

Research article

Effects of whole-body vibration on resistance training for untrained adults

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Abstract

Although resistance training (RT) combined with whole-body vibration (WBV) is becoming increasingly popular among untrained adults, the additional effects of WBV on muscle fitness are still not well understood. The aim of the present study was to evaluate the effects of WBV on muscle strength, muscle power, muscle endurance, and neuromuscular activities compared with the identical RT without WBV. Thirty-three individuals (6 males and 27 females; 22-49 years old) were randomly assigned to a training program using slow-velocity RT coupled with WBV (RT-WBV group, $n = 17$) or an identical exercise program without WBV (RT group, $n = 16$). Participants performed eight exercises per 60 min session on a vibration platform (RT-WBV group, frequency, 35 Hz; amplitude, 2 mm) twice weekly for seven weeks. To evaluate the effects of WBV, the maximal isometric and isokinetic knee extension strength, maximal isometric lumbar extension strength, countermovement-jump, and the number of sit-ups were measured before and after the trial. Significantly higher increases were observed in the maximal isometric and concentric knee extension strength ($p = 0.02$, $p = 0.04$, respectively), and maximal isometric lumbar extension strength at 60 degrees of trunk flexion ($p = 0.02$) in the RT-WBV group (+36.8%, +38.4%, +26.4%, respectively) in comparison to the RT group (+16.5%, +12.8%, +14.3%, respectively). A significant difference was also observed between the RT-WBV group (+8.4%) and the RT group (+4.7%) in the countermovement jump height ($p = 0.02$). In conclusion, the results suggest that significant additional increases in maximal isometric and concentric knee extension and lumbar extension strength, and countermovement jump height can be achieved by incorporating WBV into a slow-velocity RT program during the initial stage of regular RT in untrained healthy adults.

Key words: Vibration, novice, adults, exercise, strength, power.

Introduction

Changes in skeletal muscle with aging are associated with disability, frailty, loss of independence, and increased risks of falling and fractures. Muscle strength typically remains unchanged until approximately 50 years of age, at which point strength decreases by 15% per decade until 70 years of age (Rogers and Jarrot, 2008). Although most adults fail to adhere to an exercise program once they begin due to their lack of leisure time, this is particularly true of adults in their 20-40s who have children and/or jobs (Annesi, 2000; Annesi et al., 2004; Dishman et al., 1994). Acquiring higher levels of muscle fitness prior to the age of skeletal muscle decline represents an effective strategy for minimizing the adverse affects associated with decreased muscle strength, and this age group should be especially focused on building muscle strength.

It is known that the initial muscle strength and power gains after 2-8 weeks regular resistance training (RT) are due to neural adaptations (Fleck and Kraemer, 2003). Several reports

have suggested that RT with whole-body vibration (WBV) training enhances muscle power and strength, particularly for untrained adults (Delecluse et al., 2003; Marin and Rhea, 2010a, 2010b; Merriman and Jackson, 2009; Rehn et al., 2007; von Stengel et al., 2010). It has been speculated that neural adaptations would occur effectively with RT combined with WBV during a regular RT program, because it was observed that WBV would affect the neural systems during muscle contractions, known as the "tonic vibration reflex" (Cardinale and Bosco, 2003). However, the efficacy of WBV when incorporated into RT programs for improving muscle strength, power, and endurance compared with the identical training without WBV is less clear.

Various exercise programs using vibration platforms have been evaluated, but a standard WBV training program has yet to be established. This is largely a result of conflicting results obtained from studies that have examined additional WBV effects combined with body-weight exercises for untrained adults (Delecluse et al., 2003; de Ruyter et al., 2003). In addition, none of three training regimens found a significant additional effect of WBV on muscle strength or power with external load exercises corresponding to a 6-10 repetition maximum (RM) or 75%-90% 1RM of training intensities (Carson et al., 2010; Kvorning et al., 2006; Ronnestad, 2004). Thus, the optimal WBV training regimen in healthy adults remains controversial, but it appears that heavy loads are not suitable for WBV training programs.

Numerous RT regimens have been established and are widely practiced by untrained individuals (Fleck and Kraemer, 2003). Of the numerous RT regimens, we anticipated that RT with an intentional slow velocity would be suitable for exercise with WBV for untrained individuals. The effects of slow velocity RT are not well understood compared with conventional movement velocity, particularly the effects on muscle power, and the optimal cadence (Berger and Harris, 1966; Neils et al., 2005; Palmieri, 1987; Tanimoto and Ishii, 2006; Westcott, 2001; Young and Bilby, 1993). We hypothesized that a slow-velocity RT program with light external loads coupled with WBV would lead to improvements in muscle strength, power, endurance and neuromuscular activities compared with the identical exercise without WBV.

The aim of the present study was to investigate the effects of a seven-week slow-velocity RT program combined with WBV on muscle strength, power, endurance, and neuromuscular activities measurements compared with the same exercise program without WBV during the initial stage of a regular RT program in healthy, untrained, young to middle-aged adults.

Methods

Participants

Thirty-three untrained healthy males and females (6 males (M) and 27 females (F), 22-49 years old; 20s $n = 9$, 30s $n = 12$, 40s $n = 12$) volunteered for this study. The volunteers were recruited from local residents ($n = 26$) and graduate school students of Keio University ($n = 7$) using

Table 1. Mean acceleration (g) on the WBV platform.

| Additional weight added | | 0 kg [control] | +40 kg | +50 kg | +60 kg | +70 kg |
|-------------------------|----------------------|-------------------|--------|--------|--------|--------|
| Vibration condition | 0 Hz, 0 mm [control] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | 35 Hz, 2 mm | 2.10 | 2.75 | 2.80 | 2.91 | 2.95 |

g is the Earth's gravitational field, 9.81 m/s²

posted advertisements. Power analysis revealed that a sample size of 12 participants in each test group was required for the detection of the WBV effects on muscle strength, with the power set at 0.80 and an alpha level of 0.05. In anticipation of participant dropout, and to preserve the power for the analyses, at least 15 participants were needed in each experimental group at the beginning of the study. The eligibility criteria for participants were: 20-49 years old, had never experienced long-term WBV training, had not been undergoing conventional RT for at least six months, could refrain from engaging in any regular vigorous activities, strength training, or stabilization training, and could maintain their routine daily life through the trial. We decided on this age criterion, because muscle strength remains unchanged during the 20-40s, and the age-related muscle strength decline would be negligible until 50 years of age (Rogers and Jarrot, 2008). In addition, the health and medical history, current medical conditions, and risk factors and signs of cardiovascular or orthopedic diseases of each potential participant were evaluated using a self-guided questionnaire (Physical Activity Readiness Questionnaire) (Thomas et al., 1992). If an individual answered “No” to all questions, he or she was considered a suitable candidate and was entered into the study. The exclusion criteria were pregnancy, presence of infectious disease, and a history of severe orthopedic abnormality, diabetes, or acute hernia. This study was approved by the local ethics committee of Keio University, and written informed consent was obtained from all participants. All experimental procedures were performed in accordance with the ethical standards in the 1964 Declaration of Helsinki.

Randomization procedure

A randomized controlled trial design was used to investigate the effects of seven-week WBV training on muscle strength, power, and endurance measurements in healthy adults. Participants were randomly assigned to either a RT program with WBV (RT-WBV group, n = 17) or a non-WBV RT program (RT group, n = 16). A restricted randomization (blocking and stratification) was used to allocate participants into one of the two groups, and was performed as follows. First, six matrices (age: 20s, 30s, or 40s; gender: female or male) were created to stratify the participants. Second, we prepared six envelopes for each group, with each envelope containing ten cards labeled with either “RT” or “RT-WBV” (RT-WBV:RT, 5:5). Finally, when each participant finished all of the tests before intervention, they drew a card from the envelope corresponding to their stratified group, and were allocated to either group as designated by the selected card.

Vibration conditions

For the generation of WBV, a whole platform-oscillating device (Power Plate® Next Generation, Power Plate Inter-

national, Northbrook, IL, USA) was used. We applied WBV at a frequency of 35 Hz and an amplitude of 2 mm, and all exercises were performed with a pad provided by the manufacturer, because nearly all participants in a pilot study had experienced discomfort in their head and chest regions when exercises were performed in supine and prone positions at higher frequencies or amplitudes, or without the pad. The mean acceleration magnitudes (g) of the WBV platform were measured using a tri-axial accelerometer (CXL25GP3, Crossbow Technology, Inc., Japan), which was attached to the platform in the indentation normally used for cable attachment, and a software package designed to monitor the data (U3HV-LJ, Lab-Jack, CO, USA) at a sampling frequency of 1,000 Hz (Table 1). The mean acceleration of the vibration platform was also measured under weight-added conditions because Pel et al. (2009) found that the acceleration of the vibration platform increased with weight. Plates for weight training (Ivanko Calibrated Bumper Plates, Ivanko, USA) were used to add weight on the WBV platform. All measurements were performed in triplicate, and mean data obtained 16-25 sec after pushing the start button was used for the analyses.

Training programs

Figure 1 shows the training exercise programs used in this seven-week study. After performing a standardized warm-up involving 5 min of exercise on an ergometer and stretching (e.g., modified hurdler's stretch), participants performed 8 exercises on the pad provided by the manufacturer and wore socks, but no shoes, during the training on the vibration platform either with (RT-WBV group) or without WBV (RT group). Two exercises targeted the lower extremities and the other six were specific for the trunk muscles. Participants performed one set per exercise during the first week, and two sets for the remaining six weeks. To date, there is no well-established optimum movement cadence for muscle fitness gains. Tanimoto and Ishii (2006) found slow-velocity and tonic force generation (3 sec for concentric [lifting]/1 sec no relaxing phase [isometric phase]/3 sec for eccentric [lowering] in cadence) led to hypertrophy and muscle strength gains. It was also suggested that a training program with 4 sec for concentric/2 sec no relaxing phase/4 sec for eccentric in cadence involves less momentum, resulting in a more evenly applied muscle force throughout the range of motion (Smith and Bruce-Low, 2004). We configured our training programs following the latter training regimen, because the training regimen in cadence proposed by Tanimoto and Ishii (2006) had to use greater external loads than that of the latter regimen. Each exercise was performed for eight repetitions of 4/2/4 in cadence with intermittent rest periods of 60 sec between exercises, with the exception of the roll back and hip walking exercises which were performed continuously for 64 and 48 sec

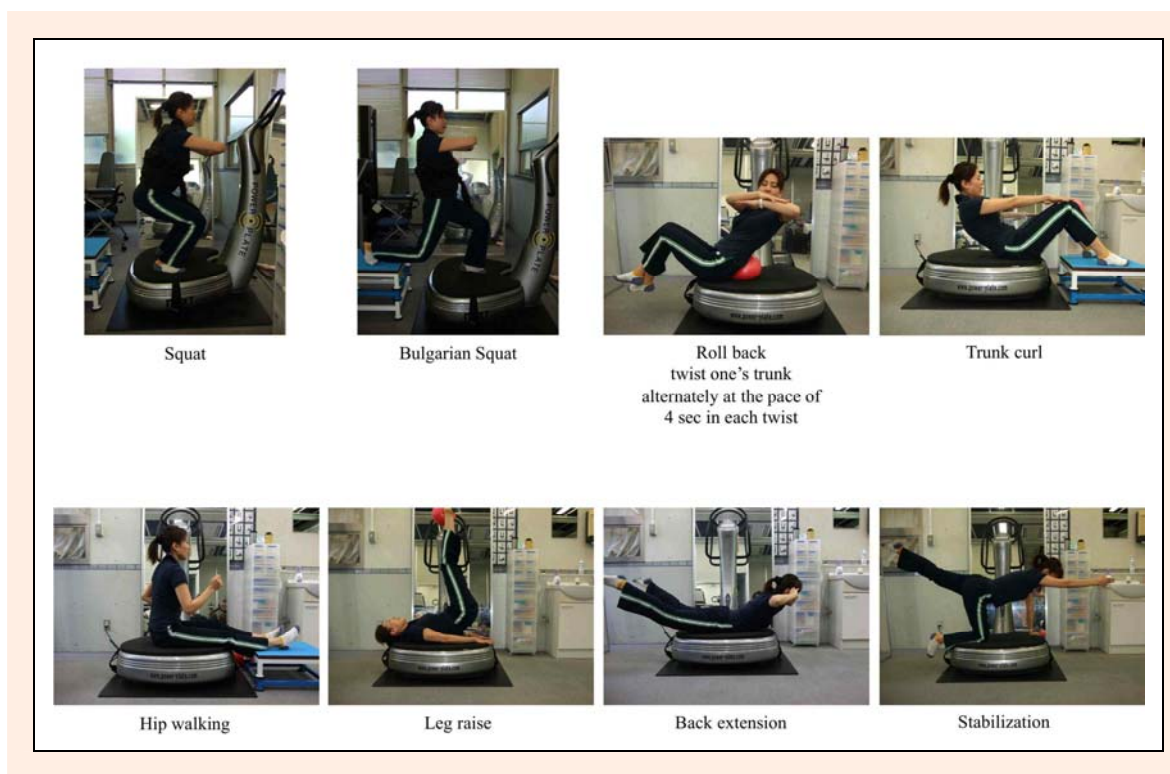


Figure 1. Illustrations of the eight exercises of the training program used in the present study. The training program consisted of two lower extremity (squats) and six trunk exercises consisting of 4 sec for concentric/2 sec no relaxing phase/4 sec for eccentric in cadence with intermittent rest periods of 60 sec between exercises, with the exception of the roll back and hip walking exercises, which were performed continuously for 64 and 48 sec without any isometric phase, respectively.

without any isometric phase, respectively. All cadences during exercises were strictly controlled by using a metronome (SQ-77, Seiko, Japan).

For the two exercises that targeted the lower extremities, body-weight exercises were performed for the first four weeks, while during the last three weeks, the exercises were performed with external weight corresponding to 10% and 15% of body mass for females and males, respectively. A weight jacket (Kool KatZ, Japan), which could load weight-bars around the abdomen and lower back from 1 kg to 20 kg was used for additional loads (Figure 1). External loads were not used in the trunk exercises in order to allow the participants to perform exercises with proper training techniques. By using two Power Plate[®] machines in the laboratory, training programs were conducted with a maximum of two participants at each time and were strictly and closely supervised by the investigators. After each training session, the participants ingested a multi-vitamin supplement (Nature Made, Otsuka, Japan), which met the dietary reference intakes recommended by the Ministry of Health, Japan, for the purpose of minimizing the potential confounding effects of insufficient food intake, especially vitamins.

Performance tests

After a standardized warm-up and stretching, the following performance tests were evaluated before and after the seven-week trial (listed in the order they were conducted): countermovement jump, maximal isometric lumbar extension, maximal isometric knee extension, maximal isokinetic knee extension, and sit-up tests. Participants performed light stretching between tests. Intraclass correla-

tion coefficients (ICC) were also evaluated within one week of all of measurements for four participants and one investigator.

Countermovement jump test

Twenty-three participants (RT-WBV, M: 1, F: 11; RT, M: 1, F: 10; 39.3 ± 7.7 years old) performed countermovement jumps using a Myotest[®] instrument (Myotest, Royal Oak, MI, USA) to assess muscle power (Casartelli et al., 2010). In a standing position, participants first made a downwards movement by bending their knees and hips, and then jumped as high as possible while keeping their hands on their waist. After returning to a standing position, the participants were given a short intermittent rest of a few seconds between each jump. The jump was repeated five times, and the mean value of the countermovement jump height (cm) was used for further analyses. The ICC for test-retest reliability of the power test was $r = 0.96$.

Lower extremity muscle strength tests

Maximal isometric and isokinetic knee extension strength were measured on the right side using a Kin-Com[®] KC500H device (Chatteex, Hixson, USA). During the tests, the right upper leg, ankle, and the hips were stabilized with safety belts. After gravity correction was performed in accordance with the manufacturer's guidelines, participants were seated with a hip joint angle of 80 degrees and arms crossed in front of the chest, and the maximal isometric 5-sec contraction was then measured at a knee angle of 60 degrees (full extension = 0 degree). The maximal isokinetic concentric and eccentric knee

extension strengths were measured at knee angles of 80 to 20 degrees and a velocity of 60 degrees sec⁻¹. The measurements for all strength tests were repeated twice with 3 min rest intervals. The peak values for the maximal isometric (force) and isokinetic (torque) knee extension contraction tests were normalized to body mass, and used for the further analyses. The ICC for test-retest reliability were $r = 0.97$ (isometric contraction), $r = 0.86$ (isokinetic concentric contraction), and $r = 0.91$ (isokinetic eccentric contraction).

Surface electromyography (sEMG)

The sEMG signals from the vastus medialis (VM) and vastus lateralis (VL) muscles of the right leg were recorded during the isometric knee extension strength test using a TeleMyo 2400T V2 system (Noraxon Inc., Scottsdale, AZ, USA) with disposable Ag/AgCl snap electrodes (EM-272, Noraxon Inc.). The figure eight-shaped adhesive area of the electrodes was 4×2.2 cm, the two circular conductive areas were 1 cm in diameter, and the inter-electrode distance was 2 cm. After the skin over the respective muscle was lightly abraded, the electrodes were fixed in accordance with the guidelines of the Surface Electromyography for the Non-Invasive Assessment of Muscles (Hermens et al., 1999). The sEMG signals were sampled at 3,000 Hz and subsequently band-pass filtered (15–500 Hz). After the electrodes were attached, the participants sat on a chair for at least 5 min to acclimatize their skin to the electrodes.

The processing of sEMG data was performed using the MyoResearch XP software, Master Package ver. 1.06.74 (Noraxon Inc.). The raw EMG signals were converted to an average root-mean square (EMGrms) with 0.5 sec smoothing windows to compare the RT-WBV and RT groups. The 0.5 sec time epochs around the isometric contraction force peak, which were shown by the Kin-Com[®] KC500H device, were used for the further analyses.

Trunk muscle strength and endurance

As no universally acknowledged test exists for measuring trunk extension strength, we measured maximal back extension strength with an isometric lumbar extension machine (MedX, Orlando, FL, USA) using testing positions that were standardized following the manufacturer's guidelines. The reliability of the maximal isometric lumbar extension strength test, as determined for seven testing positions, was high ($r = 0.78$ to 0.95) (Graves et al., 1990). After the participant was seated in the lumbar extension machine, the pelvis was first stabilized, and while the participant rested against the upper back pad (the angle of full extension was 0 degrees), a counterweight was adjusted to neutralize the gravitational force on the head, torso, and upper extremities. Maximal 5-sec lumbar extension strength was then measured in the sitting position through a 72 degrees arc of lumbar motion (at 72, 60, 48, 36, 24, 12, and 0 degrees of trunk flexion). The ICC for test-retest reliability of each angle were $r = 0.83$ to 0.94 , respectively.

Abdominal muscle endurance was evaluated by the total number of sit-ups performed in 30 sec. We applied the sit-up test used in the New Japan Fitness Test

formulated by the Ministry of Education, Culture, Sports, Science and Technology, Japan, which is nearly identical to that used in the Eurofit Fitness Testing Battery, with the exception of arm position. As the reliability of the sit-up test in the Eurofit Fitness Testing Battery was reported to be $r = 0.83$ (Tsigilis et al., 2002), and the correlation between the number of sit-ups and isokinetic strength is also relatively high ($r = 0.79$) (Yamamoto, 2004), the results of sit-up testing are considered suitable for demonstrating training effects on abdominal muscle endurance and strength. Briefly, the participant was positioned on a mat with knees bent at a 90 degrees angle, feet flat on the floor and held down by an investigator, and arms folded in front of the chest. On the command 'Go', the participant was required to raise their upper body until both elbows touched his or her thigh and then return to the floor before proceeding to the next sit-up. The ICC for test-retest reliability of sit-up test was $r = 0.91$.

Physical activity and nutritional assessment

The food intake of participants was assessed by a food frequency questionnaire based on the food groups (FFQg) software program version 2.0, which was optional software for Excel "Eiyo-kun" (Kenpaku-sha, Japan) that conformed to the Fifth Edition of Standard Tables of Food Composition in Japan of the resources research committee of the Science and Technology Agency, Japan (Takahashi et al., 2001). The face-sheet of the questionnaire included questions related to physical activity level (PAL) and sports activity. The physical activity of each participant was also assessed using a uniaxial accelerometer (Lifecorder EX, Suzuken Co., Ltd., Japan) for at least one week, including five weekdays and two weekends.

Statistical analyses

Because of unbalanced data, which violates the assumption of homogeneity of variance, a nonparametric test was performed. Group differences in age, body mass, BMI, physical activity, and dietary intake measurements at baseline were determined by Welch's t-test. The percent change in each variable from baseline to posttraining was calculated for each group. Welch's t-test was used to determine group differences. The PASW software program version 18.0 for Macintosh (SPSS, Inc., Tokyo, Japan) was used for all statistical analyses. The level of significance was set at $p < 0.05$.

Results

Participants baseline characteristics and training history

The flow of participants through the trial is shown in Figure 2. All participants in each of the RT-WBV and RT groups completed the 7 weeks training program and the pre- and post-performance tests. No significant differences between the two groups were observed in the participants' baseline characteristics, including their age, body mass, BMI, total physical activity, and total energy intake (Table 2). Based on the recorded uni-accelerometer data, nearly all participants were physically active males and females (males, 7321 counts/day; females, 6267 counts/day on average in Japan) (Ministry of Health,

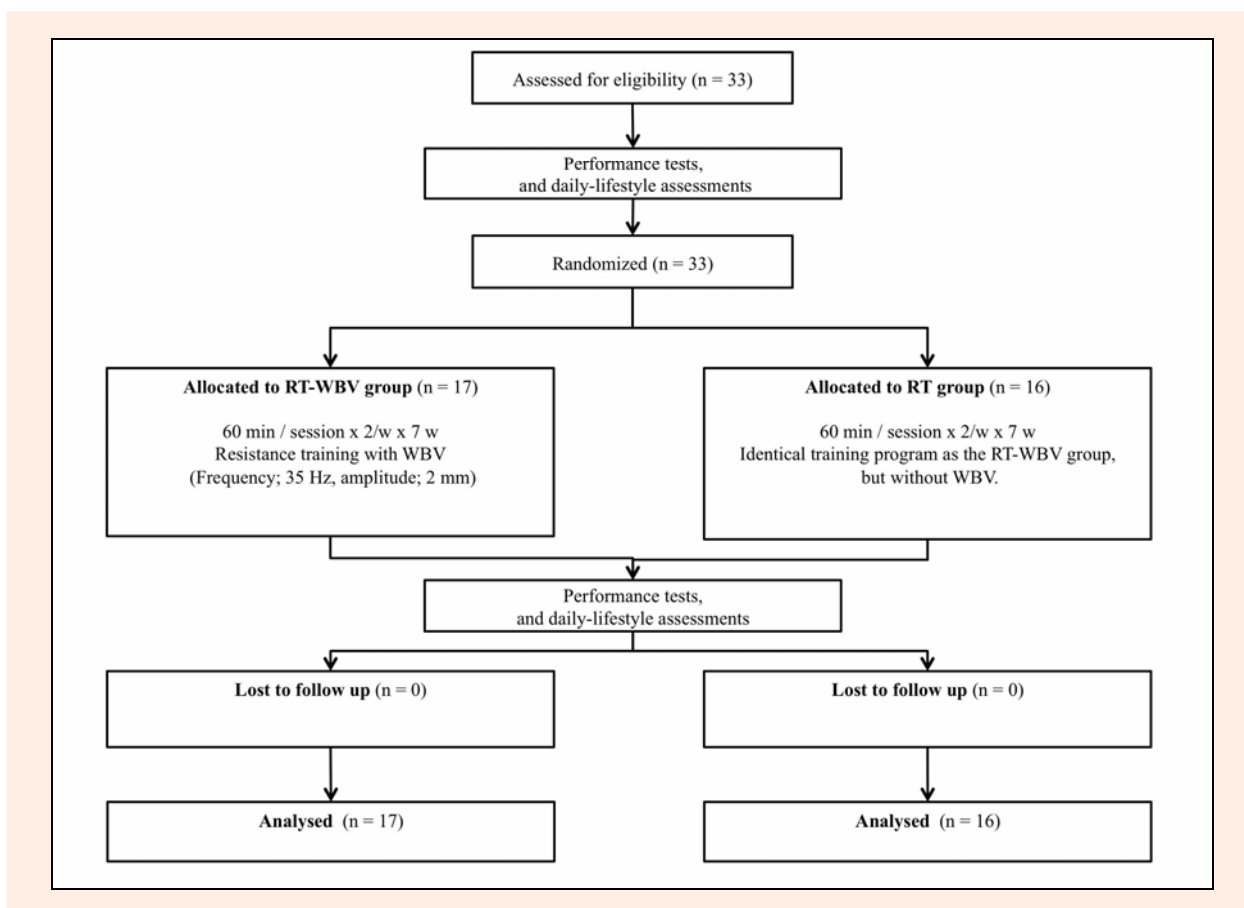


Figure 2. The flow of participants through the 7 weeks trial. The participants were randomly selected for each of the two training groups, and performed twice-weekly training (60 min sessions) either with (RT-WBV) or without (RT) WBV (frequency, 35 Hz; amplitude, 2 mm). All participants were subjected to pre- and post-performance tests to evaluate muscle strength, power, and endurance. RT, resistance training; RT-WBV, RT with whole-body vibration.

Labour and Welfare, Japan, 2010); however, with the exception of six individuals (RT-WBV, M: 2, F: 2; RT, M: 1, F: 1) who had once engaged in regular RT as part of a college sports team, all participants were novices with RT.

The participants in both training groups perceived the RT training to be physically challenging and were fatigued following the 60 min session, and experienced light to moderate delayed onset of muscle soreness after the body weight-only exercises for the first 2-3 weeks. As all participants rapidly adapted to the exercise program, beginning on the fifth week, the two lower extremity exercises were performed with weight loading, corre-

sponding to 10% and 15% of body weight for females and males, respectively. In response to weight loading, nearly all participants experienced moderate delayed onset of muscle soreness on the day after the training session, but had almost completely recovered by the beginning of the next training session.

No adverse effects during the course of the study were reported, except that one participant (37 years old woman) experienced itching in her feet when she performed exercises in the standing and supine positions on the vibration platform during the first three weeks of training, although the symptom subsequently disappeared.

Table 2. Characteristics of the participants. All values are presented as the median (range).

| | RT-WBV (n = 17) (F:14,M3) | | RT (n = 16) (F: 13, M: 3) | | Welch's t-test p-value |
|--------------------------|------------------------------|--------------|------------------------------|--------------|---------------------------|
| Age (years) | 37 | (21-49) | 39 | (22-49) | .59 |
| Height (m) | 1.60 | (1.53 -1.83) | 1.63 | (1.57-1.78) | .54 |
| Body mass (kg) | 54.9 | (44.6-78.2) | 55.5 | (50.9-76.7) | .42 |
| BMI (kg/m ²) | 21.2 | (18.2-26.7) | 20.6 | (19.7-26.3) | .43 |
| TPA (steps/day) | 11446 | (5689-23466) | 9185 | (4395-19517) | .12 |
| PAL | 1.80 | (1.3-2.8) | 1.93 | (1.5-2.6) | .14 |
| TEI (kcal/day) | 1874 | (1287-2559) | 2107 | (952-2795) | .19 |
| Protein (%) | 13.2 | (10.8-15.9) | 14.2 | (10.2-16.5) | .22 |
| Fat (%) | 29.7 | (10.8-41.8) | 30.0 | (19.6-41.3) | .89 |
| Carbohydrate (%) | 56.6 | (43.5-64.7) | 56.4 | (43.1-68.2) | .92 |

BMI, body mass index; TPA = total physical activity; PAL, physical activity level; TEI = Total energy intake; RT-WBV, resistance training with whole-body vibration; RT, resistance training

Effects of WBV on muscle power

The results of the countermovement-jump test are shown in Figure 3. A significantly higher muscle power gain was observed in the RT-WBV group than in the RT group ($p = 0.02$).

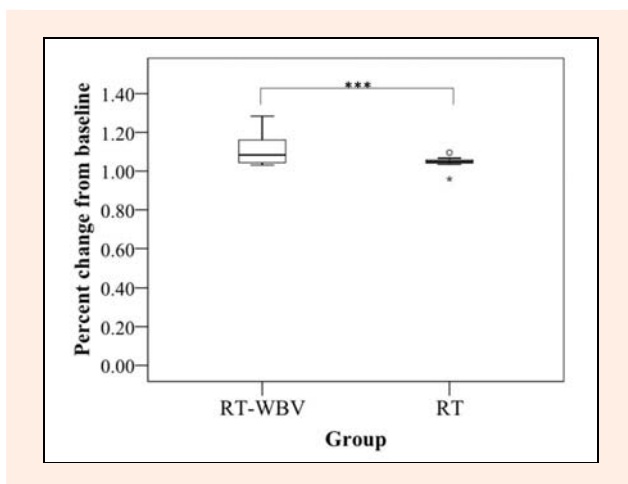


Figure 3. The percent change from baseline in the countermovement jump test was used to evaluate muscle power. RT-WBV, resistance training with whole body vibration ($n = 12$); RT, resistance training ($n = 11$). *** significant group-by-time interaction ($p < 0.05$, Welch's t -test). * and \circ outlier.

Lower extremity muscle strength

A significant difference was detected in isometric knee extension strength between the RT-WBV group (+36.8%) and the RT group (+16.5%) ($p = 0.02$) (Figure 4a). The percent change from baseline for the RT-WBV group (+38.4%) in maximal concentric contraction was also significantly greater than that for the RT group (+12.8%) ($p = 0.04$). However, no significant difference was observed in the percent change from baseline in maximal eccentric contraction between the groups (RT-WBV, +13.6%; RT, +9.2%) ($p = 0.82$) (Figure 4b, 4c).

No significant differences were observed in the EMGrms amplitude in the VM ($p = 0.22$) and VL muscles ($p = 0.08$) (Table 3).

Trunk muscle strength and endurance

The results of the maximal isometric lumbar extension muscle strength test are summarized in Table 4. Notably, at 60 degrees of trunk flexion, the RT-WBV group had significantly increased from baseline (+26.2) compared with the RT group (+14.3%) in the maximal isometric lumbar extension strength. No significant differences were observed for any of the other measured angles of trunk flexion.

For the RT-WBV group, participants improved by 6.0 (3-11) times in the number of sit-ups (post - pre), while those in the RT group increased by 3.5 (1-13) times in the number of sit-ups they could complete in the 60 seconds. No significant difference was observed in the percent change from baseline between the groups ($p = 0.39$).

Physical activity and nutritional assessment

No significant percent change from baseline between the groups in the total energy intake per day ($p = 0.66$) or the

ratio (%) of protein: fat: carbohydrate consumed during the trial protein, ($p = 0.34$); fat, ($p = 0.20$); carbohydrate, ($p = 0.74$) were noted.

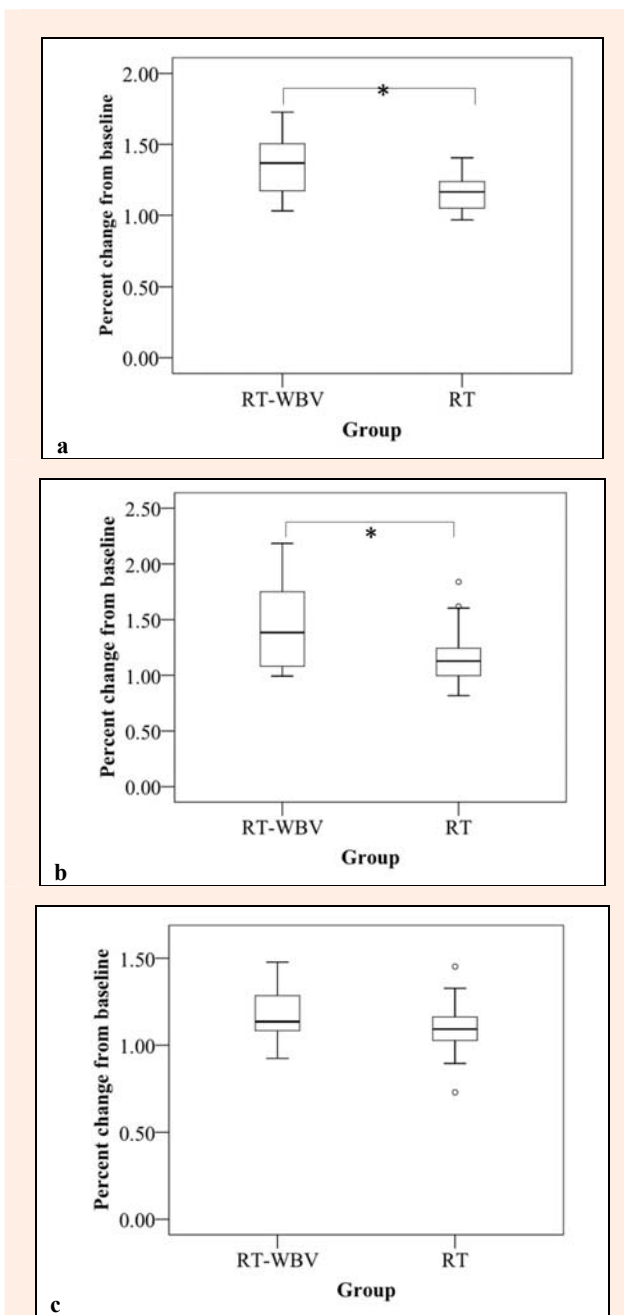


Figure 4. The effects of WBV on lower extremity muscle strength. (a) The results of maximal isometric knee extension strength tests. (b) The results of maximal isokinetic concentric knee extension strength tests. (c) The results of the maximal isokinetic eccentric knee extension strength tests. RT-WBV, resistance training with whole body vibration; RT, resistance training. *significant group-by-time interaction ($p < 0.05$, Welch's t -test). \circ outlier.

At baseline, the proportion of individuals who routinely consumed sufficient vitamin B₂, B₆, and D, as judged from the fifth edition of the Standard Tables of Food Composition, Japan was 30%, 23%, and 100%, respectively. Due to minimizing the effects of confounding in vitamin insufficiencies, all participants consumed a

Table 3. Electromyography data from the maximal isometric knee extension strength test. All values are the median (range).

| | | VM EMGrms (μ V/sec) | VL EMGrms (μ V/sec) | Welch's t-test p-value |
|--------|----------------|-----------------------------|-----------------------------|---------------------------|
| RT-WBV | Pre | 85.9 (46.2-217.0) | 41.8 (14.2-194.0) | |
| | Post | 138.5 (76.7-388.0) | 66.2 (31.0-386.0) | |
| | Percent change | 1.62 (.7-18.5) | 1.57 (.6-2.1) | 0.22 |
| RT | Pre | 67.8 (30.4-181.0) | 39.5 (15.4-123.0) | |
| | Post | 85.3 (31-386.0) | 44.5 (20.3-285.0) | |
| | Percent change | 1.29 (.6-2.1) | 1.16 (.3-3.0) | 0.08 |

EMGrms, electromyography root-mean-square; RT-WBV, resistance training with whole-body vibration; RT, resistance training; VL, vastus lateralis muscle; VM, vastus medialis muscle.

multi-vitamin supplement at the end of each training session to aid in muscle recovery and development. Finally, no significant difference in the percent change was observed between the groups in the PAL ($p = 0.80$).

Discussion

In this study, we hypothesized that a slow-velocity RT program with light external loads coupled with WBV would improve muscle strength, muscle power, muscle endurance, and neuromuscular activities in physically active untrained adults compared to the identical training without WBV. The participants performed a 7 weeks training program consisting of 60 min twice-weekly sessions and 8 exercises targeting muscles of the lower extremities and trunk region. We found that WBV had significant effects on the maximal isometric knee extension and isometric lumbar extension contractions and countermovement jump height in a population of untrained 22-49 years old adults. The participants were predominantly females with children and/or jobs. The fact that none of the participants dropped out from the study supports the feasibility of the training regimen in this population. Our results suggest that WBV augments the effects of RT on lower extremity and trunk muscle strength and muscle power, and should be of particular interest for untrained adults who desire to engage in regular RT.

The 7 weeks slow-velocity RT program enhanced muscle strength, power, endurance, and EMG activity in VM muscle. On completion of the RT program, the magnitudes of increase in maximal isometric and concentric knee extension, isometric lumbar extension contractions, and countermovement jump height were 36.8%, 38.4%, 26.4%, and 8.3%, respectively, in the RT-WBV group, and 16.5%, 12.8%, 14.3%, and 4.7%, respectively, in the RT group. Neural adaptations predominantly occur during the early stages of training (Moritani and deVries, 1979). However, the amplitude of EMG activity did not differ between the groups, although the peak force did increase in the maximal isometric knee extension in the RT-WBV group compared with the RT group. Muscle force is affected by the degree to which antagonist muscles are activated (Carolan and Cafarelli, 1992; Hakkinen et al., 1998; 2000). When vibration was applied to the soft tissue (e.g., muscle belly or tendon), the Ia afferent neurons of the muscle spindles were activated more than the II afferent neurons and Golgi tendon organs (Ribot-Ciscar et al., 1989). Although we did not measure the neuromuscular activities of antagonist muscles, vibration might inhibit antagonist muscle activations through Ia inhibitory neurons, resulting in higher force production. Previous studies have demonstrated that conventional RT for 5-10 weeks results in a 7-50% increases in knee extension strength (Kraemer et al., 2000; Mayhew and Gross, 1974;

Table 4. The results of the maximal isometric lumbar extension strength test. All values are presented as the median (range).

| | | RT-WBV | RT | Welch's t-test p-value |
|-------------------|----------------|------------------|------------------|---------------------------|
| 0 deg (Nm/kg) | Pre | 1.91 (.86-5.33) | 1.99 (.56-3.97) | |
| | Post | 2.54 (.78-5.01) | 2.11 (.49-4.69) | |
| | Percent change | 1.60 (.74-2.85) | 1.37 (.72-5.17) | .51 |
| 12 deg (Nm/kg) | Pre | 1.60 (1.06-4.86) | 1.47 (.66-3.20) | |
| | Post | 2.51 (1.05-6.15) | 2.12 (.64-3.98) | |
| | Percent change | 1.66 (.77-2.89) | 1.3 (.67-2.13) | .36 |
| 24 deg (Nm/kg) | Pre | 2.48 (1.48-6.72) | 1.81 (1.01-3.77) | |
| | Post | 2.87 (1.91-7.31) | 2.45 (1.33-4.51) | |
| | Percent change | 1.19 (.93-1.83) | 1.31 (0.89-2.45) | .48 |
| 36 deg (Nm/kg) | Pre | 2.82 (1.68-6.86) | 2.45 (1.39-4.13) | |
| | Post | 3.44 (2.67-7.68) | 2.92 (1.50-4.88) | |
| | Percent change | 1.26 (.79-1.86) | 1.17 (.99-2.01) | .60 |
| 48 deg (Nm/kg) | Pre | 3.13 (2.14-7.55) | 2.76 (1.58-5.37) | |
| | Post | 3.85 (2.57-7.97) | 3.19 (1.78-5.65) | |
| | Percent change | 1.18 (.80-2.08) | 1.2 (.83-1.73) | .54 |
| 60 deg (Nm/kg) | Pre | 3.12 (1.80-7.76) | 3.19 (1.72-5.59) | |
| | Post | 4.27 (3.01-8.46) | 3.56 (2.19-5.69) | |
| | Percent change | 1.26 (.91-1.91) | 1.14 (.91-1.56) | .02 |
| 72 deg (Nm/kg) | Pre | 3.74 (2.48-8.14) | 3.43 (2.40-6.30) | |
| | Post | 4.53 (3.46-8.81) | 4.12 (2.80-6.60) | |
| | Percent change | 1.21 (.87-1.58) | 1.14 (.95-1.40) | .39 |

RT-WBV, resistance training with whole-body vibration; RT, resistance training.

Wilmore et al., 1978), while the American College of Sports Medicine has also reported that 40% increases in muscle strength are typically observed for novices in the first 4 weeks to 2 years of training program (Kraemer et al., 2002). The exact mechanisms are still unclear, but the additional increase of knee extension strength observed in the RT-WBV group suggests that WBV could serve as an effective exercise stimulus for novice.

In our RT program, participants performed exercises for 80 sec per set with 4 sec for concentric [lifting]/2 sec no relaxing phase [isometric phase]/4 sec for eccentric [lowering] in cadence per repetition training regimen (Smith and Bruce-Low, 2004) (Figure 1). For lower extremity and trunk muscles, two exercises were performed for two sets, which resulted in additional increases of approximately 24% and 18% in maximal isometric knee extension and lumbar extension strength, and 5% in countermovement-jump, respectively, in the RT-WBV group. It is possible that a longer exposure to vibration is necessary to elicit WBV effects on muscle strength and power, because a decrease in muscle activation was reported after 30 sec muscle contractions with locally applied vibration (Bongiovanni et al., 1990). Further support for this concept was provided by Rittweger et al. (2003) who reported that the time to exhaustion was shorter in static squat exercises with WBV than the identical exercise without WBV (349 vs. 515 sec, respectively) (Rittweger et al., 2003). In the protocols of Delecluse et al. (2003) and Roelants et al. (2004), who found that WBV augmented the effect of RT training on muscle strength and power, 60 sec of body-weight exercises per set were conducted with a 5 sec rest period. Even though training intensity was relatively high (8 repetitions of 8-10 RM or 10 repetitions of 75%-90% 1RM), Kvorning et al. (2006) and Carson et al. (2010) found that short exercise times (30 sec per set) resulted in no significant difference from the identical training without WBV. Therefore, long-duration exercise programs (greater than 30-40 sec per set) appear to be more effective for achieving additional increases in muscle strength from the combination of RT exercises and WBV.

In addition to exercises of longer duration, our results suggest that external weight loading augments the effects of WBV. The observation that maximal isometric knee extension strength increased in the RT-WBV group after weight loading is supported by Ronnestad (2004), who suggested that lower extremity muscle strength could be increased by weight loading in combination with WBV during exercise. Physically, the force generated by a vibration platform (actuator) is transferred to the human body (resonator), which significantly affects the degree of muscle stimulation during WBV exercise (Rittweger, 2010). Previous studies have reported that the frequency and amplitude of vibration platforms have effects on force generation (Rittweger, 2010). In addition, we confirmed that force generation increases when weight is loaded on the vibration platform, which might affect the degree of WBV stimulation during exercise. Pel et al. (2009) found that the peak acceleration of the vibration platform increased with weight. If the actuator produces a larger force, the degree of response in the resonator would be

affected. However, no studies have reported the amount of force produced by vibration platforms under weight-loaded conditions. For example, in the study by Kvorning et al. (2006), the magnitude of force generated by a vibration platform with a 75 kg person with an additional 85 kg load was expected to be significantly different from no weight or the conditions of our study. To permit valid comparisons in future studies, in addition to force, it is also necessary to report the acceleration experienced under weight-loaded conditions.

Our findings confirmed that WBV training effects are not restricted to the lower or upper extremities, which suggests that RT with WBV may be of clinical importance due to the relationship between abdominal flexor strength and the susceptibility to lower back pain (Lee et al., 1999). Low back and knee pain are the most frequent complaints concerning physical health of both males and females aged 30 years or older and such ailments are becoming increasingly common in Japan (Suka and Yoshida, 2009). To reduce the severity and prevalence of lower back and knee pain, the incorporation of WBV into RT programs that focus on the lower extremities and trunk muscles for young to middle-aged people may be beneficial. As WBV training has also been shown to relieve chronic lower back pain sensation in elderly people (Iwamoto et al., 2005), our promising results with respect to increases in back extension muscle strength support the need to further investigate the effects of WBV on chronic musculoskeletal pain sensation in young to middle-aged individuals.

Several limitations of this study should be considered when interpreting and generalizing the findings presented here. First, this 7 weeks training period was relatively short. Thus, further studies are needed to investigate long-term training effects. However, the preliminary data show that the training regimens conducted during the 7 weeks training period should be effective for providing muscle strength and power gains, and RT combined with WBV would lead to higher muscle strength and power gains compared with the identical exercise during the initial stage of regular RT in untrained individuals. Second, the EMG was not measured in the muscle power or trunk muscle strength tests due to the lack of instruments for synchronizing muscle power and the EMG measurements, and because the waist pad of the isometric lumbar extension machine was located at an identical level as the electrode positions. However, as no significant differences were observed in the EMG patterns between the two test groups in isometric knee extension strength, it is likely that no difference would have been detected in EMG analyses during the muscle power and trunk muscle strength tests. Third, not all participants performed the countermovement jump test used to evaluate muscle power because the recruitment of participants was divided into two periods, and the instrument used for the muscle power test was only available during the second period. Finally, although the participants were randomly assigned to training groups stratified by age and sex, the study consisted predominantly of females, and there was a relatively wide range of ages. Age and sex might be effect modifiers for the muscle strength and power gains. Thus, a larger study size with a higher proportion of males

and/or a smaller range of ages is needed to confirm that the increases in strength are applicable to both males and females.

Conclusion

In conclusion, we have demonstrated that 7 weeks of slow velocity RT combined with WBV compared led to significant changes in maximal isometric knee extension and isometric lumbar extension strengths compared to RT alone during the initial stage of a regular RT program in untrained 20-49 years old adults. The slow velocity RT program led to marked muscle strength and power gains. Although our results should be verified in longer term study protocols, and in a larger number of male subjects, the additional augmentation of lower extremity and trunk muscle strength and muscle power by the incorporation of WBV into a RT program should be considered when untrained adults desire to engage in regular RT.

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Key points

- A randomized controlled trial was conducted to investigate the effects of slow velocity resistance training combined with whole-body vibration on maximal muscle strength, power, muscle endurance, and neuromuscular activities in healthy untrained individuals.
- Resistance training program for lower extremities and trunk muscles were performed twice weekly for 7 weeks.
- A 7 weeks slow velocity resistance training program with whole-body vibration significantly increased maximal isometric knee extension and lumbar extension strength and power in healthy untrained individuals.

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