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Pulling Exercises for Strength Training and Rehabilitation: Movements and Loading Conditions

Silvio Lorenzetti [1,2,*], Romain Dayer [1], Michael Plüss [1] and Renate List [1]

[1] Institute for Biomechanics, ETH Zürich, 8049 Zürich, Switzerland; rodayer@student.ethz.ch (R.D.); pluessm@ethz.ch (M.P.); rlist@ethz.ch (R.L.)
[2] Leopold-Ruzicka-Weg 4, 8093 Zürich, Switzerland
* Correspondence: slorenzetti@ethz.ch; Tel.: +41-44-633-61-95; Fax: +41-44-633-11-24

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Abstract: The back is an extremely common site of injury among both athletes and sedentary people. Furthermore, low back pain has become prevalent in our society. Maintaining strong back muscles can help prevent future pain or injuries. Here, the aim is therefore to assess the kinetic and kinematic movements of four pulling exercises with different external loading directions. Fifteen healthy subjects were analyzed using a 3D motion capture system. The pulley machine was equipped with a load cell for force data acquisition. The exercises consisted of 8 repetitions each of the lat pulldown (25% and 50% body weight (BW) extra load), the lat pulldown with 45° incline (10% and 25% BW), the seated cable row (25% and 50% BW) and the upright row (standing, 10% and 25% BW). The minimum and maximum curvature angle in the thoracic as well as the lumbar spine was larger during the upright row than during the other exercises. Furthermore, during the upright row, the sagittal moment in the shoulder joint is opposed to the other exercises in the direction of retroversion. Due to the higher lumbar curvature observed in low back patients, to avoid overload, it is not advisable for patients with back pain to perform upright rows.

Keywords: inverse dynamics; movement analysis; load condition; resistance training; back kinematics

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1. Introduction

Low back pain is arguably one of the most common health problems in the general population, and has been extensively studied in the past few decades [1,2]. Even though low back pain is not a life-threatening disorder, it remains a major health issue in all age groups. It has led to excessive medical expenditures that continue to increase with an aging population [3]. Moreover, low back pain patients are usually limited in their ability to work, which leads to extensive associated social costs [4–6]. As an example, a study in Switzerland found that the direct costs of low back pain totaled €2.6 billion, and the total expenditure represented 1.6% to 2.3% of the Gross Domenic Product [7].

More specifically, chronic low back pain represents the most debilitating condition and a leading cause of disability among the active population [8]. It is categorized as chronic pain when it affects one's quality of life over a period of at least three months. Although studies have shown that low back pain patients still have a good prognosis with conservative management, recurrence is very common [9], and it takes a substantial amount of time to recover completely [10]. However, numerous patients choose to undergo surgery for long-term pain relief [11]. Moreover, studies have reported higher depression and anxiety rates among this cohort [12]. As a result, the recovery process can become more challenging and lengthy.

With a lifetime prevalence of 80%, most people will eventually suffer from back pain [11,13]. Men and women are equally affected, and it has been shown that various factors may contribute to this condition. Low back pain is generally associated with damage to anatomical structures of the back, which can develop over time or result from acute overload. Frequently, muscle strain, ligament or intervertebral disc damage are the underlying causes. Additional factors have been linked to low back pain including age, obesity, low educational attainment or psychological disorders [11]. As outlined above, the onset of the pain is not always sudden, and it is thus difficult to identify the actual cause [14].

In most cases, trunk muscle imbalance is associated with a higher risk of developing back pain [15]. A weak core is unable to protect the spine and the surrounding structures from mechanical stress [16,17]. Developing proper posture and spinal alignment or maintaining mobility during episodes of back pain is critical to stimulating the recovery process. Additionally, a stronger back can moderately enhance power and speed, which can subsequently benefit recreational athletes in all types of activities [18–20].

Within this framework, it is clear that the population should strive to maintain a healthy and functional trunk. The conscientious practice of strength exercises for the back and abdominal muscles is not only important to alleviate acute back pain but also to minimize the incidence of recurrence. To this effect, all muscle groups in the trunk have to be trained, focusing on the interplay of antagonist as well as synergistic muscles. For this, pulling exercises using a cable machine in either a seated or standing position are commonly performed exercises.

However, it is essential to perform these moves cautiously as otherwise there is a risk of increasing the injury rate. This is of major concern to the medical community, because there is evidence that proper execution of the exercises is constantly overlooked by recreational athletes [21]. It has been established that, after the shoulders, the back is the second most common site of injury in fitness centers, which is mainly due to major overload or improper execution [22]. The loading and motion of the trunk is already known for classic exercises for the back such as deadlifts, good mornings [23] and back extensions [24]. However, it is firmly believed that variation is key in strength training or injury prevention, and it is therefore best to investigate a variety of complementary exercises.

To our knowledge, analyses of pulley exercises for the back have mainly focused on maximal power output or electromyographic (EMG) activity [25–28]. For instance, the global muscle contraction under the different activity stimuli was studied, and it was revealed that all selected exercises activate the latissimus dorsi and trapezius, but to varying degrees [29]. The cable row was found to involve the highest latissimus dorsi activity, whereas the upright row would trigger high firing activity in the upper trapezius [29]. Additionally, the kinetics and kinematics of the seated row in elite athletes was described but only included limited biomechanical associations [30]. A detailed analysis of the trunk motion and loading during different pulling exercises is lacking.

Therefore, the present study focuses on a group of complementary pulling exercises as follows: the latissimus (lat) pulldown, the 45° lat pulldown, the seated cable row and the upright row (Figures A1–A4). The aim is to quantify and compare the motion as well as the maximum external joint moments in the shoulder joint in all anatomical planes as well as on the range of motion of the spine during these exercises.

2. Methods

2.1. Subjects

A total of eight males and seven females were recruited for this study (aged 23 ± 2 years, mass 67.9 ± 11.3 kg, height 176 ± 9 cm). The inclusion criteria were as follows: aged 18–45 years, physically active (>3 h/week), and familiar with the selected exercises. Candidates were excluded if they were injured, sick or under medical treatment at the time of the experiment. Participants were asked to wear athletic shorts. Women were additionally required to wear a bikini top. The study was approved by the Ethics Committee of ETH Zürich (EK 2016-N-78), and prior to the study, all participants gave written informed consent.

2.2. Measurement Procedures

All measurements were performed using a Technogym Ercolina Rehab adjustable cable pulley station (Isotonic Line, Technogym Ltd., Cesena, Italy) in the Motion Analysis Laboratory at ETH Zürich. To define the joint centers for the skin marker model, the subjects first performed standardized basic motion tasks (BMT) [31]. After a specific five-minute warm-up session using warm up sets of the exercises, each subject received standard instructions and performed two sets of eight repetitions for the four selected pulling exercises: the lat pulldown (LP), the lat pulldown with 45° incline (45LP), the seated cable row (SR) and the upright row (UR). The UR was performed in a standing position, whereas the other exercises were performed seated.

For the SR and LP, the first set was performed with a load equal to 25% of the subject's bodyweight (BW), and the second set was performed with a load equal to 50% of the subject's BW. For the LP45 and the UR, the load was 10% BW for the first set and 25% BW for the second set. A break of 1–2 min was allowed between each set and each exercise to avoid undesired effects of fatigue.

2.3. Data Acquisition

To capture the kinematics, an opto-electronic motion capture system (Vicon, Oxford Metrics Group, Oxford, UK) was used. This system relies on 22 infrared cameras that operate at a frequency of 100 Hz. The skin markers were placed with double-sided skin-friendly tape according to List et al. [31]; 55 markers from the basic set were located on the legs, arms and trunk, and 22 markers were placed on the back (Figure A5). The markers were very light in weight and did not modify the subject's normal range of motion or influence the movements.

To generate kinetic data, a 1-kN load cell operating at 2000 Hz (SM-1000N, Interface Inc., Arizona, AZ, USA) was placed in series between the handle and the cable. Additionally, markers were distributed along the cable during the exercises to determine the precise direction of the force. This complete procedure permits comprehensive data collection for the ensuing inverse dynamics evaluation.

2.4. Data Processing and Analysis

All the kinematic data was reconstructed using Nexus (2.4, Vicon Motion Systems, Oxford Metrics Groups, Oxford, UK) and further analyzed using Matlab (MathWorks, USA, 2012a and 2015a). The kinetic data was integrated in the Matlab evaluation, and the joint moments were calculated using a quasi-static inverse dynamic approach [32,33].

Each exercise was divided into eight different cycles corresponding to the eight repetitions. The start point of each sequence was defined as the position with the shortest muscle length. Consequently, each cycle first contained an eccentric phase followed by a concentric phase. For all calculations, the average value over the eight repetitions of each individual subject was used and time-normalized.

Segments of the trunk were defined based on redundant marker clouds and corresponding relative angles were calculated. The shoulder joint was defined according to Rab [34]. Following that, the means and standard deviation (SD) were computed for the range of motion (ROM) of the shoulder joint. The ROM was defined as the difference between the smallest and largest inter-segmental angles. The standing trial was used as a basis to compute the relative positions of the two segments. For the spine, a segmental [31] and curvature approach [31,35,36] was used, and the curvature angle [37] was calculated.

Additionally, using an inverse dynamics approach, the maximum joint moments in the shoulder were calculated for the three anatomical planes and were normalized to the participant's BW. Since only a central load cell registers kinetic data, the force was assumed to be evenly split between both shoulders, and the mean value of both shoulder joint moments was then used for further calculation. Positive values indicated flexion, adduction or internal rotation moments.

The differences in the angles of curvature were statistically investigated for the four selected exercises. For the statistical testing independent samples *t*-tests and analyses of variance (one-way ANOVA [38]) with Bonferroni correction were used. These tests require normal distribution and homogeneity of variances of the data. This was tested using a Kolmogorow-Smirnow test. The significance level was set at $p < 0.05$. In order to analyze the reliability, the ICC(3,k) values were used. We assumed 0.75–0.9 as "good reliability" and values above 0.9 as "excellent reliability" [39]. All statistical analyses were performed using IBM SPSS software (Zürich, Switzerland, version 23).

3. Results

3.1. Kinematics

The ROM of the curvature angles of the thoracic spine and the lumbar spine was the same for all exercises (Tables 1 and A2). The reliability of the minimal, maximal and ROM of the curvature was "excellent" in 45 cases and "good" in 3 cases (Table A8). Furthermore, the additional extra weight did not influence the curvature angles. The minimum and maximum curvature angles in the thoracic spine and the lumbar spine were larger during UR compared to LP, 45LP and SR. In the thoracic region, the data indicated that the angle of curvature reached its peak at the end of the eccentric muscle contraction (Figure 1).

Table 1. Maximum, minimum and ROM of the curvature angles in the thoracic and lumbar regions, mean and standard deviation over all subjects.

Curvature Angle		Lat Pulldown		45° Lat Pulldown		Seated Cable Row		Upright Row	
		25% BW	50% BW	10% BW	25% BW	25% BW	50% BW	10% BW	25% BW
Max Curvature Angle, (°)	Thoracic	24.8 ± 9.1	27.6 ± 10.7	27.5 ± 9.4	26.0 ± 9.4	26.4 ± 10.6	31.5 ± 7.9	37.1 *,+,† ± 8.4	37.1 *,+,† ± 9.4
	Lumbar	16.1 ± 7.9	15.9 ± 6.8	15.8 ± 9.7	15.0 ± 8.4	12.0 ± 7.2	11.6 ± 6.5	30.7 *,+,† ± 7.6	31.1 *,+,† ± 8.0
Min Curvature Angle, (°)	Thoracic	18.1 ± 10.0	18.3 ± 10.4	18.2 ± 10.4	17.6 ± 11.0	19.4 ± 11.1	23.8 ± 9.1	27.9 *,+,† ± 8.9	28.4 *,+,† ± 9.7
	Lumbar	9.7 ± 7.3	8.9 ± 7.2	9.4 ± 8.6	8.7 ± 7.3	7.2 ± 7.4	5.3 ± 6.6	25.1 *,+,† ± 6.7	23.9 *,+,† ± 6.6
ROM Curvature Angle, (°)	Thoracic	6.7 ± 3.0	9.3 ± 2.2	9.3 ± 3.9	8.5 ± 3.8	7.1 ± 2.8	7.7 ± 2.6	9.2 ± 2.7	8.8 ± 2.7
	Lumbar	6.4 ± 2.2	7.0 ± 2.0	6.3 ± 2.6	6.3 ± 2.5	4.8 ± 2.1	6.4 ± 2.8	5.6 ± 3.0	7.2 ± 3.9

*: significantly different from LP; †: significantly different from SR; +: significantly different from LP45.

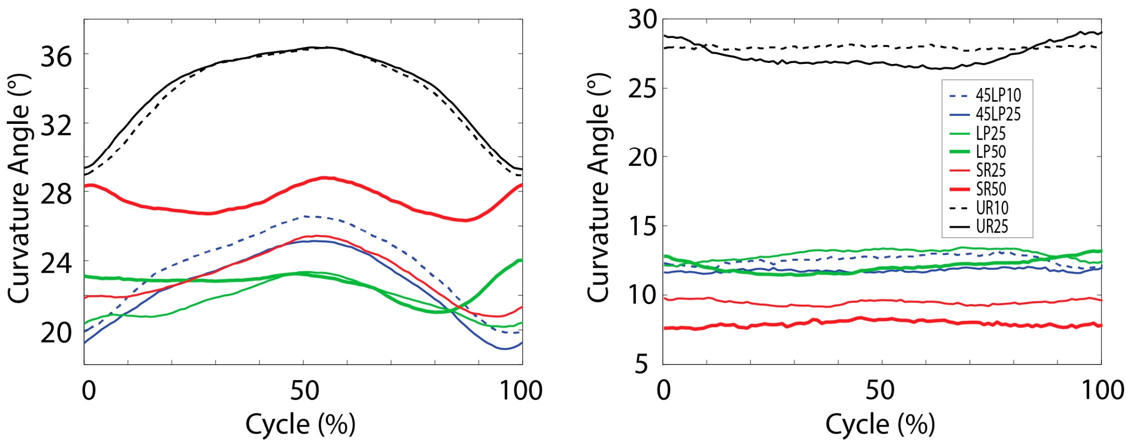

Figure 1. Mean curvature angle in the thoracic (**left**) and lumbar (**right**) region over one cycle averaged for all subjects.

For all exercises, rotation in the shoulder joint was primarily observed in the sagittal plane. The 45 LP yielded a greater sagittal ROM than all other exercises (Table A1). The UR exhibited the greatest ROM in the frontal plane and the least ROM in the transverse plane. Overall, the loading conditions did not have a significant impact on the ROM of the shoulder joint. The *p*-values and (χ^2) are presented in Table A3.

3.2. Kinetics

The maximum moments in the shoulder joint in the three anatomical planes are detailed in Table 2. Significant differences in the peak joint moments were found in the majority of cases. The SRs exhibited the highest moments in the sagittal plane. In the frontal plane, the traditional LP was the only exercise to provoke large moments (Table 2).

Table 2. The means and standard deviation over all subjects of the normalized maximum moments in the shoulder joint in the three anatomical planes.

Shoulder Joint Moment		Lat Pulldown		45° Lat Pulldown		Seated Cable Row		Upright Row	
		25% BW	50% BW	10% BW	25% BW	25% BW	50% BW	10% BW	25% BW
M_{max} Shoulder Joint [Nm/BW]	Sagittal	$0.28^{+,\P}$ ± 0.06	0.58 ± 0.11	$0.07^{\P}$ ± 0.02	$0.19^{*,\dagger,\P}$ ± 0.05	$0.34^{+,\P}$ ± 0.09	0.60 ± 0.11	-0.15^{+} ± 0.02	$-0.24^{*,+,\dagger}$ ± 0.04
	Frontal	$-0.32^{+,\dagger,\P}$ ± 0.02	$-0.64^{\dagger}$ ± 0.05	$-0.07^{\P}$ ± 0.02	$-0.25^{*,\dagger,\P}$ ± 0.03	$-0.03^{*,+,\P}$ ± 0.01	-0.06^{*} ± 0.02	0.07^{+} ± 0.02	$0.09^{*,+,\dagger}$ ± 0.03
	Transverse	$0.15^{+,\dagger,\P}$ ± 0.02	$0.26^{\dagger}$ ± 0.03	$0.13^{\P}$ ± 0.02	$0.27^{*,\dagger,\P}$ ± 0.02	$-0.11^{*,+,\P}$ ± 0.03	-0.22^{*} ± 0.05	-0.02^{+} ± 0.01	$-0.04^{*,+,\dagger}$ ± 0.01
	Absolute	$0.45^{\dagger\P}$ ± 0.04	$0.89^{\dagger}$ ± 0.08	$0.15^{\P}$ ± 0.02	$0.41^{\dagger,\P}$ ± 0.03	$0.34^{*,+,\P}$ ± 0.09	0.62^{*} ± 0.11	0.16^{+} ± 0.01	$0.25^{*,+,\dagger}$ ± 0.03

*: significantly different from LP; †: significantly different from SR; +: significantly different from 45LP; ¶: significantly different from UR.

The maximum total moments in the shoulder joint did not correlate directly with the extra load. The sagittal, frontal and transverse moments mainly differed significantly when comparing the different exercises using the same load. On the sagittal plane, where the largest moments were typically reported, the UR was the only movement that induced an extension moment (Table 2). In the transverse plane, the LP and 45LP generated an external rotation moment due to the larger-than-shoulder-width grip and the subsequent external shoulder rotation (Table 2).

The shoulder joint moments with respect to the shoulder joint angle are illustrated in Figures 2–4. Predominantly, a load increase led to an analogous amplification of the moment, namely, an upward shift in the moment curve. Remarkably, large differences between the concentric and eccentric phases could be observed in the three anatomical planes for all exercises (Figures 2–4). Except during URs, higher moments were achieved during the concentric loading phase. The *p*-values and (χ^2) are presented in the Tables A4–A7.

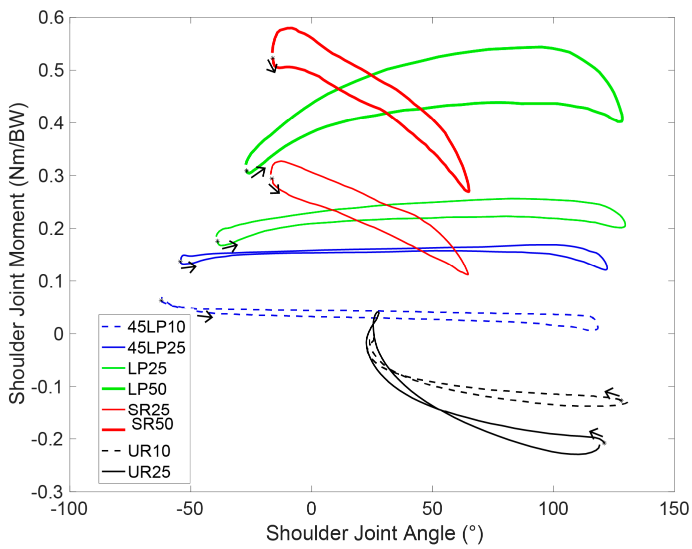

Figure 2. Normalized moments versus angles in the sagittal plane (flexion (+) and extension (−)) in the shoulder joint, averaged over all subjects.

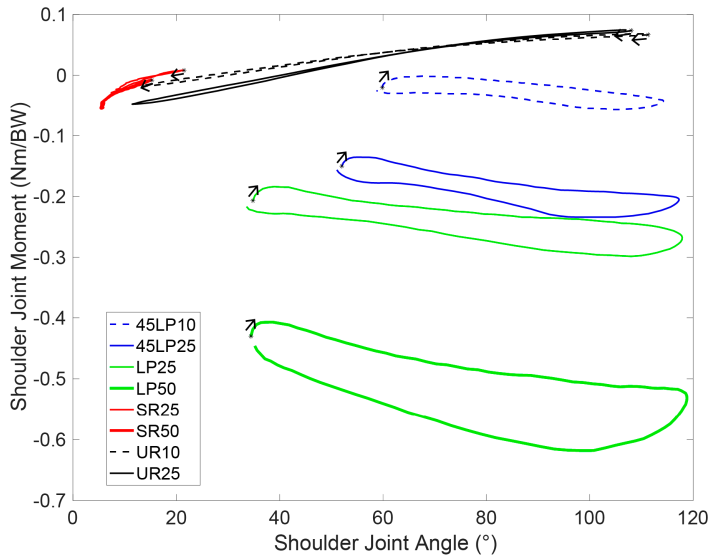

Figure 3. Normalized moments versus angles in the frontal plane (adduction (+) and abduction (−)) in the shoulder joint, averaged over all subjects.

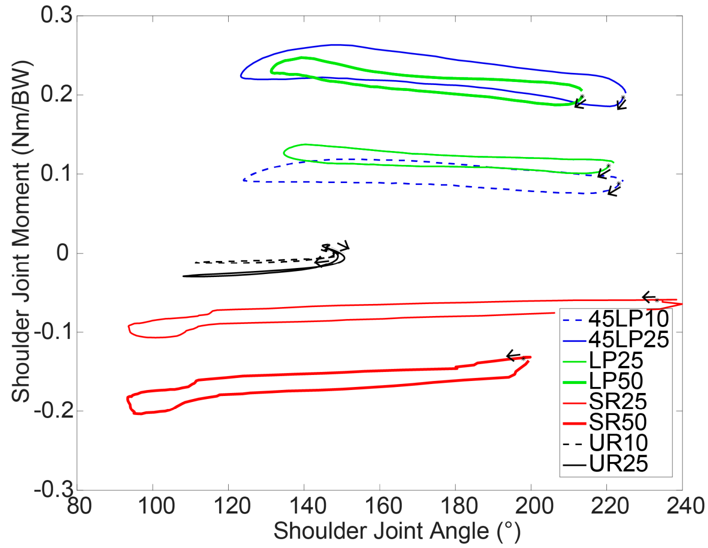

Figure 4. Normalized moments versus angles in the transverse plane (internal (+) and external (−) in the shoulder joint, averaged over all subjects.

4. Discussion

The loading conditions in the shoulder joint, as well as the movement of the trunk, during four different strength training exercises for the back were analyzed. The ROM of the curvature angle did not differ between the exercises. The maximal curvature and its corresponding angle are exercise-dependent, and may vary substantially. In this study, higher curvature angles during URs were attained in the lumbar and thoracic regions. It has been previously established that higher lumbar shear forces are related to a vast increase in the risk of injury [40]. Since strong erector muscles have been associated with lower shear forces [41], patients should ensure that these muscles are robust and stable enough before performing URs. Maintaining an appropriate lordotic curvature in the lumbar region will help reap the benefits of this exercise and lower the risk of injury. The standing position required for this exercise likely plays a crucial role in the increased curvature (Figure 1). Subjects who participate in these exercises should especially be careful during eccentric muscle contraction when the curvature angle reaches its peak (Figure 1). Recreational athletes tend to loosen tension in the core muscles during the eccentric phase and then rely on the passive resistance and weight of the upper limbs, which explains the higher trunk flexion.

Full range of motion has been associated with greater strength and muscle gains [42–44]. In this context, the LP and 45LP can be considered superior to the other exercises with regard to conditioning. From a biomechanical perspective, a complete ROM is also desirable because it helps target solely the region of interest and reduces the impact on other body parts. Regarding the ROM in the lower and upper back, no significant differences in ROM were observed among the exercises. The rotation between the lumbar and the thoracic segment was more pronounced in the sagittal plane; however, little inter-segmental motion was observed (mean < 10°).

On the three anatomical planes, the moments in the shoulder joint resulted in different directions depending on the movement (Figures 2–4). This implies different agonist muscles and, consequently, different loading patterns. Remarkably, no accurate load-dependency was exposed in the results, and significant differences were thus observed between most exercises. As an illustration, due to the constrained movement, SRs only exhibited consequential moments in the sagittal plane, Other exercises could not emulate the extension moments in the sagittal plane that were obtained during URs (Figure 2). Drawing conclusions from these data, it can be assumed that the four exercises can complement each other in this respect.

Doma et al. [25] reported similar ROM in the back during the LPs. The results of Schellenberg et al. [23] also confirmed our findings regarding the ROM in the thoracolumbar spine. Deadlifts and good mornings were investigated by these authors, and both studies exhibited similar results as observed in the present work, namely, an extra load did not significantly influence the ROM.

A limitation of this study is the substantial inter-subject variability for the shoulder moments and the spinal curvature. Therefore, the means have to be considered carefully. The intra-subject variability was typically smaller than the inter-subject variability.

The four selected exercises showed different loading patterns, and our data indicated that these exercises allow for a complete back workout and could assuredly be included in a lower back pain prevention program or a strength training workout routine. To the best of our knowledge, healthy subjects could benefit from a program that combines these different exercises and, consequently, train through a full range of motion in the three principal directions. However, depending on the aim of the workout (e.g., targeting a precise lumbar curvature or minimizing the loading in a particular part of the back), these exercises can also be selected individually. Due to the higher lumbar curvature observed during URs, lower back pain patients may be advised to not perform this exercise during phases of acute pain, and to perform the exercise carefully—and thus with a proper stabilization of the spine—in order to avoid higher loads.

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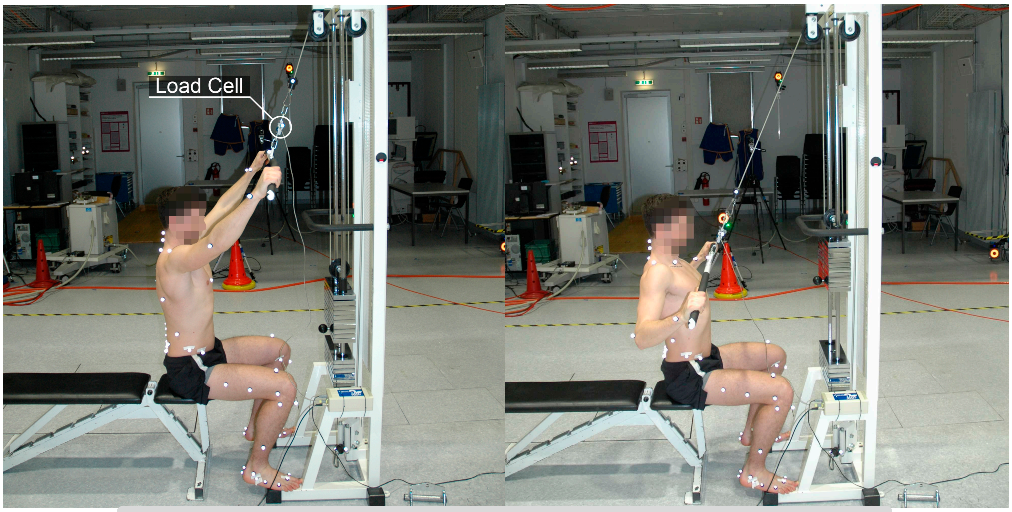
Author Contributions: Silvio Lorenzetti: Design of the study, writing of the manuscript; Romain Dayer: Collection of the data, evaluation of the data, writing of the manuscript; Michael Plüss: Statistical evaluation of the data, working on the revisions; Renate List: Design of the study, writing of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

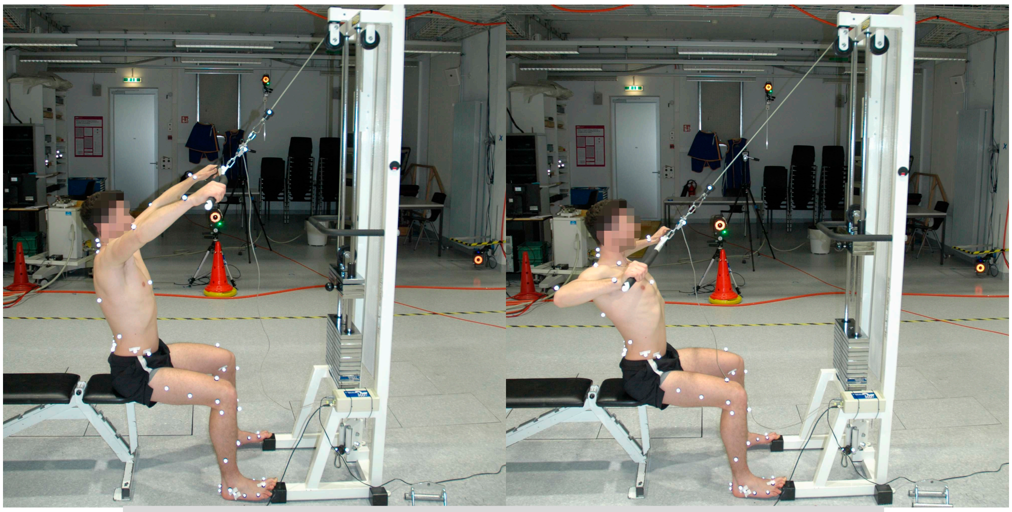
Appendix A



Lat Pulldown (LP)

- Start in a seated position with the arms extended vertically.
- Pull down the bar in front of your head until it touches your chest.
- Keep your back and head straight during the extension of the back.
- Keep the forearms pointed downward during the entire exercise.
- Slowly return to the initial position.

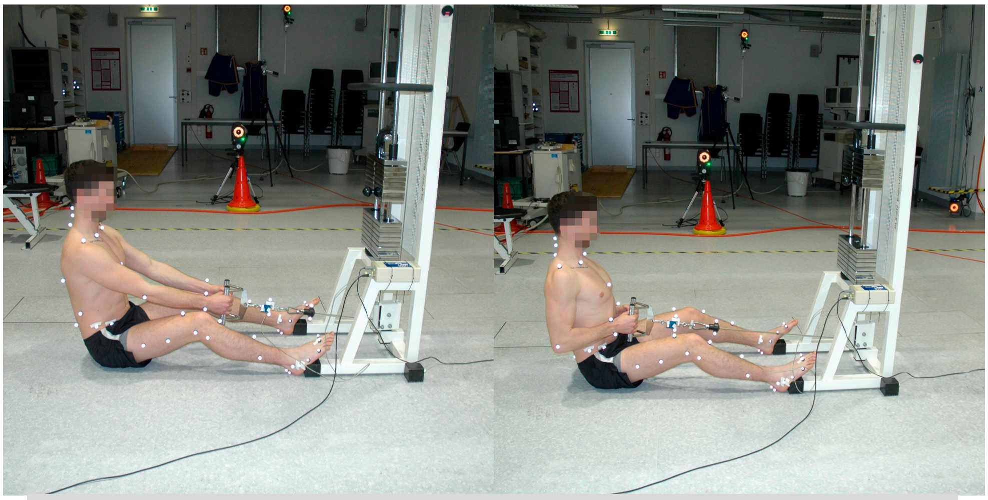
Figure A1. Experimental setup and execution of the lat pulldown. The subject with a complete "IfB marker set" is shown List et al. 2013 [31].



45° Lat Pulldown (45LP)

- Start in a seated position with the arms extended at 45 degrees.
- Pull down the bar towards your chest until it touches it.
- Keep your back and head straight during the extension of the back.
- Keep your core muscles engaged during the entire exercise.
- Slowly return to the initial position.

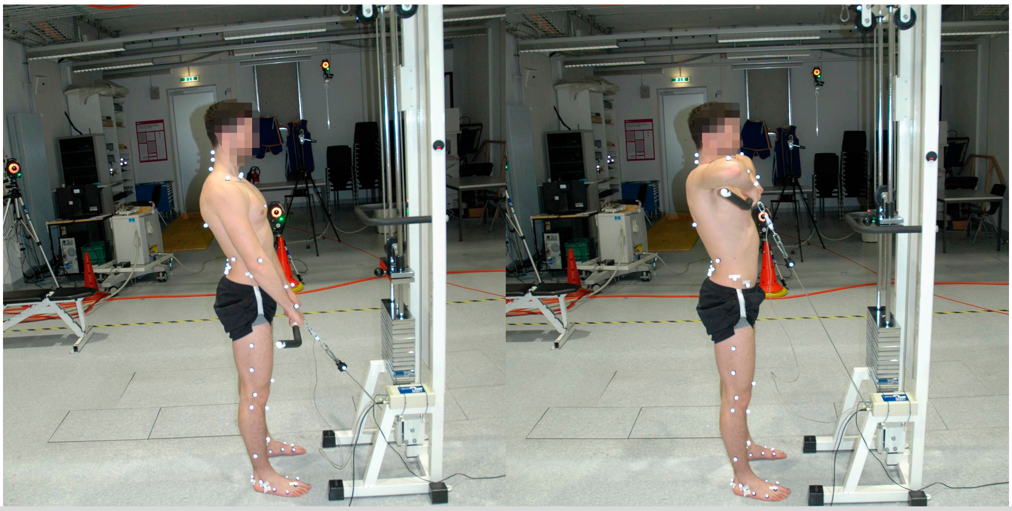
Figure A2. Experimental setup and execution of the 45° lat pulldown. The subject with a complete IfB marker set is shown.



Seated Cable Row (SR)

- Start in a seated position with the arms extended horizontally and the trunk straight.
- Place your feet on the footrest keeping your legs slightly bent.
- Pull the bars towards your upper abdominals.
- Continue pulling until it touches your torso while engaging your core muscles.
- Retract the scapula and keep the back straight during the entire exercise.
- Slowly return to the initial position.

Figure A3. Experimental setup and execution of the seated cable row. The subject with a complete IfB marker set is shown.



Upright Row (UR)

- Stand upright keeping your feet shoulder-width apart.
- Extend your arms downward and slightly bend your knees to comfortably grab the bar.
- Keep your torso upright and your core muscles engaged during the entire exercise.
- Pull the bar vertically and keep your elbows slightly higher than your hands at all times.
- Lift your arms until your elbows reach shoulder height.
- Slowly return to the initial position.

Figure A4. Experimental setup and execution of the upright row. The subject with a complete IfB marker set is shown.

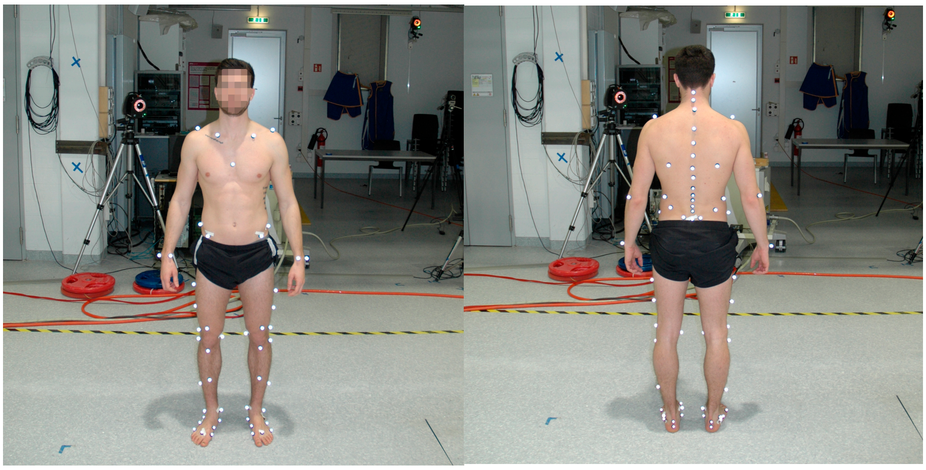


Figure A5. Subject with complete IfB marker set. On the left side: 55 markers on the legs, pelvis, shoulders and arms. On the right side: 22 markers on the back.

Table A1. Range of motion (ROM) and standard deviation in the segments of the spine and in the shoulder joint for all subjects. Body weight (BW).

Segmental Motion		**Lat Pulldown**		**45° Lat Pulldown**		**Seated Cable Row**		**Upright Row**	
		25% BW	**50% BW**	**10% BW**	**25% BW**	**25% BW**	**50% BW**	**10% BW**	**25% BW**
ROM Lumbar Rel thoracic Back (°)	Sagittal	5.2 ± 1.2	9.6 ± 4.5	7.2 ± 3.4	7.2 ± 3.2	3.8 ± 1.4	5.5 ± 2.3	4.2 ± 1.6	6.7 ± 3.9
	Frontal	2.1 ± 0.7	2.6 ± 1.0	1.9 ± 0.4	2.1 ± 0.5	2.0 ± 0.4	2.3 ± 0.8	1.6 ± 0.4	2.1 ± 0.7
	Transverse	1.4 ± 0.4	2.1 ± 0.5	1.3 ± 0.4	1.5 ± 0.3	1.0 ± 0.3	1.2 ± 0.5	1.2 ± 0.3	1.5 ± 0.5
ROM Shoulder Joint (°)	Sagittal	172.9 ± 9.6	158.9± 15.3	218.8 ± 46.2	191.1 ± 33.3	78.7 ± 19.9	82.3 ± 10.4	114.9 ± 14.6	106.4 ± 20.0
	Frontal	88.4 ± 10.6	86.7± 11.0	58.8 ± 14.8	69.7 ± 14.2	16.8 ± 5.3	13.1 ± 3.6	102.2 ± 10.6	100.1 ± 13.9
	Transverse	90.5 ± 13.4	85.1± 18.6	102.1 ± 8.7	104.0 ± 10.0	147.0 ± 40.6	111.7 ± 58.5	45.1 ± 5.9	50.3 ± 10.5

Table A2. Mean and maximum values over all subjects for the curvature in the thoracic and lumbar regions.

Curvature		**Lat Pulldown**		**45° Lat Pulldown**		**Seated Cable Row**		**Upright Row**	
		25% BW	**50% BW**	**10% BW**	**25% BW**	**25% BW**	**50% BW**	**10% BW**	**25% BW**
Mean Curvature (1/m)	Thoracic	1.78 ± 0.73	1.85 ± 0.71	1.89 ± 0.74	1.81 ± 0.76	1.83 ± 0.77	2.16 ± 0.58	2.61 ± 0.62	2.63 ± 0.67
	Lumbar	1.63 ± 1.92	0.58 ± 2.01	1.72 ± 2.01	1.46 ± 1.70	−1.19 ± 1.00	−0.45 ± 1.27	4.94 ± 1.58	4.84 ± 1.76
Max Curvature (1/m)	Thoracic	2.03 ± 0.70	2.20 ± 0.72	2.19 ± 0.71	2.09 ± 0.71	2.09 ± 0.76	2.45 ± 0.54	2.84 ± 0.60	2.85 ± 0.64
	Lumbar	2.16 ± 2.01	1.16 ± 2.11	2.22 ± 2.18	1.96 ± 1.83	−0.82 ± 1.06	0.14 ± 1.43	5.46 ± 1.88	5.58 ± 2.08

Table A3. *P*-values and (χ^2) for the maximum, minimum and ROM of the curvature angles in the thoracic and lumbar regions, mean and standard deviation over all subjects—was not analysed.

***P*-Values and (χ^2)**			**Lat Pulldown**	**45° Lat Pulldown**	**Seated Cable Row**	**Upright Row**
Max Curvature Angle (°)	Thoracic	LP	-			
		45LP	1.000 (0.001)	-		
		SR	1.000 (0.020)	1.000 (0.014)	-	
		UR	0.000 (0.258)	0.000 (0.250)	0.006 (0.168)	-
	Lumbar	LP	-			
		45LP	1.000 (0.001)	-		
		SR	0.237 (0.083)	0.473 (0.049)	-	
		UR	0.000 (0.509)	0.000 (0.475)	0.000 (0.643)	-

Table A3. *Cont.*

P-Values and (χ^2)			Lat Pulldown	45° Lat Pulldown	Seated Cable Row	Upright Row
Min Curvature Angle (°)	Thoracic	LP	-			
		45LP	1.000 (0.000)	-		
		SR	1.000 (0.028)	0.932 (0.032)	-	
		UR	0.001 (0.219)	0.000 (0.219)	0.073 (0.107)	-
	Lumbar	LP	-			
		45LP	1.000 (0.000)	-		
		SR	0.591 (0.047)	0.755 (0.037)	-	
		UR	0.000 (0.561)	0.000 (0.543)	0.000 (0.656)	-
ROM Curvature Angle (°)	Thoracic	LP	-			
		45LP	1.000 (0.016)	-		
		SR	1.000 (0.014)	0.343 (0.052)	-	
		UR	1.000 (0.028)	1.000 (0.000)	0.283 (0.083)	-
	Lumbar	LP	-			
		45LP	1.000 (0.007)	-		
		SR	0.796 (0.051)	1.000 (0.018)	-	
		UR	1.000 (0.003)	1.000 (0.000)	1.000 (0.016)	-

Table A4. *P*-values and (χ^2) for normalized absolute values of sagittal moments over all subjects—was not analysed.

P-Values and (χ^2)	LP25	LP50	45LP10	45LP25	SR25	SR50	UR10	UR25
LP25	-							
LP50	-	-						
45LP10	-	-	-					
45LP25	0.002 (0.404)	-	-	-				
SR25	0.056 (0.149)	-	-	0.000 (0.532)	-			
SR50	-	0.608 (0.010)	-	-	-	-		
UR10	-	-	0.000 (0.817)	-	-	-	-	
UR25	0.581 (0.131)	-	-	0.236 (0.233)	0.000 (0.356)	-	-	-

Table A5. *P*-values and (χ^2) for normalized absolute values of frontal moments over all subjects—was not analysed.

P-Values and (χ^2)	LP25	LP50	45LP10	45LP25	SR25	SR50	UR10	UR25
LP25	-							
LP50	-	-						
45LP10	-	-	-					
45LP25	0.000 (0.680)	-	-	-				
SR25	0.000 (0.986)	-	-	0.000 (0.967)	-			
SR50	-	0.000 (0.982)	-	-	-	-		
UR10	-	-	0.356 (0.031)	-	-	-	-	
UR25	0.000 (0.958)	-	-	0.000 (0.905)	0.000 (0.668)	-	-	-

Table A6. *P*-values and (χ^2) for normalized absolute values of transversal moments over all subjects—was not analysed.

P-Values and (χ^2)	LP25	LP50	45LP10	45LP25	SR25	SR50	UR10	UR25
LP25	-							
LP50	-	-						
45LP10	-	-	-					
45LP25	0.000 (0.926)	-	-	-				
SR25	0.000 (0.356)	-	-	0.000 (0.925)	-			
SR50	-	0.008 (0.225)	-	-	-	-		
UR10	-	-	0.000 (0.957)	-	-	-	-	
UR25	0.000 (0.927)	-	-	0.000 (0.986)	0.001 (0.756)	-	-	-

Table A7. *P*-values and (χ^2) for normalized absolute values of total moments over all subjects—was not analysed.

P-Values and (χ^2)	LP25	LP50	45LP10	45LP25	SR25	SR50	UR10	UR25
LP25	-							
LP50	-	-						
45LP10	-	-	-					
45LP25	0.387 (0.220)	-	-	-				
SR25	0.000 (0.396)	-	-	0.005 (0.220)	-			
SR50	-	0.000 (0.680)	-	-	-	-		
UR10	-	-	0.043 (0.139)	-	-	-	-	
UR25	0.000 (0.899)	-	-	0.000 (0.861)	0.000 (0.346)	-	-	-

Table A8. ICC(3,k) values of the maximal, minimal and range of motion ROM of the Curvature.

ICC		LP25	LP50	45LP10	45LP25	SR25	SR50	UR10	UR25
Max Curvature Angle (°)	Thoracic	0.996	0.995	0.996	0.997	0.994	0.994	0.996	0.999
	Lumbar	0.988	0.981	0.995	0.991	0.997	0.96	0.998	0.997
Min Curvature Angle (°)	Thoracic	0.997	0.996	0.996	0.997	0.996	0.996	0.993	0.997
	Lumbar	0.993	0.983	0.995	0.992	0.998	0.995	0.998	0.996
ROM Curvature Angle (°)	Thoracic	0.979	0.879	0.971	0.966	0.923	0.960	0.938	0.95
	Lumbar	0.906	0.774	0.979	0.948	0.966	0.821	0.988	0.983

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