Journal of Strength and Conditioning Research

Biomechanical Analysis of Suspension Training Push-up

--Manuscript Draft--

Manuscript Number:	JSCR-08-8952R1
Full Title:	Biomechanical Analysis of Suspension Training Push-up
Short Title:	Suspension training push-up
Article Type:	Original Research
Keywords:	body weight training; instability; pushing exercise; force; resistance training; functional training
Corresponding Author:	Cristina Cortis, Ph.D. University of Cassino e Lazio Meridionale Cassino, ITALY
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	University of Cassino e Lazio Meridionale
Corresponding Author's Secondary Institution:	
First Author:	Giuseppe Francesco Giancotti
First Author Secondary Information:	
Order of Authors:	Giuseppe Francesco Giancotti
	Andrea Fusco
	Carlo Varalda, Ph.D.
	Laura Capranica
	Cristina Cortis, Ph.D.
Order of Authors Secondary Information:	
Manuscript Region of Origin:	ITALY
Abstract:	The aims of this study were to evaluate the load distribution between upper and lower extremities during suspension training (ST) push-up at different length of ST device and to predict useful equations to estimate the training load. After giving their informed consent of participation, twenty-five subjects (male=17, female=8; age=28.1±5.2years; weight=69.4±14.3kg; height=171.6±11.3cm; BMI=23.4±3.3kg·m-2) were involved in the study. Each subject performed 14 static push-ups at 7 different lengths of ST device in two 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 multi-level model regression (P<0.05) was used. Results showed that when the length of ST device increased, the body inclination decreased, while the ground reaction force decreased and the load on the ST device increased. Moreover, when subjects moved from extended to flex elbow, the ground reaction force decreased and the load on the ST device increased. In the created regression model (ICC=0.24), the reaction force was the dependent variable, while length of 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.
Response to Reviewers:	Manuscript JSCR-08-8952 "Biomechanical Analysis of Suspension Training Push-up" Following your decision letter on our manuscript “Biomechanical Analysis of

Suspension Training Push-up" (MS# JSCR-08-8952), we revised our work according to the reviewers' recommendations before re-submitting it for publication in the "The Journal of Strength and Conditioning Research".

We wish to thank the reviewers for the interesting and useful comments that helped enhancing the quality of our paper. We do hope that, thanks to the reviewers' comments, we could successfully deal with the requested revisions. To facilitate the identification of the revisions, we have highlighted in red color all new or modified sentences according to the reviewers.

In particular, we better developed the practical question in the introduction of the paper and the practical applications section. The study did not included subjects under the age of 18 years, but we double-checked data to verify that mean and SD did not suggest subjects may have been under the age of 18 years.

We include affiliation and contact information for the corresponding author in the title page of the paper. We double-checked tables (made in word) and figures (with no black eyes or masking) numbers, also indicating where they should be placed in the text. All the submitted files (manuscript, figures and tables) are word documents.

We finally checked all formatting according to JSCR guidelines.
Sincerely,
Cristina Cortis

Answers to Reviewer 1 (Manuscript JSCR-08-8952 "Biomechanical Analysis of Suspension Training Push-up")

We wish to thank Reviewer 1 for his/her positive judgment, interesting and useful comments that helped enhancing the quality of our paper. We do hope that, thanks to the reviewer's comments, we could successfully deal with the requested revisions, highlighted in red in the text.

Reviewer 1

Question 1: The methods really need to be carefully spelled out and developed so we understand from your Approach to the Problem how your procedures and protocols used will be able to produce data that is both reliable and valid to support your hypothesis and answer your questions.
Answer: As required, we better developed the methods section, and especially the experimental design and the rationale of the study, as follows:
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) due to several biomechanical aspects, such as the body inclination, the length of ST device, the feet position and the combination of those factors (12, 16). Although these parameters could affect 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 length of ST device and elbow position (flex and extended) and to develop useful equations to estimate the training load.

Question 2: The methods need to include what was done with all aspects of the procedures from their reference for validation and the reliability in your hands and then paying attention to the fact others want to use similar approaches you need to make the procedures clear and check that the equipment used is there as well and where to get it. Reference out things but do not make the reader go back and hunt for what you did, as this is frustrating so be careful with this.
Answer: We agree with Reviewer 1 that the procedures needed an implementation so

	that others could use similar approaches. We therefore added additional information in the Subjects and the Procedures sections, as follows: Subjects Twenty five (17 male and 8 female) physically active (engaging in at least 3-day/week of moderate-to-intense physical activity) college students (Sport Science Major) gave their written consent of participation after receiving both written and oral information regarding testing procedures. Subjects were included in the study (carried out from May to June 2015) if reporting ST experience (at least 1 session weekly for the previous year), and they were excluded if reporting any pre-existing condition such as musculoskeletal disorders or physical injury. The study was approved by the local Institutional Review Board, 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 …Each subject performed fourteen static push-ups in seven different lengths of ST device (178 cm, 188 cm, 198 cm, 208 cm, 218 cm, 228 cm and 238 cm, Figure 1) ranging from the easiest to the hardest intensity, in two different elbow positions (flex and extend elbow, Figure 2). At least 3-minute sitting rest was allowed among testing positions so that the whole procedure was carried out within a 1-hour period. Question 3: Do a check on formatting per subtitles and also check with journal format, especially in the informed consent process which is to be written informed consent and if under 18 years of age a parent or guardian must also consent. Wording is critical and is make sure your study was approved by and Ethics Board or IRB. Answer: As required, we checked on formatting per subtitles and with journal format, amending the whole paper accordingly. The study did not included subjects under the age of 18 years, but we double-checked data to verify that mean and SD did not suggest subjects may have been under the age of 18 years. Question 4: You n size is really important to know you ok for your statistical analyses. Is your reliability of the measures solid, ICCRs etc. Answer: The present study included 25 (17 male and 8 female) physically active college students which is in line with similar researches (mean sample n size = 22). Furthermore we checked whether reliability measures (ICCs) for the independent variables were provided in the experimental approach to the problem (and in the references), as follows: A cell load (range from - 10000 N to 10000 N; sensitivity ≈–4 pC/N; linearity ≤ ±0.5% FSO) and a force platform (range from 0 N to 10000 N; linearity < ±0.5% FSO) were used to evaluate the load distribution between upper and lower limbs, respectively, while a motion analysis software was used to calculate the body inclination angle. A two-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 flex (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, while length of ST device, BMI, BMI2 and elbow position (elbow in extension = 0; elbow in flexion = 1) as independent variables. Question 5: Owing to the fact I have to rate the impact of the paper, it is not clear to me how important these data are to the field practitioner and this needs to be better presented as to its importance to the literature as I am not clear how important your question and the answer really is from what we already know. Answer: We agree with Reviewer 1 that the previous version of the paper did not highlight enough the impact of the data to field practitioners. Therefore, we implemented the Experimental Approach to the Problem and the Practical Applications to better introduce the rational of the study and its importance from a practical point of view, as follows: 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) due to several biomechanical aspects, such as the body inclination, the length of ST device, the feet position and the combination of those factors (12, 16). Although these parameters could affect 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 length of ST device and elbow position (flex and extended) and to develop useful equations to estimate the training load.
A cell load (range from - 10000 N to 10000 N; sensitivity ≈–4 pC/N; linearity ≤ ±0.5% FSO) and a force platform (range from 0 N to 10000 N; linearity < ±0.5% FSO) were used to evaluate the load distribution between upper and lower limbs, respectively, while a motion analysis software was used to calculate the body inclination angle. A two-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 flex (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, while length of ST device, BMI, BMI2 and elbow position (elbow in extension = 0; elbow in flexion = 1) as 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.

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 ST device are modified. In particular, when the length of 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 flex elbows compared to 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 weight of 80 kg and a height of 180 cm (consequently with a BMI of 24.7 kg·m-2) trains with a ST device length of 180 cm, by applying the predicted equations (Loadextension = 179.8692 - 0.3329871·180 - 3.014736·24.7 + 0.0581454·24.72), it is possible to estimate that he/she will receive a load corresponding to 80.9% of his/her body weight on lower limbs during the extension, while he/she will receive a load corresponding to 63.0% of his/her body weight during the flexion (Loadflexion = 179.8692 - 0.3329871·180 - 3.014736·24.7 + 0.0581454·24.72 - 17.94356). Therefore, with a 180 cm length of ST device, this subject will perform a 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% body weight), he/she will need to adjust the ST device to 197.8 cm, as the result of the equation: Lengthextension = (75 - 179.8692 + 3.014736·24.7 - 0.0581454·24.72)/ - 0.3329871. Consequently, being equal the length of the straps, he/she will receive a 45.7 kg load with elbow in flexion (Loadflexion = 75 - 17.94356 = 57.1% body weight). Finally, to receive a maximum load of 60 kg, the same subject needs to adjust the straps at a 197.8 length, with the minimum load during exercise with flex 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.

Answers to Reviewer 2 (Manuscript JSCR-08-8952 "Biomechanical Analysis of

Suspension Training Push-up")

We wish to thank Reviewer 2 for his/her positive judgment, interesting and useful comments that helped enhancing the quality of our paper. We do hope that, thanks to the reviewer's comments, we could successfully deal with the requested revisions, highlighted in red in the text.

Reviewer #2

Question 1: The introduction needs to be hypothesis driven to allow the reader to see the basis of your hypothesis. It also needs to be clear what the practical question is that you are trying to address. How is the answer to this question important to the field as this is not clear or obvious? How is this study and impactful study and not trivial as this needs more clarity as well. The key issue here is to make sure you set up your approach to the problem. How does the strength and conditioning professional use this information as this is a primary feature of the journal so you study A or B topics how is this topic important for the strength coach to know and if you find X or Y how does this impact the day to day view of what the strength and conditioning professional do as this is related to the impact and importance of the study, even if a sport science project this has to be kept in mind or it is only a paper with little impact on the profession.
Answer: We agree with Reviewer 2 that the previous version of the paper lacked for a better connection from the introduction to the experimental approach. Therefore, we better developed the introduction, by adding new relevant references, we implemented the methods section (especially the experimental design and the rationale of the study), and the Practical Applications to better introduce the rational of the study and its importance from a practical point of view, as follows:

Introcuction
Body weight training is a popular form of resistance training become in the last years an inexpensive way to exercise effectively (23). Among those activities, Suspension Training (ST) promotes bodyweight in multi-directional movements as a form of exercise, by using two independently moving handles suspended by two straps with a fixed anchor position above the exerciser (1, 13).
The ST concept is based on three 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 claimed to be utilized 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 with the use of the Redcord slings ST device) with respect to open-kinetic-chain ones, ST has been showed 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 and colleagues (20) evaluated metabolic and cardiovascular response of a 9-min high-intensity interval training using a ST device. Results showed an average exercise intensity of 83% of maximal heart rate (HRmax) and 56% of maximal oxygen consumption (VO2max), with an energy expenditure (EE) of 97 kcal during the training session (corresponding about to 650 kcal·hr-1). Evaluating the metabolic and cardiovascular responses during and after (two 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 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 elicit 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, when comparing electromyography activity of rectus abdominis during traditional push-up, ST push-up and crunch, Snarr and colleagues (21) showed that ST push-up elicit higher activation with respect to traditional one and similar activation to crunch. De Mey and colleagues (10) compared half push-up, knee push-up, knee prone bridging plus, and pull-up performed with and without a 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 those factors. Until now only few studies investigated biomechanical characteristics of ST. In particular, the loads on the ST device and ground reaction force during push-up at four 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 ST device during ST back-row at four different body inclinations (30°, 45°, 60° and 75° with respect to the vertical position) and six 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 four equations to estimate the load on the straps at the four measured angles. Although they used different methods of angle measurement and exercises, both studies highlighted that the load on the ST device increase when the body inclination from the floor decrease (12, 16).

However, measuring the angles during ST exercise could not always be feasible, and to the best of our knowledge no study investigated the effect of 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 fix the feet position.

Therefore, the aims of this study were: i) to evaluate the loads on the straps and ground force reaction during ST push-up at different length of ST device and ii) 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) due to several biomechanical aspects, such as the body inclination, the length of ST device, the feet position and the combination of those factors (12, 16). Although these parameters could affect 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 length of ST device and elbow position (flex and extended) and to develop useful equations to estimate the training load.

A cell load (range from - 10000 N to 10000 N; sensitivity ≈–4 pC/N; linearity ≤ ±0.5% FSO) and a force platform (range from 0 N to 10000 N; linearity < ±0.5% FSO) were used to evaluate the load distribution between upper and lower limbs, respectively, while a motion analysis software was used to calculate the body inclination angle. A two-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 flex (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, while length of ST device, BMI, BMI2 and elbow position (elbow in extension = 0; elbow in flexion = 1) as 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.

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 ST device are modified. In particular, when the length of 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 flex elbows compared to 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 weight of 80 kg and a height of 180 cm (consequently with a BMI of 24.7 kg·m-2) trains with a ST device length of 180 cm, by applying the predicted equations (Loadextension = 179.8692 - 0.3329871·180 - 3.014736·24.7 + 0.0581454·24.72), it is possible to estimate that he/she will receive a load corresponding to 80.9% of his/her body weight on lower limbs during the extension, while he/she will receive a load corresponding to 63.0% of his/her body weight during the flexion (Loadflexion = 179.8692 - 0.3329871·180 - 3.014736·24.7 + 0.0581454·24.72 - 17.94356). Therefore, with a 180 cm length of ST device, this subject will perform a 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% body weight), he/she will need to adjust the ST device to 197.8 cm, as the result of the equation: Lengthextension = (75 - 179.8692 + 3.014736·24.7 - 0.0581454·24.72)/ - 0.3329871. Consequently, being equal the length of the straps, he/she will receive a 45.7 kg load with elbow in flexion (Loadflexion = 75 - 17.94356 = 57.1% body weight). Finally, to receive a maximum load of 60 kg, the same subject needs to adjust the straps at a 197.8 length, with the minimum load during exercise with flex 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.

Question 2: The methods must be clear so that the study can be replicated as to equipment, subjects context of training level and where they are in their training cycle and rationales for the design for each independent and dependent variable as we need to know more about the subjects, any procedures, etc. This needs to be very highly specific as to source of equipment etc.
Answer: As required, we improved the Experimental Approach to the Problem, by providing more detailed information regarding the study design and the subjects, as follows:

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) due to several biomechanical aspects, such as the body inclination, the length of ST device, the feet position and the combination of those factors (12, 16). Although these parameters could affect 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 length of ST device and elbow position (flex and extended) and to develop useful equations to

estimate the training load.
A cell load (range from - 10000 N to 10000 N; sensitivity ≈–4 pC/N; linearity ≤ ±0.5% FSO) and a force platform (range from 0 N to 10000 N; linearity < ±0.5% FSO) were used to evaluate the load distribution between upper and lower limbs, respectively, while a motion analysis software was used to calculate the body inclination angle. A two-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 flex (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, while length of ST device, BMI, BMI2 and elbow position (elbow in extension = 0; elbow in flexion = 1) as 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.
Subjects
Twenty five (17 male and 8 female) physically active (engaging in at least 3-day/week of moderate-to-intense physical activity) college students (Sport Science Major) gave their written consent of participation after receiving both written and oral information regarding testing procedures. Subjects were included in the study (carried out from May to June 2015) if reporting ST experience (at least 1 session weekly for the previous year), and they were excluded if reporting any pre-existing condition such as musculoskeletal disorders or physical injury. The study was approved by the local Institutional Review Board, 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.

Question 3: What is the training background coming into the study and what time of year etc were they tested.
Answer: As required, we provided more information regarding the participants in the study, as follows:

Subjects
Twenty five (17 male and 8 female) physically active (engaging in at least 3-day/week of moderate-to-intense physical activity) college students (Sport Science Major) gave their written consent of participation after receiving both written and oral information regarding testing procedures. Subjects were included in the study (carried out from May to June 2015) if reporting ST experience (at least 1 session weekly for the previous year), and they were excluded if reporting any pre-existing condition such as musculoskeletal disorders or physical injury. The study was approved by the local Institutional Review Board, 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.

Question 4: The practical application should be relevant to the coach, make sure in any revision allowed you do not call for more research in this section. What should the coach or practitioner now do after reading your paper, does it affect practice is the key factor in this section, check it over.
Answer: As required, we checked and improved the practical applications, as follows:

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 ST device are modified. In particular, when the length of 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 flex elbows compared to 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 weight of 80 kg and a height of 180 cm (consequently with a BMI of 24.7 kg·m-2) trains with a ST device length of 180 cm, by applying the predicted equations (Loadextension = 179.8692 - 0.3329871·180 - 3.014736·24.7 + 0.0581454·24.72), it is possible to estimate that he/she will receive a load corresponding to 80.9% of his/her body weight on lower limbs during the extension, while he/she will receive a load corresponding to 63.0% of his/her body weight during the flexion (Loadflexion = 179.8692 - 0.3329871·180 - 3.014736·24.7 + 0.0581454·24.72 - 17.94356). Therefore, with a 180 cm length of ST device, this subject will perform a 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% body weight), he/she will need to adjust the ST device to 197.8 cm, as the result of the equation: Lengthextension = (75 - 179.8692 + 3.014736·24.7 - 0.0581454·24.72)/ - 0.3329871. Consequently, being equal the length of the straps, he/she will receive a 45.7 kg load with elbow in flexion (Loadflexion = 75 - 17.94356 = 57.1% body weight). Finally, to receive a maximum load of 60 kg, the same subject needs to adjust the straps at a 197.8 length, with the minimum load during exercise with flex 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.

Question 5: Check JSCR literature base for related papers for connection for this line of research in the journal.
Answer: As requested we checked JSCR related literature. As we implemented the introduction, the methods and the practical applications, we included the following new references:

3. American College of Sports Medicine. Position stand: progression models in resistance training for healthy adults. Med Sci Sports Exerc 41(3): 687-708, 2009.
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(6): 1626-1635, 2014.
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(6): 1673-1679, 2011.
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.

Corresponding author
Cristina Cortis, PhD
Via S. Angelo - Località Folcara
03043 Cassino (FR)
Tel: +39 0776 299 4436
Fax: +39 0776 299 3839
e-mail: c.cortis@unicas.it

Prof. Dr William J Kraemer
Journal of Strength and Conditioning Research

Cassino, Italy, February 16th 2017

Dear Prof. Dr. Kraemer,

It is our pleasure to submit for publication in the Journal of Strength and Conditioning Research our paper “Biomechanical analysis of suspension training push-up”. This manuscript contains material that is original and not previously published in text or on the Internet, nor is it being considered elsewhere until a decision is made as to its acceptability by the Journal of Strength and Conditioning Research Editorial Review Board. The undersigned Authors transfer the ownership of copyright to Journal of Strength and Conditioning Research should their work be published in this journal. Each of the authors has read and concurs with the content in the final manuscript. The material within has not been and will not be submitted for publication elsewhere except as an abstract. They state that they were fully involved in the study that they have designed and carried out; that they have participated in drafting and revising the manuscript submitted, which they approve in its contents; that they have no conflicts of interest and relevant financial interests related to the research. They also state that the research reported in the paper was undertaken in compliance with the Helsinki Declaration and the International Principles governing research on humans.

Best regards,

Cristina Cortis, PhD

Biomechanical Analysis of Suspension Training Push-up

Giancotti Giuseppe Francesco[1], Fusco Andrea[1], Varalda Carlo[2], Capranica Laura[3], Cortis Cristina[1]

[1]*Department of Human Sciences, Society and Health, University of Cassino e Lazio Meridionale, Italy*

[2]*Italian Weightlifting Federation FIPE, Rome, Italy*

[3]*Department of Movement, Human and Health Sciences, University of Rome Foro Italico, Italy*

Corresponding author

Cristina Cortis, PhD

Via S. Angelo - Località Folcara

03043 Cassino (FR), Italy

Tel: +39 0776 299 4436

Fax: +39 0776 299 3839

e-mail: c.cortis@unicas.it

Running head: Suspension training push-up

Laboratory: Sport and Exercise Physiology "Marco Marchetti", Department of Human Sciences, Society and Health, University of Cassino e Lazio Meridionale, Italy

No funds were received for this work received from any of the following organizations: National Institutes of Health (NIH); Wellcome Trust; Howard Hughes Medical Institute (HHMI); and other(s).

Biomechanical Analysis of Suspension Training Push-up

ABSTRACT

The aims of this study were to evaluate the load distribution between upper and lower extremities during suspension training (ST) push-up at different length of ST device and to predict useful equations to estimate the training load. After giving their informed consent of participation, twenty-five subjects (male=17, female=8; age=28.1±5.2years; weight=69.4±14.3kg; height=171.6±11.3cm; BMI=23.4±3.3kg·m^{-2}) were involved in the study. Each subject performed 14 static push-ups at 7 different lengths of ST device in two 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 multi-level model regression ($P<0.05$) was used. Results showed that when the length of ST device increased, the body inclination decreased, while the ground reaction force decreased and the load on the ST device increased. Moreover, when subjects moved from extended to flex elbow, the ground reaction force decreased and the load on the ST device increased. In the created regression model (ICC=0.24), the reaction force was the dependent variable, while length of 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.

INTRODUCTION

Body weight training is a popular form of resistance training become in the last years an inexpensive way to exercise effectively (23). Among those activities, Suspension Training (ST) promotes bodyweight in multi-directional movements as a form of exercise, by using two independently moving handles suspended by two straps with a fixed anchor position above the exerciser (1, 13).

The ST concept is based on three 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 claimed to be utilized 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 with the use of the Redcord slings ST device) with respect to open-kinetic-chain ones, ST has been showed 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 and colleagues (20) evaluated metabolic and cardiovascular response of a 9-min high-intensity interval training using a ST device. Results showed an average exercise intensity of 83% of maximal heart rate (HRmax) and 56% of maximal oxygen consumption (VO_2max), with an energy expenditure (EE) of 97 kcal during the training session (corresponding about to 650 kcal·hr^{-1}). Evaluating the metabolic and cardiovascular responses during and after (two 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 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 elicit 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, when comparing electromyography activity of rectus abdominis during traditional push-up, ST push-up and crunch, Snarr and colleagues (21) showed that ST push-up elicit higher activation with respect to traditional one and similar activation to crunch. De Mey and colleagues (10) compared half push-up, knee push-up, knee prone bridging plus, and pull-up performed with and without a 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 those factors.

Until now only few studies investigated biomechanical characteristics of ST. In particular, the loads on the ST device and ground reaction force during push-up at four 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 ST device during ST back-row at four different body inclinations (30°, 45°, 60° and 75° with respect to the vertical position) and six 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 four equations to estimate the load on the straps at the four measured angles. Although they used different methods of angle measurement and exercises, both studies highlighted that the load on the ST device increase when the body inclination from the floor decrease (12, 16).

However, measuring the angles during ST exercise could not always be feasible, and to the best of our knowledge no study investigated the effect of 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 fix the feet position.

Therefore, the aims of this study were: i) to evaluate the loads on the straps and ground force reaction during ST push-up at different length of ST device and ii) 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) due to several biomechanical aspects, such as the body inclination, the length of ST device, the feet position and the combination of those factors (12, 16). Although these parameters could affect 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 length of ST device and elbow position (flex and extended) and to develop useful equations to estimate the training load.

A cell load (range from - 10000 N to 10000 N; sensitivity ≈–4 pC/N; linearity ≤ ±0.5% FSO) and a force platform (range from 0 N to 10000 N; linearity < ±0.5% FSO) were used to evaluate the load distribution between upper and lower limbs, respectively, while a motion analysis software was used to calculate the body inclination angle. A two-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 flex (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, while length of ST device, BMI, BMI^2 and elbow position (elbow in extension = 0; elbow in flexion = 1) as 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.

Subjects

Twenty five (17 male and 8 female) physically active (engaging in at least 3-day/week of moderate-to-intense physical activity) college students (Sport Science Major) gave their written consent of participation after receiving both written and oral information regarding testing procedures. Subjects were included in the study (carried out from May to June 2015) if reporting ST experience (at least 1 session weekly for the previous year), and they were excluded if reporting any pre-existing condition such as musculoskeletal disorders or physical injury. The study was approved by the local Institutional Review Board, 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.

Insert Table 1 about here

Procedures

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

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

Insert Figure 1 and 2 about here

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, Oregon, 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 with the horizontal line of the xiphoid process. All trials were recorded by 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 three visual markers were aligned) with respect to the horizontal surface.

Statistical Analysis

Microsoft Excel 2010 (Microsoft Corporation, Redmond, Washington, USA) and Stata statistical software version 14.1 (StataCorp, College Station, Texas, USA) were used for statistical analysis. Means and standard deviations for all descriptive characteristics of the subjects were calculated, while mean value for all data recorded by force plate and cell load was calculated and then normalized in relation to body weight using the following formula:

Load (%Body weight) = Load (kg) · Body weight^{-1} · 100.

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

A multi-level model regression (or hierarchical linear model, 17) was carried out 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.

RESULTS

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

Insert Table 2 about here

Insert Figure 3 about here

Ground reaction forces and loads applied on the ST device in relation to the position are showed in Figure 4 and 5, respectively. When the length of ST straps increased, the ground reaction force decreased, while the load on the ST device increased. Moreover, higher values on the force plate were recorded with extended elbow with respect to flex elbow and, vice versa, lower values on the load cell were recorded with extended elbow compare to flex elbow.

Insert Figure 4 and 5 about here

The multi-level model regression analysis (Table 3) produced the ground force reaction (dependent variable) prediction equations using the length of ST device, BMI, BMI^2 and the elbow position (elbow in extension = 0; elbow in flexion = 1). Significant effects ($P<0.05$) 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 force reaction:

$$Load = 179.8692 - 0.3329871 \cdot Length - 3.014736 \cdot BMI + 0.0581454 \cdot BMI^2 - 17.94356 \cdot Elbow\ position$$

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

$$Length = (Load_{extension} - 179.8692 + 3.014736 \cdot BMI - 0.0581454 \cdot BMI^2) / - 0.3329871$$

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

$$Load_{flexion} = Load_{extension} - 17.94356$$

Insert Table 3 about here

DISCUSSION

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

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

To the best of our knowledge, no studies investigated variation in load distribution as the length of 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, while the load on the force platform reduced. Furthermore, being the length of the straps 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 ST device in vertical position.

One of the main problems during ST exercise is the quantification of load distribution between upper and lower limbs. Recently, four formulas to estimate the traction load on the straps in four 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 carried out to evaluate the significance of the predicted formulas.

In the present 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 force reaction, dependent variable) depends on differences among individuals, while 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 opposite formula the length of ST device can be calculated to be able to train with the known load, with the elbow in an extended position. Considering that during ST push-up the length of the straps stay equal, it is possible to evaluate the ground reaction force with flex elbows. In particular, moving from extend to flex elbow position, the ground reaction force decrease of 17.9% of body weight.

Some limitations should be acknowledged for this study. ST push-up was evaluated in static position. Nevertheless, evaluating push-up with extended and flex elbow, equations to estimate minimum and maximum load during exercise have been predicted. ST push-up was only evaluated with the feet positioned under anchored point. Probably, moving feet position and being equal the length 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 position 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 ST device are modified. In particular, when the length of 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 flex elbows compared to 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 weight of 80 kg and a height of 180 cm (consequently with a BMI of 24.7 kg·m^{-2}) trains with a ST device length of 180 cm, by applying the predicted equations ($Load_{extension}$ = 179.8692 - 0.3329871·180 - 3.014736·24.7 + 0.0581454·24.7^2), it is possible to estimate that he/she will receive a load corresponding to 80.9% of his/her body weight on lower limbs during the extension, while he/she will receive a load corresponding to 63.0% of his/her body weight during the flexion ($Load_{flexion}$ = 179.8692 - 0.3329871·180 - 3.014736·24.7 + 0.0581454·24.7^2 - 17.94356). Therefore, with a 180 cm length of ST device, this subject will perform a 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% body weight), he/she will need to adjust the ST device to 197.8 cm, as the result of the equation: $Length_{extension}$ = (75 - 179.8692 + 3.014736·24.7 - 0.0581454·24.7^2)/ - 0.3329871. Consequently, being equal the length of the straps, he/she will receive a 45.7 kg load with elbow in flexion ($Load_{flexion}$ = 75 - 17.94356 = 57.1% body weight). Finally, to receive a maximum load of 60 kg, the same subject needs to adjust the straps at a 197.8 length, with the minimum load during exercise with flex 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.

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 edition).* 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(3): 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(3): 457-472, 2008.
5. Bettendorf, B. TRX suspension training bodyweight exercises: scientific foundations and practical applications. San Francisco: *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(11): 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/Diferencas na ativacao muscular entre a realizacao de flexoes com apoio fixo e com um sistema de suspensao unilateral em forma de v em diferentes alturas. *Motricidade* 10(4): 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(3): 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(6): 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(2): 65-72, 2015.

12. Gulmez, I. Effects of angle variations in suspension push-up exercise. *J Strength Cond Res* 31(4): 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(6): 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(1): 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 edition).* Shelton: 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(1): 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 Human Perf* 2(3): 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(3): 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(12): 3436-3442, 2016.

23. Thompson, WR. Worldwide survey of fitness trends for 2017. *ACSM's Health Fit J* 20(6): 8-17, 2016.

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.

Figures legend

Figure 1. Push-up at different length of the Suspension Training device.

Figure 2. Suspension Training push-up with extended and flex elbow positions.

Figure 3. Box plot of body inclination in relation to length of Suspension Training (ST) device during push-up with extended and flex elbow positions.

Figure 4. Box plot of ground reaction force in relation to length of Suspension Training (ST) device during push-up with extended and flex elbow positions.

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

Tables legend

Table 1. Means and standard deviations of subject descriptive characteristics.

BMI = Body Mass Index.

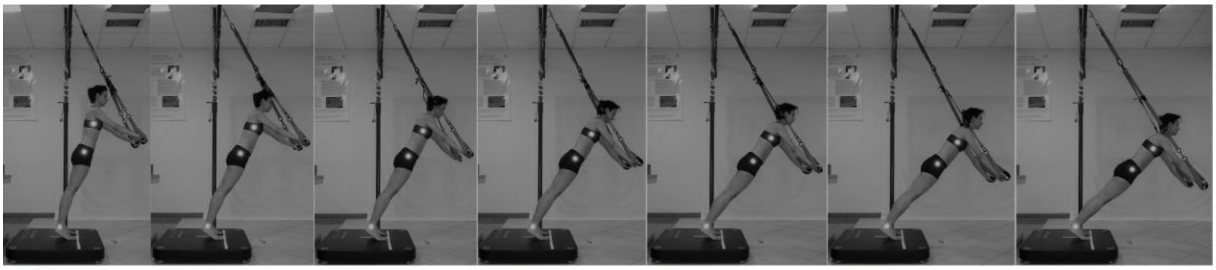
Table 2. Means and standard deviations of body inclination angles, ground reaction force and load on the Suspension Training (ST) device expressed as percentage of the total load at different length of ST device.

Table 3. Multi-level model regression between dependent variable (load on the force plate normalized in relation to body mass) and independent variables (length of Suspension Training device in cm, BMI, BMI^2 and elbow position).

BMI=Body Mass Index; Elbow=elbow position (elbow in extension = 0; elbow in flexion = 1); _cons=intercept; coef.=coefficient; SE=standard errors; CI=Confidence Interval.

Figure 1

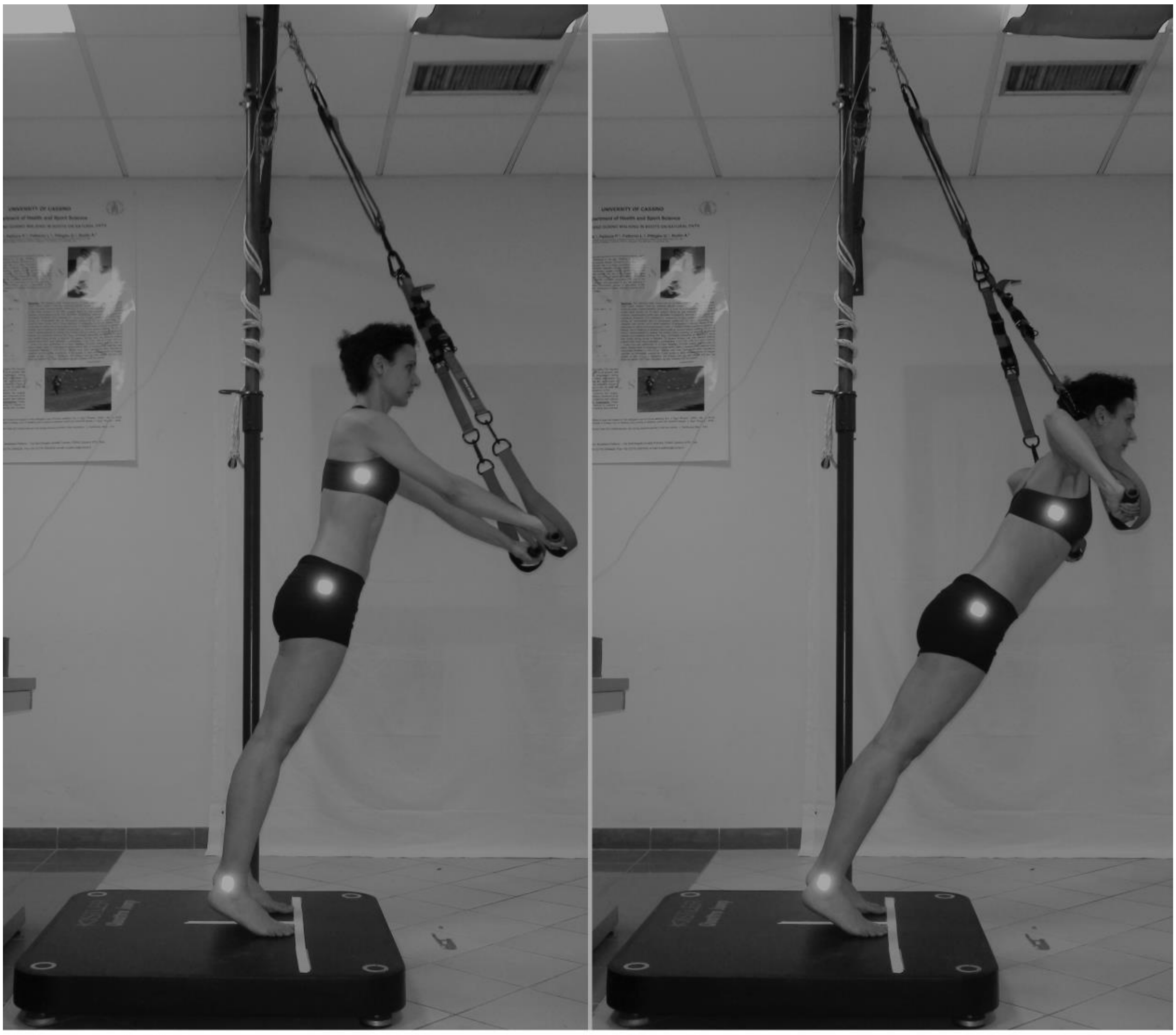
Figure 1. Push-up at different length of Suspension Training device.



178 cm 188 cm 198 cm 208 cm 218 cm 228 cm 238 cm

Figure 2

Figure 2. Suspension Training push-up at different elbow positions.



Extended elbow Flex elbow

Figure 3

Figure 3. Box plot of body inclination in relation to length of Suspension Training (ST) device during push-up with extended and flex elbow positions.

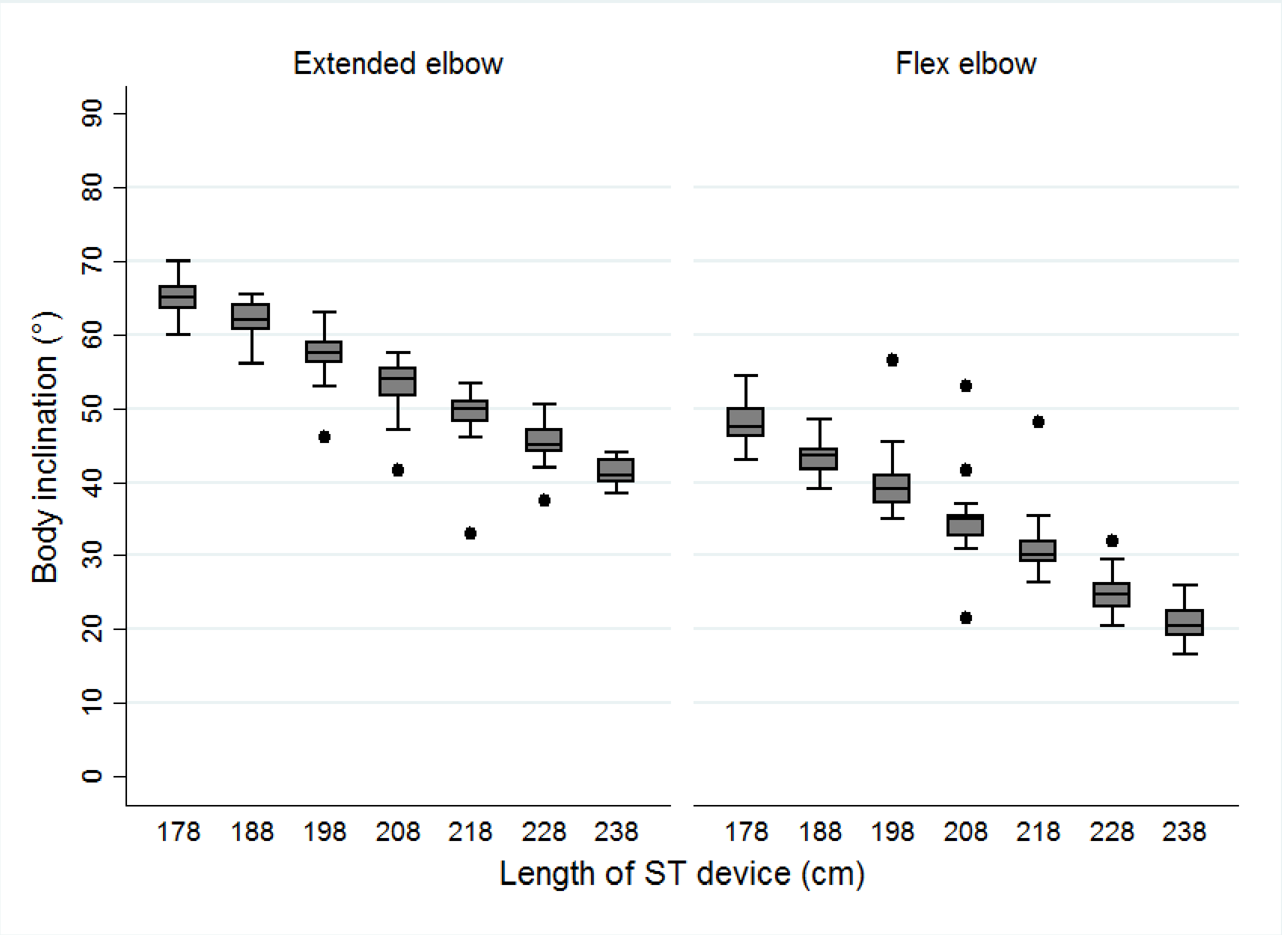


Figure 4. Box plot of ground reaction force in relation to length of Suspension Training (ST) device during push-up with extended and flex elbow positions.

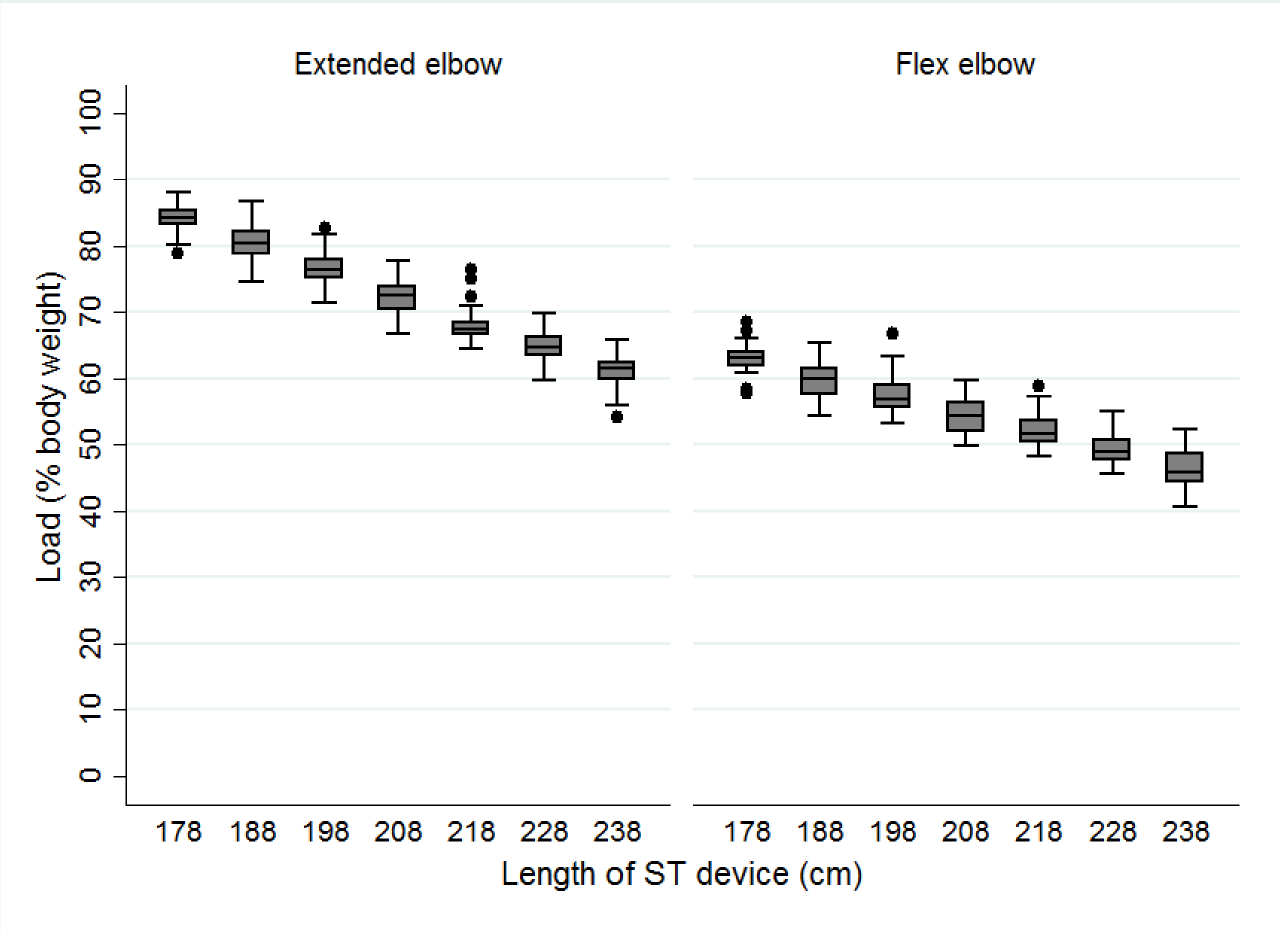


Figure 5

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

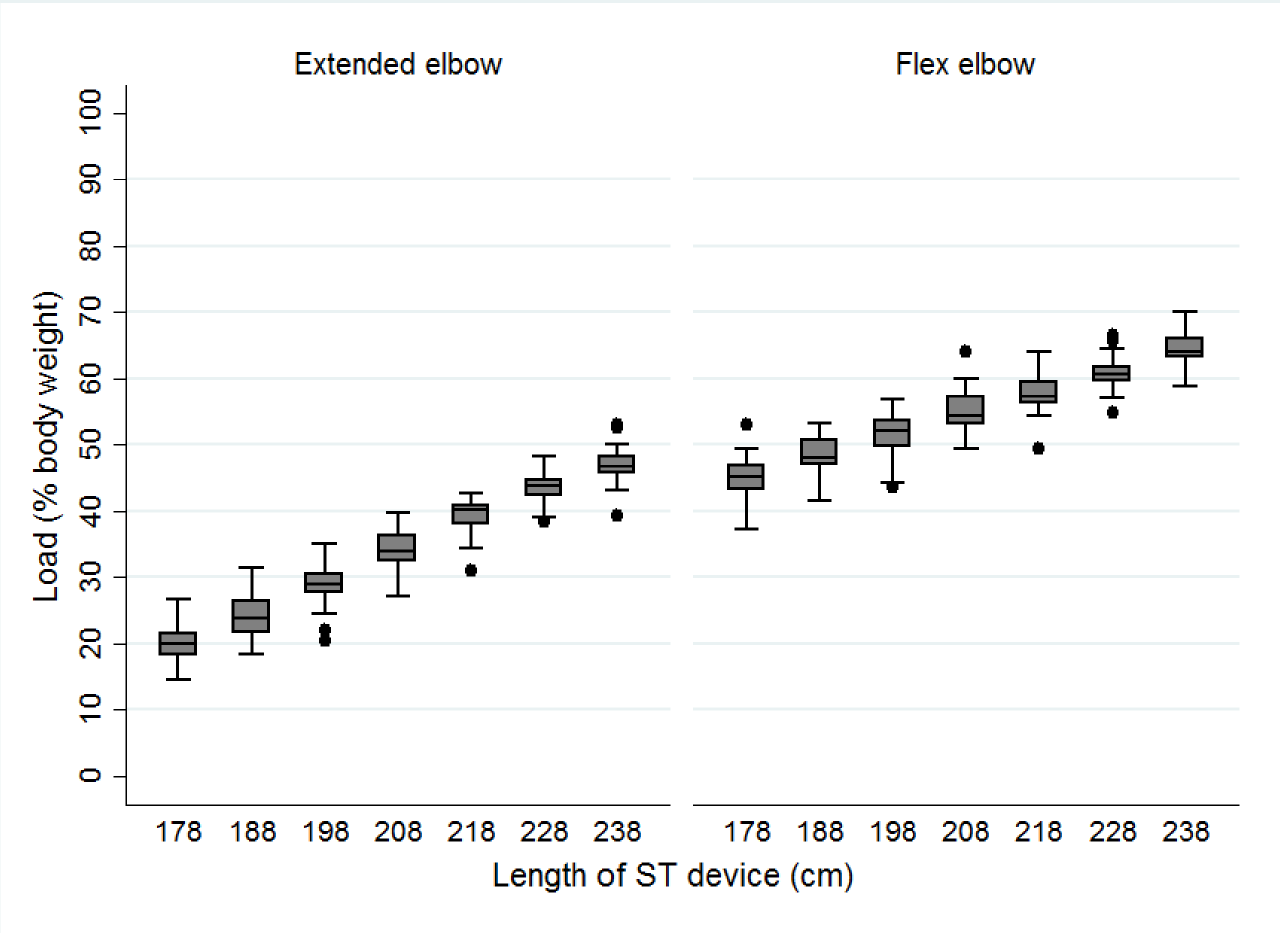


Table 1. Means and standard deviations of subject descriptive characteristics.

BMI = Body Mass Index.

	Total (n=25)	Female (n=8)	Male (n=17)
Age (Years)	28.1±5.2	27.3±6.6	28.5±4.5
Weight (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

Table 2

Table 2. Means and standard deviations of body inclination angles, ground reaction force and load on the Suspension Training (ST) device expressed as percentage of the total load at different length of ST device.

	Extended elbow			Flex 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

Table 3. Multi-level model regression between dependent variable (load on the force plate normalized in relation to body mass) and independent variables (length of Suspension Training device in cm, BMI, BMI^2 and elbow position).

BMI=Body Mass Index; Elbow=elbow position (elbow in extension = 0; elbow in flexion = 1); _cons=intercept; coef.=coefficient; SE=standard errors; CI=Confidence Interval.

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