difficult and thus more force is required to continue travel. In jump squat training, this means that the external force applied may be lower where the band is relaxed or higher where the band is most stretched.

Assisted Jumping

"Assisted Jumping" is a variation of the jump squat that uses elastic bands to reduce eccentric loads on landings and to help propel body mass upwards during the propulsive phase. In this apparatus, elastic bands are secured at some point above the jumper – to a point on the ceiling or a rack above – and to the jumper's waist.

Assisted Jumping is the opposite of using elastic bands to provide downwards resistance during the upward propulsive movements of the jump, or what otherwise is referred to as "Resisted Jumping". Assisted Jumping allows the subject to practice vertical jumping at an effective mass below bodyweight.

Studies using Assisted Jumping apparatus and exercise protocols demonstrate that elite jump athletes can improve jump performance through neurological adaptations having to do more with improved velocity and intermuscular coordination than muscle hypertrophy or inherent force production.

Sheppard et al (2011) evaluated the effects of Assisted Jump training on jump performance of elite college volleyball players[69]. Two groups performed identical training protocols: 5 minutes of training warm-up and dynamic stretching followed by 5 – 7 sets of 5 jumps, 3 times per week for a total of 5 weeks. Reps per set were held at 5 and the number of sets per week was progressively increased. One group performed vertical countermovement jumps (Jump Squats) and the other Assisted countermovement jumps. Both groups were actively engaged in-season, while also doing regular volleyball and strength sessions during the course of the study. Athletes were then tested for improvements two ways: (1) on their maximum vertical countermovement jump height and (2) with a spike jump with approach steps, as would be practiced for the sport of volleyball. Sheppard at al found that repetitive Assisted countermovement jump training resulted in superior improvements in jump height under both test conditions with large effect. Normal countermovement jump training did not result in significant gains in either jump test.

Assisted Jump – Research Conclusions

These jump improvements occurred under conditions where the eccentric and concentric loads of the jump were actually reduced by use of the exercise apparatus.

Sheppard et al. concluded that Assisted repetitive vertical countermovement jump training provided a novel, over-speed training stimulus that led to an increased rate of muscle shortening and greater movement velocity due in part to a decrease in antagonist co-activation.

In other words, neural adaptations were achieved by use of the apparatus with otherwise neurologically mature, elite jumping athletes, during in-season training through practice and repetition of a vertical jump squat with no other sport-specific technique between the two training groups. Furthermore, these performance enhancements acquired from repetitive Assisted vertical jump squats carried over to a more sport specific jump task.

In addition to improvements in jump performance, providing a means to practice vertical jumps with a resistance below that of body weight and at velocities and metabolic intensities above normal, could introduce a novel training stimulus, both fun and challenging.

Resisted Jumping

"Resisted Jumping" using elastic stretch bands typically affixes one end of the elastic band to the ground and another to the exercisers waist. When the jumper bends their knees to squat down the resistance of the band decreases and as they propel themselves upward and attempt to accelerate off the ground the band stretches and the external resistance force builds. Unlike Assisted Jumping, resistance band training applied to jump squats does not dampen the impact of landings and does not unweight the subject below body mass during use. The use of elastic band resisted squat jumping with other strength and plyometric exercise protocols in high school and college athlete populations has produced mixed results with respect to lower body power.

Rhea et al used the same commercially available elastic band resistance system in two studies with 12 week training programs with both high school and highly trained college athletes. In both studies greater improvements in lower body power output were achieved when incorporating resisted band training with traditional strength and conditioning approaches[70 71]. However, in other studies with 6 week training programs, the same elastic band system was used with college-aged athletes to improve vertical jump performance and it was found that the use of elastic bands in squat jump exercises -- with and without arm movements – offered no additional advantages over conventional strength and plyometric training[72 73].

These elastic sport cord studies asked: did the addition of sport cord resisted squat jumps offer appreciable benefits or advantages over traditional methods for improving lower body power and vertical jump height? Confounding the analysis of variations in experimental results may be the difference in training volume.

With respect to vertical jump height performance, a meta-analysis of 56 plyometric training studies elucidated the various factors that affect the impact of plyometric training on vertical jump performance[74]. Greater training volumes of more than 10 weeks and more than 20 sessions, using high-intensity programs (e.g. > 50 jumps per session) maximized the probability of performance improvements. However, traditional plyometric training is very demanding on athletes and while applying external resistance and/or significant training volume may provide a stimulus for greater enhancements in performance, it may also further increase the potential for overuse injuries associated with high-impact landings.

The Pneubounder: Pneumatic Rebound Device

The Pneubounder utilizes pneumatic resistance and a novel platform design to address current limitations of power training methods by:

(i) retaining the benefits of performing exercise in functional upright postures while dampening the impact shock from ground-based exercises,

(ii) removing potentially dangerous external loads, and

(iii) providing a high degree of safety when performing multiple sets and repetitions.

The Pneubounder provides a rehabilitation alternative to a minitrampoline for those that should avoid valgus deviations to the lower leg[75] and for progressively increasing high velocity muscle contractions and the range of motion over which eccentric contractions are applied.

The Pneubounder also incorporates aspects of both Assisted and Resisted Jumping without the difficult and time consuming task of attaching elastic bands with the appropriate resistance. Similar to elastic cords, the pressure gradient of pneumatic resistance on the Pneubounder is such that as the user's legs or body come up on the upstroke, the amount of force against muscles and joints tapers. During downward extension, the resistance builds. This resistance gradient permits the user to safely develop strength across a fuller range of hip motion with improvements in dynamic flexibility. **Modulating eccentric loads, impact forces, range of motion and balance requirements enables broad applications for a wide variety of populations and exercise objectives.**

The machine's pneumatic technology is the key to its versatility. Two modes of operation exist, valves open or closed. With the valves open the user pushes air out of the cylinders during the extension phase of movement and then draws air back in during the flexion phase. Valves may be opened incrementally to increase or decrease the difficulty of the exercise, engaging more or less whole body musculature and the corresponding physiological demands of the exercise. With the valves closed the user works entirely against a sealed volume of air that compresses and expands during movement. The system of air management on the machine affects the spring rate, pressure gradient and degree of dampening during use.

MAJOR RESEARCH FINDINGS

- **<u>Pneubounding qualifies as a plyometric exercise.</u>**

With valves closed, the machine's pneumatic technology enables varying degrees of SSC jumping exercise without the jarring landings of conventional plyometrics.

In a ground-based jump, upon a hard landing the center of mass continues downward while eccentric contractions in the legs decelerate the movement. On the Pneubounder each propulsive movement is immediately followed by upward pressure on the feet through the pneumatically pressurized platform constantly underfoot. Consequently, the upstroke on the machine is where the eccentric contractions take place and quick reversal from eccentric to concentric provide the plyometric dynamic of jumping.

Combining an analysis of data collected on peak muscle activation patterns with measurements of joint motion, exercise repetitions performed on the Pneubounder contain the upright, triple-extension motion pattern with sufficient eccentric and concentric loading patterns to fall within the broadly accepted range of "gold standard" exercise methods for lower body power development, such as the typical countermovement jump squat. In fact, peak muscle activity was not found to be different when jumps were performed on the ground compared to those on the Pneubounder.

With the dampening of the pneumatics and constant contact with the foot platform, Pneubounding is dissimilar to depth jumps and other high impact plyometrics. Depth jumps are a class of plyometrics reserved only for highly prepared athletes. When performing depth jumps athletes step off of elevated platforms to overload the eccentric stretch phase of the countermovement jump which is expected to invoke the myotatic stretch reflex.

Recommendations prior to adding depth jumps and other intense plyometrics to a workout suggest an ability to squat 1.5[76] to 2.5[77] times bodyweight. Depth jumps work to fine-tune the transition from load to explode after landing or stepping into a jump. While this reactive ability is critically important for many sports, research has demonstrated that Assisted Jumping and loaded squat jumps are just as effective at improving vertical jump performance as high-impact plyometrics[78 79]. As a result, the SSC of plyometric exercise offered by the Pneubounder is expected to be a potent stimulus for development of functional lower extremity power.

- **<u>The Pneubounder may alternate between plyometric and light-load, high-velocity (Ballistic) training.</u>**

Variations of exercise action on the Pneubounder are achieved through manipulation of air pressure and release. With valves open on the Pneubounder, jumping exercises become highly concentric during both flexor and extensor phases of the movement. The extension phase is still very similar to that when the valves are closed, targeting the extensor muscles concentrically. However, with valves open the flexion phase now requires more forceful concentric contractions of the flexor muscles to draw air back into the cylinders. In order for the platform to stay elevated during use, the air drawn in during flexion must equal the air pushed out during extension. To draw air in, the up-stroke phase must be performed just as ballistically as the extensor phase.

This creates an ideal environment for light-load, high-velocity training that target a very large number of muscles not only within the lower extremities, but also within the core and possibly within the upper extremities if the handrail is utilized effectively.

This mode of operation functionally targets the hip flexor muscles, which is often very difficult to accomplish in a jump type movement. Ground-based tuck jumps are sometimes used to engage the hip flexors, but at the expense of the propulsive component while on the ground.

Muscles unaccustomed to high eccentric loads may experience more damage than concentric muscle actions[80], during the landing phase of the jump. Because Pneubounding exercise reduces eccentric loading and primarily becomes concentric as the valves open wider, very little post-exercise muscle soreness was reported in multiple trials across the varied subjects in our research. This is beneficial for those who can't be slowed by multiple days of recovery. Research on intense, ground-based plyometrics has provided evidence that following an undampened plyometric exercise protocol, the ability of the muscle to generate power can be reduced for at least 3 days[81]. Exercise on the Pneubounder can serve as a progression towards the more intense eccentric loads of depth jumping, running downhill or proceeding down a flight of stairs, depending on the needs of the individual.

Wide variations in velocity, range of motion and force, in an upright, closed-chain exercise, with multiple safety features to safeguard against injury that may occur because of fatigue or a loss of form, combine to allow sets of repeated jump squats.

This can be instrumental for getting in the repetitions required to (1) teach greater gluteal activation and proximodistal kinetic chaining in a hip-loaded position, (2) condition neurological adaptations that improve velocity of movement, such as intermuscular coordination and golgi tendon organ (GTO) disinhibition, and (3) repeat all-out efforts using large muscles and large range of motion with sufficient duration to evoke glycolytic (anaerobic) metabolism and metabolic stress, conditions known to improve power stamina and facilitate exercise-induced hypertrophy for growth, repair and maintenance of muscles and tendons[82 83 84 85 86].

- **<u>The closed-kinetic chain elements of the Pneubounder enable targeted facilitation of joint stabilizing muscles in the low back, hip, knee and ankle.</u>**

Analysis of muscle activation and motion patterns simultaneously illustrated functional use of stabilizing muscles, including lumbar (multifidus), abdominal (rectus abdominus), hip (gluteus medius), knee (vastus medialis and vastus medialis obliqqus (VMO), and ankle (gastrocnemius and tibialis anterior) (See Illustration in Figure 4).

While unilateral use was not specifically examined by our research, our observations suggest that closed-chain single-leg exercises should be as effective as their bilateral equivalents. For those requiring single-leg push-off power it is important to train unilaterally to optimize neural control and muscle development. Unilateral training will also minimize chances for underdevelopment of the non-dominant limb and potential for injury[87].

Due to the versatility of the machine, single-leg exercises may be performed with appropriate loading such that the core and stabilizing muscles can be trained without increased risk for injury. Many ground-based single-leg exercises expose the single-leg to the same level of force that is shared between the legs in a double-leg exercise. This places excessively large frontal plane moments in the hips and lumbar spine.

Practitioners who use plyometrics to train dynamic stability are advised to create programs that progress the intensity of the exercise and difficulty of the landing phase of the jump for improvements in balance, postural control and stability[88]. The closed-chain, low-impact nature of the Pneubounder and its perturbations of pneumatic resonance provide an excellent modality for augmenting conventional plyometric exercises with such challenge progressions, with reduced risk of injury during training sessions.

Broad dynamic activation of core musculature during Pneubounding can be inferred from neuromuscular responses to this training mode, as measured with surface EMG. Relatively high peak activation of core muscles likely bring muscular synergists to bare during the exercise, as outlined in Table 1 below.

- **<u>Pneumatic technology allows functional training at velocity through a full range of motion.</u>**

Analysis of high-speed video provided evidence for a large range of motion with a variable load gradient. This provides a potentially safer platform for improving both range of motion and broader power development.

At initiation of knee and hip extension, the positioning of the pelvis relative to the lumbar spine and thighs is critical for both strength and stability, providing the foundation for the ensuing propulsive phase. In many jump training paradigms the hips are so highly loaded in the flexed position that it is difficult to functionally train. Exploiting a greater range of motion during jump training can increase the potential for increased jump performance[89].

At the other end of the motion, it is critical for performance to be able to push through the entire extension. If agonist muscle activation is ended early, or antagonists activated too early, power output and jump height is compromised. As a result, the Pneubounder is engineered for full range of motion jump training or for small incremental range as may be required.

With the resistance and shock absorbency in pneumatic cylinders, there are no boxes, external straps or weight bars directly on the body that could present a risk of injury or attenuate effort for fear of falling, stumbling or taking a hard landing. This also makes set-up time on and off the machine very fast, unlike using stretch bands. By minimizing the potential of stumbles or bad landings during repeated jump training, confidence and best effort repetitions can be improved by reducing the fear of injury during training.

Permitting the user to choose from a wide variety of intensities on the machine allows incremental development of elastic strength and conditioning of visco-elastic muscle tissue (e.g. tendons and elastic elements of muscle) to increase performance and reduce potential injury caused by inadequate preparation for fast, explosive movements. These aspects of use make Pneubounding a potentially attractive addition in pre-season training or late stage rehabilitation.

A potential concern of training on the Pneubounder for performance athletes observed in our studies was reduced hip extension and ankle plantarflexion compared to ground-based jumps. In sport performance, vertical leaps and sprint strides are enhanced with technique using full hip extension. Pneubounder subjects in our experiments had a tendency to pull the hips back during push-pull style Pneubounding in order to unlock the hip joint to permit rapid hip flexion on the upstroke of the bounder jump immediately following the full downstroke. With coaching and practice Pneubounding technique should be able to accommodate greater hip extension when it is desired.

Ankle plantarflexion on the Pneubounder appears limited as the subject presses the platform down to full air compression in the cylinder and does not come up on the balls of the feet as one typically would in jumping. However, peak muscle activity measured with surface EMG in lab experimentation with Division 1 College power athletes found statistically similar muscle response in gastrocnemius (plantar flexor musculature) between ground-based jumps and Pneubounder jumps. This indicates neuromuscular response of the plantar flexors during Pneubounding comparable to full plantar flexion as seen in ground-based jumping (Figure 3).

Jumps, sprints, kicks and lunges are all made more powerful through kinetic chaining or coordination of the order of muscle firing from the gluteals on down in a proximodistal direction. This power transport is considered <u>essential</u> in the execution of explosive lower extremity movements[90], particularly for improved jump height. While ankle plantarflexors (e.g. soleus, gastrocnemius) contribute to increases in jump height -- particularly during the final 20% of the jump movement -- the gluteus maximus and vasti muscles are the major energy producers of the lower extremities and dominate the instantaneous power of the trunk[91].

As sprint take-offs and vertical jumps are most highly determined by gluteal and quadriceps engagement, it is here we see Pneubounding offers advantages for reinforcing core-centered propulsion dynamics through repetitions and de-emphasizing "calve-jumping", as is often observed in immature athletes. The hip extension and ankle plantarflexion that does occur while Pneubounding was observed to be similar to that observed in Olympic-style lifts.

Unlike a conventional leg press machine, the Pneubounder permits and encourages acceleration in hip and knee extension and flexion through the final range of the movement, a key aspect for determining jump height from the ground.

It is widely held amongst sport scientists that accelerative intent to move quickly can be a very potent stimulus for power development. As one opens the air valves on the Pneubounder for greater intensity, greater acceleration is required of the user.

In conclusion, though the subjects in our studies tended towards reduced full extension of hip and ankle as one would find in conventional vertical jump technique, in light of the advantages of the equipment and the ability to increase Pneubounding hip extension through practice when desired, we do not anticipate any detriment to training on the equipment and in fact would expect lower extremity power and jump skill to improve, even amongst neurologically mature jump athletes. As with all gym equipment, it is for the athlete and strength coach to take the gains made in the gym and further their transference to sport specific technique.

- **<u>The power measurement system of the Pneubounder proves to be valid and accurate.</u>**

Coaches are generally advised to select tests that are biomechanically similar to the movement patterns of their sport or functional task. Sensor technology (digital accelerometers and pressure sensors) and software embedded in the Pneubounder provide an objective and very convenient means for testing

  - peak power, anaerobic power, work or caloric burn,
  - unilateral asymmetries or bilateral deficit in strength or power, and
  - performance baselines using the squat jump or countermovement exercise.

Furthermore, real-time performance feedback during an exercise session can improve technique development and performance or support motivation to train hard and allow comparisons of an athlete to themselves or others[92].

The “gold standard” for testing peak power – a single vertical jump – uses a force platform to derive power, velocity and jump height. Accelerometers have been proven accurate for use in tests of muscle power[93]. The Bosco Power Test measures average power or “power endurance”, by having the subject perform repeated vertical jump squats on a force platform for durations lasting up to 60 seconds[94]. Like a Wingate Test (performed on a bicycle ergometer), both the Bosco and Wingate protocols are used to measure a subjects rate of fatigue, a measure of intramuscular coordination and muscle buffering. Force platforms can be expensive and impractical for a training environment. Using time between foot contacts on a contact mat system is potentially flawed as subjects can vary test results by exaggerating flight times by pulling their knees up before landing.

To test the accuracy of the assumption that pressure in the Pneubounder cylinders correlated to force, a commercial biomechanics force platform was mounted on the Pneubounder foot bed (Figure 1). A very high correlation was found between peak force on the force platform and pressure within the cylinders ($r=0.947$). Furthermore, analysis of the formulas and software algorithms of the machine conform to accepted industry standards for computing velocity, power, and work of the user. Incorporating signal processing technology, the Pneubounder has the potential for reporting data samples at a rate of 250/second so that power is measured through-out the jump stroke and the peak per stroke is accurately captured. Having real-time, constant sampling of sensor readings during the jump stroke is an improvement over systems that only measure peak power or averages of peak power across multiple jumps.

As previously discussed, force and power output at various positions within the movement are critically important for overall performance.

Therefore, it is ideal to know more than just peak and average power. Real-time performance feedback during jump sessions provides a platform for sport-performance coaching and testing. Baseline levels of peak and anaerobic power both bilaterally and unilaterally are important for program development and course of rehabilitation following an injury. Accurate and timely feedback is also important for user motivation, driving quality repetitions and harder training sessions.

- **<u>High-Intensity Interval Training (HIIT) on the Pneubounder stimulates healthy metabolic adaptations.</u>**

HIIT with cycling and running exercise modalities has been found to produce healthy benefits in brief exercise sessions over just a few weeks, benefits once thought to be achievable only through longer exercise sessions and many months of endurance training. A study was performed at CSU to explore the potential for the Pneubounder to do the same.

Results found that cycling, running, and Pneubounding were equally effective at reducing oxidative stress (P=0.05), an important marker of metabolic health. These results confirm the versatility of the Pneubounder as a tool not only for lower extremity power development, but also for improving health markers associated with quality of life in young and "active aging" population groups. For those that are not interested or able to perform maximal effort intervals, the versatility of the Bounder allows it to be used for anaerobic training of lesser intensity as well as aerobic training.

CONCLUSIONS:

A variety of neuromuscular parameters contribute to the development of explosive strength and power. No single exercise or machine develops all aspects. The Pneubounder's advantage is its ease of use, versatility, convenience, and safety for providing a wide range of users the opportunity to develop speed strength, explosive power and power stamina using the triple-extension, jump squat motor pattern, with or without digital performance feedback.

Squats possess the biomechanical foundations underlying competitive play and personal bests in sport and fitness. Jump squat movements more closely mimic real-world athletic moves. Explosive squat movements activate large fast-twitch muscle fibers in a manner applicable to real life and with practice can improve the rate of force development of extensor muscles, promoting faster reflexes, higher leaps and harder hits.

The Pneubounder is a training station that teaches optimal engagement of the gluteal muscles of the hips, quadriceps of the knees, and plantarflexors of the ankles for propulsive movements and allows safe repetitions of fundamental movement patterns to shape the nervous system for greater drive and coordination.

For the vast majority of fitness enthusiasts and competitive athletes, depth jumps, Olympic-style lifts, and heavy-weight squats are not required to achieve high degrees of performance or functional strength. The risks of overuse injuries due to high impact force and the potential loss of training days from delayed onset of muscle soreness, make high-impact jump training useful in limited doses for some competitive jump sport activities. The Pneubounder can augment high-impact jumps for maximizing training time during a packed training schedule or for getting in the requisite training frequency required for positive adaptations to occur.

Analyses of kinematic (motion), kinetic (force), neuromuscular (muscle activation) and metabolic (physiological) data provide support for a wide range of efficacious applications of the equipment, ranging from gentle and easy rebounding exercise or controlled SSC movements with eccentric loading, all the way to explosive, high-intensity ballistic jump training. Evidence from our research indicates that protocols proven effective in ground-based plyometric, ballistic and high-intensity interval training should be highly transferable to the Pneubounder for achieving gains in:

- Explosive strength and vertical jump height,
- Targeted facilitation of the joint stabilizing muscles of the trunk and lower extremities,
- Power stamina, muscle buffering, and fatigue resistance,
- Conditioning of visco-elastic muscle tissue for injury prevention and performance,
- Dynamic stabilization, deceleration control, proprioception and balance,
- Metabolic function, fitness level, and body composition in a time-efficient, whole body exercise.

RESEARCH METHODS AND RESULTS

This section provides additional detail on the studies performed at CSU and the USAFA.

Study 1 – Kinematic and Kinetic Analysis

A pilot research study conducted at CSU collected positional data from which a large number of kinematic and kinetic variables could be computed and analyzed. A single-subject experienced with the Pneubounder and plyometric ground-based jumps was recorded with a high-speed camera operating at 250 fps. The camera was positioned orthogonal to the right sagittal plane of the jumper at a distance of ~3 m. The subject performed short, quick hops with the valves closed and both countermovement and tuck jumps with the valves open on the Pneubounder. These jumps were replicated on the ground. The subject was outfitted with retro-reflective markers on the right side of the body so that sagittal plane joint motion and overall center of mass motion could be computed from the digitized video. A marker was also placed on the moving platform of the Pneubounder so that relative motion could be examined. Vertical ground reaction force was calculated using Newton's Second Law of Motion ($\sum F=m*a$), with the subject's mass and center of mass acceleration. Power output was calculated through the product of the vertical ground reaction force and relative velocity between the subject's center of mass velocity and that of the Pneubounder platform. All data processing was performed with Vicon Motus software. Since kinematic data tends to remove high frequency components of movement, such as those experienced during landings, a separate data collection was performed for validation of the initial data. A Bertec force platform was securely bolted to the platform during performance of the Pneubounder jumps (Figure 1) and ground-based jumps were performed on identical force platforms that were mounted level to the surrounding floor. The subject was outfitted with retro-reflective markers and motion data was captured and processed similar to the original data. Peak and average forces were compared across methods within each jump style using correlation (Pearson's R) and linear regression passing through the origin. All correlations were extremely high ($r >= 0.808$) with lines of best fit very close to identity (Figure 2). Based on these results it was determined that calculation of ground reaction force using the kinematic data under these jump scenarios was valid.

The results from this study confirmed that the Pneubounder jumps contained triple-extension joint motion of the lower extremities with no high-impact landing phase. Instead, the dampening of the pneumatics allowed for the fluid application of forces throughout the full range of motion. The dampening appears to increase the duration of propulsive phase, putting the muscles under tension longer than their ground-based equivalent.

Because the feet maintain contact with the Pneubounder platform, the amount of plantar flexion of the ankle is reduced. Hip extension also appears to be reduced, most likely a consequence of holding onto the handlebar for safety. In general, joint motion during the propulsive phase appears to be quite similar to the second pull of Olympic-style weightlifting exercises.

Figure 1: Front and side views of force platform mounted on top of Pneubounder foot platform.

By assessing instantaneous power output, it was confirmed that operation of the Pneubounder with the valves closed creates an eccentric loading phase that immediately precedes the concentric propulsive phase, thereby replicating the desired SSC for functional power training. Because the high-impact landing is removed on the Pneubounder, it would not be categorized as intense plyometric exercise requiring the prerequisite 1.5-2.5 times bodyweight squat prior to initiation of use. However, it is plyometric at the level of jump squats and assisted/resisted jumps using bungee cords.

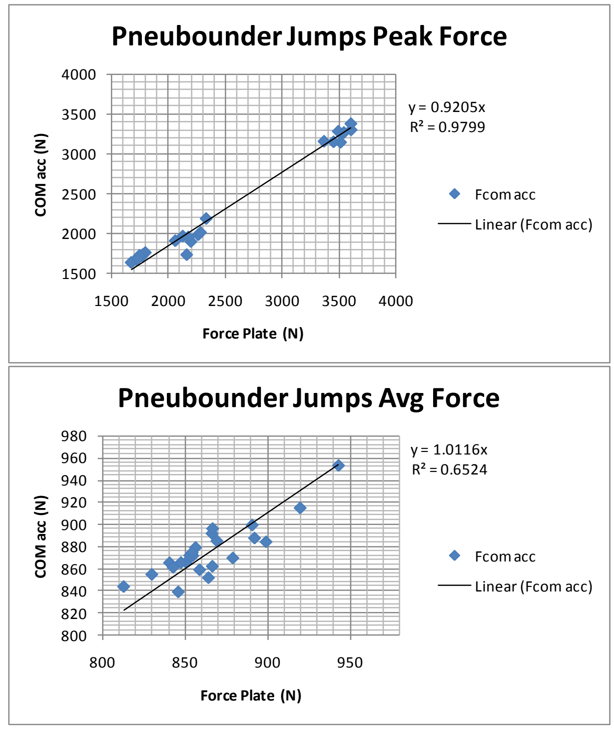

Figure 2: Comparison of peak (left) and average (right) vertical platform ground reaction forces on the Pneubounder using COM acceleration and the force platform, all jump styles combined.

With the valves wide open, the SSC is attenuated, producing a movement that is highly concentric for both sides of the joints. Regardless of the valve settings, repetitions occur much more quickly than their ground-based equivalents. The pneumatic dampening removes the time delay of the flight phase that occurs in ground-based jumps. Furthermore, the user does not have to reset him or herself prior to performing another repetition. This creates an environment where many quality repetitions can be performed very quickly either for power development or anaerobic training.

The concentric-concentric mode of action with the valve open is quite unique, introducing a highly functional means to train the hard-to-target hip flexors as well as other joint stabilizers. Training both sides of the joint in a ballistic manner conforms with principles believed to increase athlete durability and could positively impact stride performance in sprints.

Study 2 –Neuromuscular Analysis

In collaboration with the US Air Force Academy Human Performance Laboratory the neuromuscular activity of Pneubounding was compared to ground-based countermovement jumping. The study and findings were presented at the 2009 national annual meeting of the American College of Sports Medicine and subsequently published in abstract form in *Medicine & Science in Sports & Exercise* (Vol. 45, #5S).

Fourteen channels of surface electromyography were collected on core and lower extremity muscles with a Noraxon system coupled to Vicon Nexus. Eight college-aged, elite-level athletes served as the subjects. The study results found no statistical differences in any peak muscle activity between the Pneubounder and ground-based countermovement jumps ($p > 0.05$) (Figure 3). These results add further evidence that jumps performed on the Pneubounder are highly specific to ground-based countermovement jumps and sharing the same plyometric characteristics as ground-based countermovement jumps.

A biomechanical and neuromuscular analysis finds that the Pneubounder should be an excellent mode for dynamically strengthening core and lower-extremity joint stabilizers (Table 1). Viewing the motion overlayed with synchronized muscle activations in the Vicon Polygon software, we were able to observe the kinetic chaining that occurs on the machine as these muscles switch on and off through the full range of motion (Figure 4). Furthermore, it becomes more evident at which points during the stroke these stabilizer muscles are most active. Incorporating that understanding into injury prevention and treatment procedures allows for dynamic learning to occur in strengthening these muscles and coordinating when to activate them. Teaching propulsive movements from the hip-loaded position in a proximodistal fashion improves the kinetics of power generation.

Additional feedback measures (e.g. mirrors, manual cueing, Theraband) may be used in sessions to make users aware of maladaptive dynamic movement patterns (e.g. knee valgus) during a "live" jump stroke. The first step in modifying a learned behavior is developing an awareness of the pattern and the motor strategies or habits that maintain it.

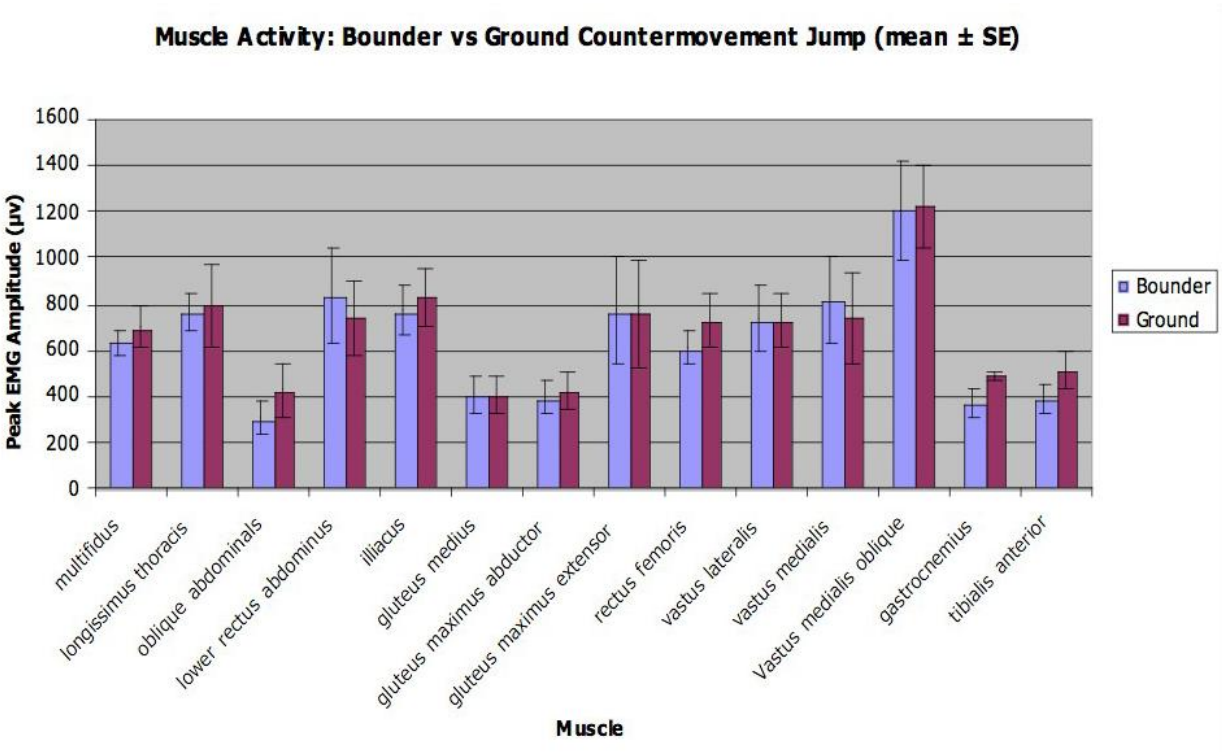

Figure 3: Peak muscle activity during Bounder and ground-based vertical jumps.

Table 1: Synergists of the tested muscles inferred to be engaged while Pneubounding.

Primary Muscle Tested	Anatomical position	Synergistic muscles
Multifidus	A small set of medial muscle fibers along the spinus process, concentrated in the lumbar area and attaching to the margin of the sacrum. Critically important in spinal stability and posture control.	Erector spinae, quadratus lumborum,
Longissimus Thoracis	Transverse processes of all thoracic vertebrae and between tubercles and angles of lower ten ribs. Extends the spine and controls side flexion	Quadratus lumborum, iliocostalis thoracis, semispinalis
External Oblique abdominus	Fibers run from the ribs to the iliac crest on the lateral aspects of the torso.	Internal obliques (for torso stabilization).
Lower rectus abdominus	A long flat muscle originating from the pubic crest and inserting on the zyphoid process, at the bottom of the sternum. Stabilizes the torso and flexes the pelvis.	Transversus abdominus, obliques
Illiacus	Originates at upper inside surface of the iliac bone and inserts on the lessor trochanter of the proximal femur. Flexes the hip.	Psoas, tensor fascia latae, rectus femoris,
Rectus femoris	A polyarticular muscle running down the center of quadriceps that originates on the anterior inferior iliac spine and inserts into the quadriceps tendon on the anterior proximal tibia. Flexes the hip and extends the knee.	Iliopsoas, tensor fascia latae
Gluteus Medius	Originates on the ilium and iliac crest and attaches on the lateral surface of the greater trochanter. Abducts and rotates the thigh and stabilizes the body when balanced on one foot.	Gluteus Minimus
Vastus Medialis	Originates on the iliac spine and inserts into the quadriceps tendon on the tibia. Combined with the lower fibers of the vastus medialis oblique, this muscle extends and stabilizes the knee and patella.	Vastus Lateralis, Vastus Intermedius

Figure 4: Qualitative examination of muscle activation on the Pneubounder with Vicon Polygon software. Illustrated are the gluteus medius, abductor portion of gluteus maximus, illiacus, VMO, tibialis anterior, and gastrocnemius during a tuck jump performed on the Pneubounder.

Study 3 – Power measurement and Feedback Validation

At the same time that the Bertec force platform was mounted on the Pneubounder for Study 1 validation, algorithms were being developed for the immediate electronic display and storage for offline analysis of performance. Based on a feasibility analysis, it was determined that force calculation should be performed using the air pressure in the cylinders – since they should be directly proportional if friction drag was negligible. In order to test this hypothesis an analog pressure gage was attached to the Pneubounder. The gage had a deflection arm tracking peak pressure. Using this,

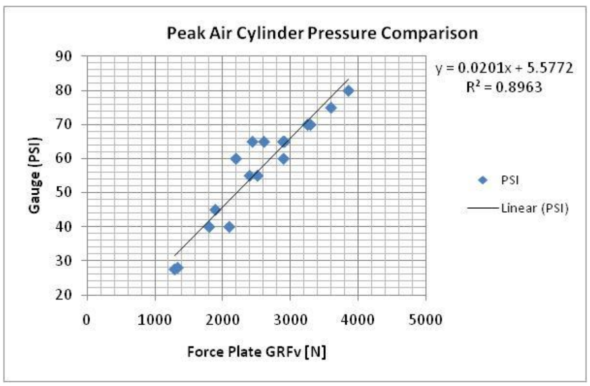

Figure 5: Comparison of peak PSI from pressure gauge and peak vertical platform ground reaction forces.

peak pressure was crudely correlated with peak force measured by the force platform. Even with the limitations of this approach, the correlation between the two was extremely high (r=0.947, Figure 5). Based on these results, and the expectation that a higher correlation would have been found with more sophisticated means of measuring peak pressure, it was determined that pressure was an appropriate source from which to calculate the ground reaction force between the jumper and Pneubounder platform in the feedback algorithms.

Subsequent to validating peak pressure as highly correlated with peak ground reaction force, a sample set of data output using the Pneubounder's sensor array was simulated in Matlab software and compared to the data from Study 1. The proprietary software separates the force of the moving mass of the machine from the user's force to derive an accurate measure of their power output.

The Pneubounder's firmware synthesizes the combined data of an accelerometer with a pressure sensor with high sampling rate capabilities during the jump stroke. This allows an accurate integration for the computation of velocity. The product of force and velocity then provides an accurate calculation of instantaneous power. From there, peak power and average power per stroke can be extracted, as well as rate of force development, work and energy (Calories).

A unique metric, the rate of peak power development, is also calculated and reported. This should prove useful at the end of the stroke where acceleration should be maximized for enhanced ballistic performance.

Programming is also included to perform Bosco and Wingate-type anaerobic capacity tests, critical for training evaluation. **In short, the hardware and software of the Pneubounder produce accurate and valid data for a variety of jump techniques, including both singular maximal effort jumps and recurring jump strokes in series**.

Study 4 – Metabolic Experiment

The influence of exercise modality on physiologic and metabolic adaptations was examined to further understand HIIT. Twenty-seven sedentary college students were randomized into 3 equal groups that performed either stationary cycling, running on a non-motorized treadmill, or Pneubounding with the valves open. A total of 9 training sessions were completed by each subject within a 3 week period. Each training session required 4-8, 30-second maximal efforts separated by 4 minutes of active rest. The number of maximal efforts slowly increased through the 3 week period.

Maximum oxygen consumption (VO2max) and time to exhaustion at 80% VO2max were tested before and after the 3 weeks of training. Since effort could be quantified on the cycle ergometer and treadmill, those in the cycling group were tested while cycling and those in the running and Pneubounder groups were tested on the treadmill. (This study was conducted on an early version of the Pneubounder without electronic display.) Resting blood and tissue samples were also collected pre and post training for examination of metabolic changes. DEXA scans were performed pre and post to assess body composition and bone density.

VO2max did not change with training in any of the groups (main effect $p=0.09$ with no interaction between groups). However, time to exhaustion did increase (main effect $p=0.006$ with no interaction between groups). From the blood and tissue, training was found to decrease oxidative stress, represented by oxidized LDL (main effect $p=0.05$ with no interaction between groups). Training did not change any of the other markers (insulin, glucose, adiponectin, C-Peptide, C Reactive Protein, PEDF, VEGF, Irisin) in any of the groups (main effect $p>0.05$ with no interaction between groups).

The increase in time to exhaustion was related to the decrease in oxidative stress ($r=-0.51$, $p=0.013$). There were no changes in body composition with this short exposure to intense exercise. However, bone mineral content did increase in the runners ($p=0.04$). These results confirm the versatility of the Pneubounder as a tool not only for lower-extremity power development, but also for increased physiological health.

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[1] The discussion within this Report is intended to present generally accepted concepts of lower extremity strength and power. For more thorough coverage of these topics the reader is encouraged to refer to NSCA's Essentials of Strength Training and Conditioning edited by Baechle and Earl (published by Human Kinetics) and Strength and Conditioning Journal (Vol. 34, #4, December 2012) dedicated to power.

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