BIOMECHANICAL ANALYSIS OF SUSPENSION TRAINING PUSH-UP

GIUSEPPE F. GIANCOTTI,[1] ANDREA FUSCO,[1] CARLO VARALDA,[2] LAURA CAPRANICA,[3] AND CRISTINA CORTIS[1]

[1]*Department of Human Sciences, Society and Health, University of Cassino and Lazio Meridionale, Cassino, Italy;* [2]*Italian Weightlifting Federation FIPE, Rome, Italy; and* [3]*Department of Movement, Human and Health Sciences, University of Rome "Foro Italico", Rome, Italy*

ABSTRACT

Giancotti, GF, Fusco, A, Varalda, C, Capranica, L, and Cortis, C. Biomechanical analysis of suspension training push-up. *J Strength Cond Res* 32(3): 602–609, 2018—The aims of this study were to evaluate the load distribution between upper and lower extremities during suspension training (ST) push-up at different lengths of ST device and to predict useful equations to estimate the training load. After giving informed consent for participation, 25 subjects (17 men and 8 women; age = 28.1 ± 5.2 years; body mass = 69.4 ± 14.3 kg; height = 171.6 ± 11.3 cm; body mass index (BMI) = 23.4 ± 3.3 $kg \cdot m^{-2}$) were involved in the study. Each subject performed 14 static push-ups at 7 different lengths of ST device in 2 different elbow positions. The load distribution between upper and lower extremities was evaluated through a load cell and a force platform, respectively. To evaluate body inclination, all tests were recorded and analyzed through motion analysis software. To estimate the training load, a multilevel model regression ($p \leq 0.05$) was used. Results showed that when the length of the ST device increased, the body inclination decreased, whereas the ground reaction force decreased and the load on the ST device increased. Moreover, when subjects moved from extended to flexed elbow, the ground reaction force decreased and the load on the ST device increased. In the created regression model (intraclass correlation coefficient = 0.24), the reaction force was the dependent variable, whereas the length of the ST device, BMI, and elbow position were the independent variables. The main findings were that the load distribution between upper and lower extremities changes both when modifying the body inclination and the length of the straps. The use of predicted equations could help practitioners to personalize the workouts according to different specific aims by modifying the length of the ST device to guarantee load progression.

KEY WORDS body weight training, instability, pushing exercise, force, resistance training, functional training

Address correspondence to Cristina Cortis, c.cortis@unicas.it.

32(3)/602–609

Journal of Strength and Conditioning Research

INTRODUCTION

Body weight training is a popular form of resistance training that in the last years became an inexpensive way to exercise effectively (23). Among those activities, suspension training (ST) promotes bodyweight in multidirectional movements as a form of exercise, using 2 independently moving handles suspended by 2 straps with a fixed anchor position above the exerciser (1,13).

The concept of ST is based on 3 fundamental principles (5): vector-resistance, stability, and pendulum. The first one gives the opportunity to regulate resistance by changing the angle (i.e., the higher the body is from the ground, the easier the exercise); the second concerns the base of support and balance (i.e., the more points of contact the body has with the ground and the farther apart the stance is, the easier an exercise will be); and the last deals with the starting position in relation to the anchor point (i.e., the farther away from neutral position the body is, the harder an exercise will be). Moreover, ST is claimed to be used by all fitness levels to improve strength, endurance, flexibility, and core stability within a single workout (11). In particular, comparing the effect of closed-kinetic-chain exercises (performed using the Redcord slings ST device) with respect to open-kinetic-chain ones, ST has been shown as effective for strength gains and functional improvement in women (9), and throwing performances in NCAA Division I softball players (18). Furthermore, ST proved to be an alternative to traditional warm-up in throwing accuracy and throwing velocity in baseball players (14).

Considering the popularity of ST, several studies were performed in the last years to investigate cardiovascular, neuromuscular, and biomechanical characteristics of this activity. Snarr et al. (20) evaluated metabolic and cardiovascular responses of a 9-minute high-intensity interval training using an ST device. Results showed an average exercise intensity of 83% of maximal heart rate (HRmax) and 56%

of maximal oxygen consumption ($\dot{V}O_2max$), with an energy expenditure (EE) of 97 kcal during the training session (corresponding about to 650 $kcal \cdot h^{-1}$). Evaluating the metabolic and cardiovascular responses during and after (2 hours) 1-hour ST workout, an average exercise intensity of 69% of HRmax, with an EE of 340 kcal during the training session and 150 kcal during the 2-hour recovery period have been reported (11). According to American College of Sports Medicine (ACSM) guidelines (2), results of both studies suggest that ST could be classified as moderate-to-vigorous intensity exercise.

Given the instability characteristics of ST, several studies focused on neuromuscular activation of exercises, suggesting that ST elicits higher muscle activation then traditional ones (6,7,22), with push-up being one of the most investigated (4,8,15,19,21). In particular, greater muscular (i.e., rectus abdominis, external oblique, internal oblique, latissimus dorsi, pectoralis major, anterior deltoid, and triceps brachii) activation during ST push-up has been reported with respect to traditional one (4,19). Moreover, comparing electromyography activity of rectus abdominis during traditional push-up, ST push-up and crunch, Snarr et al. (21) showed that ST push-up elicits higher activation with respect to traditional one and similar activation to crunch. De Mey et al. (10) compared half push-up, knee push-up, knee prone bridging plus, and pull-up performed with and without an ST device. Although a lower serratus anterior muscle activation during the ST exercises performed on the knee (i.e., knee push-up and knee prone bridging plus) was reported, the main finding was that scapular muscle activation decreased, whereas glenohumeral muscle activation increased regardless of the exercise performed, showing that not all muscles increase their activation levels in response to an unstable surface.

Considering the fundamental principles of ST, the evaluation of the load distribution between upper and lower limbs is affected by several biomechanical aspects, such as the body inclination, the length of ST device, the feet position, and the combination of these factors. Until now, only few studies investigated the biomechanical characteristics of ST. In particular, the loads on the ST device and ground reaction force during push-up at 4 different angle inclinations of the ST device (0, 15, 30, and 45°) have been determined and compared (12), indicating that the load on the device increased both during elbow flexion with respect to elbow extension and when ST angle decreased.

Melrose and Dawes (16) evaluated the load on the ST device during ST back-row at 4 different body inclinations (30, 45, 60, and 75° with respect to the vertical position) and 6 different feet distances from the hanging point (from the vertical hanging point, the distance of feet were increased of 30.5 cm). Findings showed that the load on the ST device was directly proportional to body inclination and indirectly proportional to the distance of the feet from the vertical hanging point (i.e., higher load values on the straps were recorded in the horizontal positions and when the feet position was closer to vertical hanging point). Furthermore, researchers predicted 4 equations to estimate the load on the straps at the 4 measured angles. Although they used different methods of angle measurement and exercises, both studies highlighted that the load on the ST device increases when the body inclination from the floor decreases (12,16).

However, measuring the angles during ST exercises could not always be feasible, and to the best of our knowledge, no study investigated the effect of the ST device length on the distribution of loads between upper and lower limbs. It was hypothesized that the load distribution could change when modifying the length of ST device while maintaining a fixed feet position.

Therefore, the aims of this study were: (a) to evaluate the loads on the straps and ground reaction force during ST push-up at different lengths of ST device and (b) to predict useful equations to estimate the training load.

Methods

Experimental Approach to the Problem

Prescribing an appropriate exercise progression is fundamental to achieve strength gains (3) and to explicitly quantify the training volume and intensity is a crucial aspect in resistance exercise, and therefore during ST (22). When using dumbbells, weight plates, and machines, exercise intensity can be easily calculated as percentage of maximum loads.

Conversely, the quantification of intensity and load during ST exercises are challenging (12) because several biomechanical aspects, such as the body inclination, the length of the ST device, the feet position, and the combination of these factors (12,16). Although these parameters could affect

Table 1. Mean and *SD* of subject descriptive characteristics.*

	Total ($n = 25$)	Women ($n = 8$)	Men ($n = 17$)
Age (y)	28.1 ± 5.2	27.3 ± 6.6	28.5 ± 4.5
Mass (kg)	69.4 ± 14.3	52.5 ± 6.8	77.3 ± 8.9
Height (cm)	171.6 ± 11.3	160.3 ± 4.7	176.9 ± 9.4
BMI ($kg \cdot m^{-2}$)	23.4 ± 3.3	20.5 ± 2.8	24.7 ± 2.5

*BMI = body mass index.

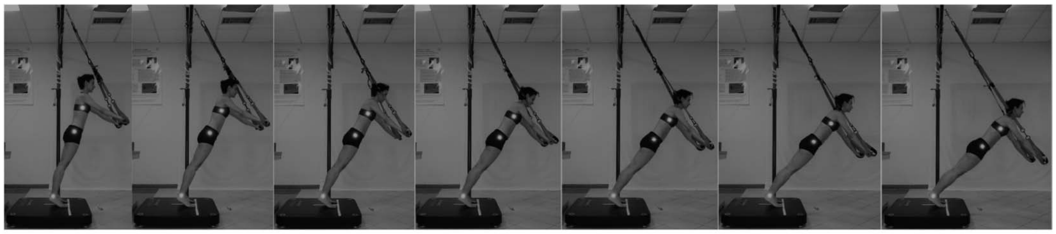

Figure 1. Push-up at different lengths of the suspension training device.

the load distribution between upper and lower limbs, only few studies investigated the biomechanical characteristics of ST by taking into consideration these variables. Therefore, this study was designed to investigate load distribution between upper and lower limbs during ST static push-up at different lengths of ST device and elbow position (flexed and extended) and to develop useful equations to estimate the training load.

A cell load (range from −10,000 to 10,000 N; sensitivity ≈ −4 pC/N; linearity ≤±0.5% Full Scale Output [FSO]) and a force platform (range from 0 to 10,000 N; linearity <±0.5% FSO) were used to evaluate the load distribution between upper and lower limbs, respectively, whereas motion analysis software was used to calculate the body inclination angle. A 2-way mixed-effects model was applied to data recorded by the cell load and the force plate to verify measurements reliability. High intraclass correlation coefficients (ICCs) were found for the cell load and the force plate in the flexed (cell load: ICC = 0.96, 95% confidence interval [CI]: 0.93–0.98; force plate: ICC = 0.97, 95% CI: 0.95–0.99) and extended position (cell load: ICC = 0.91, 95% CI: 0.85–0.95; force plate: ICC = 0.98, 95% CI: 0.96–0.99). To create useful equations, a multilevel regression was used. The loads on the force plate and on the straps were identified as dependent variables, whereas the length of the ST device, body mass index (BMI), BMI^2, and elbow position (elbow in extension = 0; elbow in flexion = 1) were independent variables.

Before starting the experimental session, subjects were administered 10-minute specific warm-up including dynamic and static ST push-ups. To avoid any potential fatigue effect, subjects were required to refrain from any moderate-to-vigorous physical activity for at least 24 hours before the experimental session.

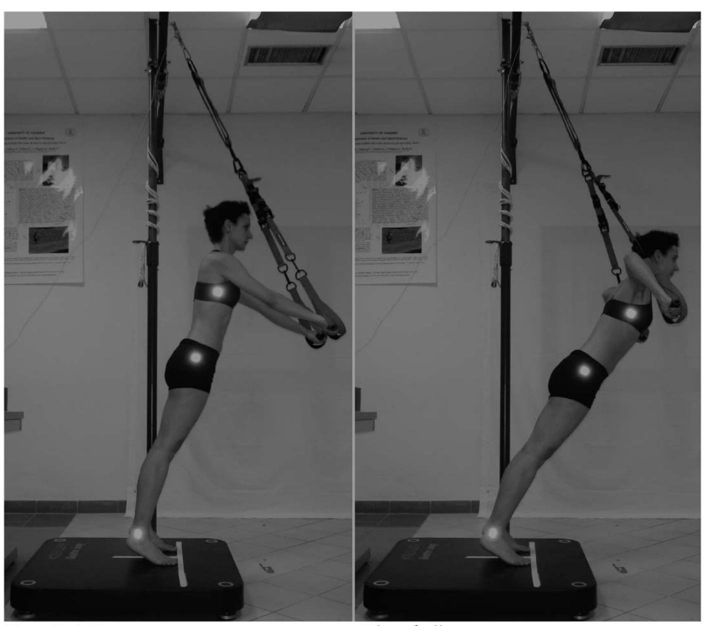

Figure 2. Suspension training push-up with extended and flexed elbow positions.

Subjects

Twenty-five (17 men and 8 women) physically active (engaging in at least 3 days a week of moderate-to-intense physical activity) college (age range: 23–41 years old) students (Sport Science Major) gave their written consent of participation after receiving both written and oral information regarding testing procedures. Consent for publication of figures was also obtained with the subject's photograph. Subjects were included in the study (performed from May to June 2015) if they reported ST experience (at least 1 session weekly for the previous

Table 2. Mean and *SD* of body inclination angles, ground reaction force, and load on the suspension training (ST) device expressed as percentage of the total load at different lengths of the ST device.

	Extended elbow			Flexed elbow		
Length (cm)	Angles (°)	Ground reaction force (%)	Load on ST device (%)	Angles (°)	Ground reaction force (%)	Load on ST device (%)
178	65.0 ± 2.3	80.9 ± 2.7	19.1 ± 2.7	47.9 ± 3.0	58.5 ± 2.8	41.5 ± 2.8
188	62.0 ± 2.4	77.1 ± 3.0	22.9 ± 3.0	43.2 ± 2.6	55.2 ± 2.6	44.8 ± 2.6
198	56.9 ± 4.1	72.7 ± 3.0	27.3 ± 3.0	39.8 ± 4.5	52.9 ± 3.0	47.1 ± 3.0
208	53.0 ± 3.4	68.0 ± 2.5	32.0 ± 2.5	34.6 ± 5.2	49.8 ± 2.6	50.2 ± 2.6
218	49.2 ± 3.9	63.5 ± 2.6	36.5 ± 2.6	31.1 ± 4.3	47.6 ± 2.2	52.4 ± 2.2
228	45.3 ± 2.5	59.8 ± 2.2	40.2 ± 2.2	25.0 ± 2.6	44.7 ± 2.1	55.3 ± 2.1
238	41.4 ± 1.8	56.5 ± 2.4	43.5 ± 2.4	20.8 ± 2.5	41.8 ± 2.4	58.2 ± 2.4

year), and they were excluded if they reported any pre-existing condition such as musculoskeletal disorders or physical injury. The study was approved by the Department of Human Sciences, Society and Health of the University of Cassino and Lazio Meridionale and was performed in accordance with the Declaration of Helsinki for Human Research of 1964 (last modified in 2000). All descriptive characteristics of the subjects are reported in Table 1.

Procedures

Before starting the experimental sessions, body mass was measured through a force plate (Kistler Quattro Jump 9290AD; Kistler, Winterthur, Switzerland), whereas the height was measured using a stadiometer (Seca, model 709; Vogel & Halke, Hamburg, Germany).

Each subject performed 14 static push-ups in 7 different lengths of the ST device (178, 188, 198, 208, 218, 228, and 238 cm, Figure 1) ranging from the easiest to the hardest intensity, in 2 different elbow positions (flexed and extended elbow, Figure 2). At least 3-minute sitting rest was allowed among testing positions so that the whole procedure was performed within a 1-hour period.

During the tests, the force plate was used to record the ground reaction force, while a load cell (Kistler 9321B; Kistler, Winterthur, Switzerland) equipped with amplifier (Kistler 5001; Kistler, Winterthur, Switzerland) and data acquisition system (Tektronix TBS 1202B; Tektronix, Beaverton, OR, USA) were used to record the traction load on the straps. Load cell was fixed between the anchor point and the ST device (AINS Suspension Training FIPE, Rome, Italy), anchored at 2.65 m above the force platform. Participants were asked to stand barefoot on the force plate, with their feet shoulder width apart positioned under the anchored point.

Visual markers were applied to participants' right lateral malleolus, greater trochanter, and to the point where the vertical line from the mid axilla intersects the

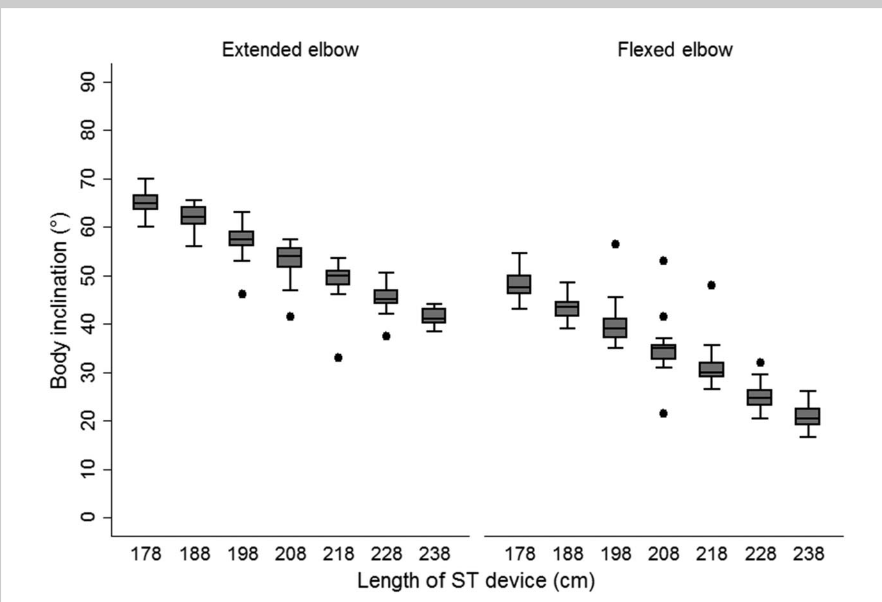

Figure 3. Box plot of body inclination in relation to the length of the suspension training (ST) device during push-up with extended and flexed elbow positions.

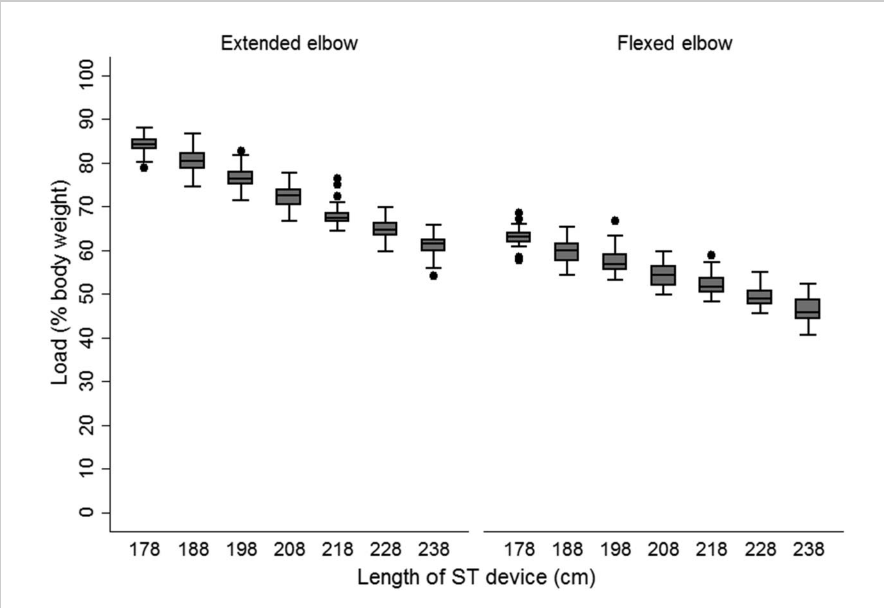

Figure 4. Box plot of ground reaction force in relation to the length of the suspension training (ST) device during push-up with extended and flexed elbow positions.

horizontal line of the xiphoid process. All trials were recorded by a video camera (Sony Camcorder HDR-CX290/B; Sony, Minato, Tokyo, Japan) fixed at 4.50 m from the subjects and 0.90 m above the ground. Recorded videos were imported on motion analysis software (Dartfish Team Pro 5.5; Dartfish, Fribourg, Switzerland) to calculate the body inclination (when the 3 visual markers were aligned) with respect to the horizontal surface.

Statistical Analyses

Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA) and Stata statistical software version 14.1 (StataCorp, College Station, TX, USA) were used for statistical analysis. Mean and *SD* for all descriptive characteristics of the subjects were calculated, whereas the mean value of all data recorded by the force plate and cell load was calculated and then normalized in relation to the body weight using the following formula: load (%body weight) = load (kg) x body weight^{-1} x 100.

The load distribution was also expressed as percentage of the total load.

A multilevel model regression (or hierarchical linear model [17]) was performed to predict a model useful to estimate the distribution of training load to upper and lower limbs. Statistical significance (p) was set at 0.05.

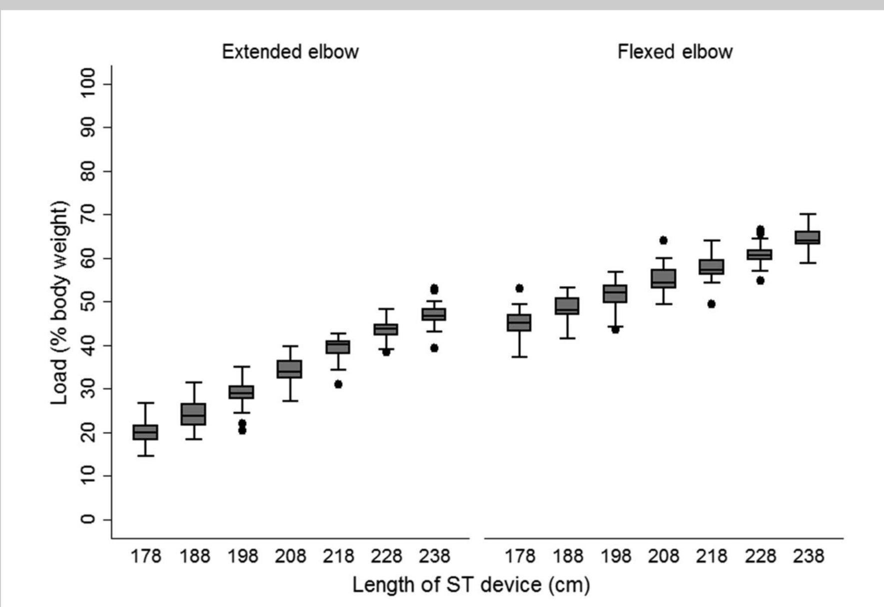

Figure 5. Box plot of load on the suspension training (ST) device in relation to the length of the device during push-up with extended and flexed elbow positions.

Results

Results showed that when body inclination increased, the ground force reaction increased, whereas the load on the ST device decreased (Table 2). In particular, body inclination angles were indirectly proportional to the length of the ST device (Figure 3).

Ground reaction forces and loads applied on the ST device in relation to the position are showed in Figures 4 and 5, respectively. When the length of ST straps increased, the ground reaction force decreased, whereas the load on the ST device increased. Moreover, higher values on the force plate were recorded with extended elbow with

Table 3. Multilevel model regression between dependent variable (load on the force plate normalized in relation to body mass) and independent variables (length of the suspension training device in centimeters, BMI, BMI^2, and elbow position).*

Load	Coef.	SE	z	$p > \|z\|$	95% CI
Length	−0.3329871	0.0066725	−49.90	0.000	−0.3460651 to −0.3199092
BMI	−3.014736	1.23525	−2.44	0.015	−5.435782 to −0.5936895
BMI^2	0.0581454	0.0257662	2.26	0.024	0.0076445 to 0.1086462
Elbow	−17.94356	0.2663926	−67.36	0.000	−18.46568 to −17.42144
_cons	179.8692	14.68748	12.25	0.000	151.0823 to 208.6562

*coef. = coefficient; SE = standard errors; CI = confidence interval; BMI = body mass index; Elbow = elbow position (elbow in extension = 0; elbow in flexion = 1); _cons = intercept.

respect to flexed elbow and, vice versa, lower values on the load cell were recorded with extended elbow when compared to flexed elbow.

The multilevel model regression analysis (Table 3) produced the ground reaction force (dependent variable) prediction equations using the length of the ST device, BMI, BMI^2, and the elbow position (elbow in extension = 0; elbow in flexion = 1). Significant effects ($p \leq 0.05$) were found for all variables used in the model, which presented an ICC of 0.24.

From the model, it was possible to extrapolate the following formula to predict the ground reaction force:

$$\text{Load} = 179.8692 - 0.3329871 \times \text{length} - 3.014736 \times \text{BMI} + 0.0581454 \times \text{BMI}^2 - 17.94356 \times \text{elbow position}$$

Furthermore, through the opposite formula, it is possible to calculate the length of the ST device to train to the known load with elbow in extension:

$$\text{Length} = \left(\text{Load}_{\text{extension}} - 179.8692 + 3.014736 \times \text{BMI} - 0.0581454 \times \text{BMI}^2\right) / -0.3329871$$

Finally, the length of the straps being equal, it is possible to evaluate the load with elbow in flexion by the following formula:

$$\text{Load}_{\text{flexion}} = \text{Load}_{\text{extension}} - 17.94356$$

Discussion

The aims of this study were: (a) to evaluate the loads on the straps and ground reaction force during push-up at different lengths of ST device; and (b) to predict useful equations to estimate the training load. The main findings were that the load distribution between upper and lower extremities changes both when modifying the body inclination and the length of the straps, confirming the original hypothesis of this research.

Results of this study, in which body inclination was calculated through video-analysis, are comparable to previous ones (12,16), in which goniometer with 2 laser point streams or wooden goniometer were used. For the vector-resistance principle, the ground reaction force is directly proportional to body inclination in relation to a horizontal surface. Consequently, the load on the ST device is indirectly proportional to body inclination with respect to the horizontal surface (12,16).

To the best of our knowledge, no studies investigated variation in the load distribution as the length of the ST device changes. Findings of this study highlighted that when the length of the straps increased, body inclination angle decreased and, at the same time, traction force on the ST device increased, whereas the load on the force platform decreased. Furthermore, the length of the straps being equal, during the flexion phases, the load on the ST device increased and the ground reaction force decreased. These results agree with a recent study (12), which highlighted that the maximal load on the straps was recorded when subjects performed ST push-up in the flexion phase and with the ST device in a vertical position.

One of the main problems during ST exercise is the quantification of load distribution between upper and lower limbs. Recently, 4 formulas to estimate the traction load on the straps in 4 specific body inclination angles during ST back-row were estimated taking into consideration only the body mass of the subjects (16). In this study, by modifying the length of the straps, subjects had to align ankle and shoulder joints with a wooden goniometer to calculate the body inclination. However, it is difficult to measure the angles during ST exercise, especially during group or home environment workouts. Moreover, no statistical analysis was done to evaluate the significance of the predicted formulas.

In this study, through a multilevel regression, a useful equation to calculate the ground reaction force during ST push-up was created taking into consideration the length of the ST device, the BMI, and the elbow position. In particular, the addition of a quadratic term of BMI to the multilevel regression model significantly improved the ICC value from 0.28 to 0.24. An ICC of 0.24 suggests that 24% of the outcome variability (ground reaction force, dependent variable) depends on differences among individuals, whereas the remaining 76% depends on differences between the measurements made in the same individual.

Usually, during workouts, the practitioners know the training load and need to know the length of the straps. Through the opposite formula, the length of the ST device can be calculated to be able to train with the known load, with the elbow in an extended position. Considering that the length of the straps stays equal during ST push-up, it is possible to evaluate the ground reaction force with flexed elbows. In particular, moving from extended to flexed elbow position, the ground reaction force decrease of 17.9% of body weight.

Some limitations of the study should be acknowledged. ST push-up was evaluated in the static position. Nevertheless, evaluating push-up with extended and flexed elbow, equations to estimate minimum and maximum loads during exercise have been predicted. ST push-up was evaluated only with the feet positioned under anchored point. Probably, moving the feet position and using an equal length of the ST device, body inclination angle and load distribution between upper and lower extremities would be different. Therefore, further studies are encouraged to evaluate and to predict useful equations for ST push-up with different feet positions and for others ST exercises.

Practical Applications

The results of this study suggest that the load distribution to upper and lower limbs change both when the body inclination and the length of the ST device are modified. In particular, when the length of the ST device increased (moving from a vertical to a horizontal position), the ground reaction force decreased and the load on the straps increased. Additionally, when subjects performed ST push-up with flexed elbows compared with extended elbows, the body inclination with respect to the ground decreased and, consequently, the load on the force plate decreased and the force on the cell load increased. The use of predicted equations could help trainees and instructors to personalize the workouts according to different specific aims. From a practical point of view, if a subject with a body mass of 80 kg and a height of 180 cm (consequently with a BMI of 24.7 $kg \cdot m^{-2}$) trains with an ST device length of 180 cm, by applying the predicted equations ($Load_{extension} = 179.8692 - 0.3329871 \cdot 180 - 3.014736 \cdot 24.7 + 0.0581454 \cdot 24.7^2$), it is possible to estimate that the subject will receive a load corresponding to 80.9% of the body weight on lower limbs during the extension, while receiving a load corresponding to 63.0% of the body weight during the flexion ($Load_{flexion} = 179.8692 - 0.3329871 \cdot 180 - 3.014736 \cdot 24.7 + 0.0581454 \cdot 24.7^2 - 17.94356$). Therefore, with a 180-cm length of ST device, this subject will perform an ST push-up with a load on lower limbs ranging from a minimum of 50.4 kg to a maximum of 64.7 kg.

Conversely, if the same subject wants to train with a maximum load on lower limbs of 60 kg (corresponding to 75% of body weight), he or she will need to adjust the ST device to 197.8 cm, as the result of the equation: $Length_{extension} = (75 - 179.8692 + 3.014736 \cdot 24.7 - 0.0581454 \cdot 24.7^2) / -0.3329871$. Consequently, the length of the straps being equal, he or she will receive a 45.7-kg load with elbow in flexion ($Load_{flexion} = 75 - 17.94356 = 57.1\%$ of body weight). Finally, to receive a maximum load of 60 kg, the same subject needs to adjust the straps at a 197.8-cm length, with the minimum load during exercise with flexed elbow being 45.7 kg. Therefore, the manufacturing companies of ST devices may insert length indicators on the straps, facilitating and accelerating the adjustment of the device during workouts.

Acknowledgments

The authors would like to express their gratitude to Prof. Dr. Bruno Federico whose statistical expertise was invaluable during the analysis of the data, to Mirco Cacchiani, Matteo Campobasso, Lorenzo Cocco, Jessica Pascarella and Diego Spinosa who collaborated in the data acquisition, and to the subjects involved in the study for their committed participation.

References

1. Allison, K and Cervantes, S. *U.S. Patent No. 9,345,922.* Washington, DC: U.S. Patent and Trademark Office, 2016.
2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription* (9th ed.). Philadelphia, PA: Lippincott, Williams & Wilkins, 2014.
3. American College of Sports Medicine. Position stand: Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
4. Beach, TA, Howarth, SJ, and Callaghan, JP. Muscular contribution to low-back loading and stiffness during standard and suspended push-ups. *Hum Mov Sci* 27: 457–472, 2008.
5. Bettendorf, B. TRX suspension training bodyweight exercises: Scientific foundations and practical applications. San Francisco, CA: Fitness Anywhere Inc., 2010.
6. Byrne, JM, Bishop, NS, Caines, AM, Crane, KA, Feaver, AM, and Pearcey, GE. Effect of using a suspension training system on muscle activation during the performance of a front plank exercise. *J Strength Cond Res* 28: 3049–3055, 2014.
7. Calatayud, J, Borreani, S, Colado, JC, Martin, F, Batalha, N, and Silva, A. Muscle activation differences between stable push-ups and push-ups with a unilateral v-shaped suspension system at different heights. *Motricidade* 10: 84–93, 2014.
8. Calatayud, J, Borreani, S, Colado, JC, Martín, FF, Rogers, ME, Behm, DG, and Andersen, LL. Muscle activation during push-ups with different suspension training systems. *J Sports Sci Med* 13: 502–510, 2014.
9. Dannelly, BD, Otey, SC, Croy, T, Harrison, B, Rynders, CA, Hertel, JN, and Weltman, A. The effectiveness of traditional and sling exercise strength training in women. *J Strength Cond Res* 25: 464–471, 2011.

10. De Mey, K, Danneels, L, Cagnie, B, Borms, D, T'Jonck, Z, Van Damme, E, and Cools, AM. Shoulder muscle activation levels during four closed kinetic chain exercises with and without Redcord slings. *J Strength Cond Res* 28: 1626–1635, 2014.
11. Dudgeon, WD, Herron, JM, Aartun, JA, Thomas, DD, Kelley, EP, and Scheett, TP. Physiologic and metabolic effects of a suspension training workout. *Int J Sports Sci* 5: 65–72, 2015.
12. Gulmez, I. Effects of angle variations in suspension push-up exercise. *J Strength Cond Res* 31: 1017–1023, 2017.
13. Hetrick, RA. *U.S. Patent No. 7,090,622*. Washington, DC: U.S. Patent and Trademark Office, 2006.
14. Huang, JS, Pietrosimone, BG, Ingersoll, CD, Weltman, AL, and Saliba, SA. Sling exercise and traditional warm-up have similar effects on the velocity and accuracy of throwing. *J Strength Cond Res* 25: 1673–1679, 2011.
15. McGill, SM, Cannon, J, and Andersen, JT. Analysis of pushing exercises: Muscle activity and spine load while contrasting techniques on stable surfaces with a labile suspension strap training system. *J Strength Cond Res* 28: 105–116, 2014.
16. Melrose, D and Dawes, J. Resistance characteristics of the TRX™ suspension training system at different angles and distances from the hanging point. *J Athl Enhancement* 4: 1–5, 2015.
17. Norman, GR and Streiner, DL. *Biostatistics: The Bare Essentials* (4th ed.). Shelton, CT: People's Medical Publishing House, 2014.
18. Prokopy, MP, Ingersoll, CD, Nordenschild, E, Katch, FI, Gaesser, GA, and Weltman, A. Closed-kinetic chain upper-body training improves throwing performance of NCAA Division I softball players. *J Strength Cond Res* 22: 1790–1798, 2008.
19. Snarr, RL and Esco, MR. Electromyographic comparison of traditional and suspension push-ups. *J Hum Kinet* 39: 75–83, 2013.
20. Snarr, RL, Esco, MR, and Nickerson, BS. Metabolic and cardiovascular demands of a high-intensity interval exercise bout utilizing a suspension device. *J Sport Hum Perf* 2: 1–8, 2014.
21. Snarr, RL, Esco, MR, Witte, EV, Jenkins, CT, and Brannan, RM. Electromyographic activity of rectus abdominis during a suspension push-up compared to traditional exercises. *J Exer Phys Online* 16: 1–8, 2013.
22. Snarr, RL, Hallmark, AV, Nickerson, BS, and Esco, MR. Electromyographical comparison of pike variations performed with and without instability devices. *J Strength Cond Res* 30: 3436–3442, 2016.
23. Thompson, WR. Worldwide survey of fitness trends for 2017. *Acsm's Health Fit J* 20: 8–17, 2016.